Revised Study Material on DAESI

Volume I

Diploma in Agricultural Extension Services for Input Dealers



National Institute of Agricultural Extension Management (MANAGE)

(An Autonomous Organization of Ministry of Agriculture and Farmers Welfare, Govt. of India)

Rajendranagar, Hyderabad 500 030, Telangana, India

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Diploma in Agricultural Extension Services for Input Dealers (DAESI)

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FOREWORD

Indian agriculture is presently at a critical juncture, shaped by increasing climate variability, growing pressure on natural resources, rapid technological advancements, deeper market integration, and heightened expectations from farmers for accurate, timely, and scientifically sound advisory services. In this dynamic and evolving context, agricultural input dealers have emerged as vital frontline extension functionaries and trusted knowledge intermediaries for the farming community.

Recognizing the pivotal role of input dealers in strengthening last-mile extension delivery, the Diploma in Agricultural Extension Services for Input Dealers (DAESI) programme was originally conceptualized and initiated in the year 2003 as an innovative capacity-building initiative. The programme was designed to professionalize agricultural input advisory services by equipping dealers with scientific knowledge, practical skills, and ethical responsibility. In recognition of its relevance and impact, the DAESI programme received structured support from the Ministry of Agriculture and Farmers Welfare, Government of India, from the year 2015–16 onwards, enabling its systematic expansion and strengthening across the country through MANAGE, SAMETIs and ATMAs.

As the existing syllabus of DAESI was last revised in 2016, now it has been revised **into** 16 modules comprising 70 chapters, 80 sessions, and 160 learning hours, represents a significant advancement in aligning extension education with contemporary agricultural challenges. The curriculum has been extensively updated to address emerging priorities such as agro-ecological approaches, soil health management, climate change adaptation, integrated pest and nutrient management, safe and judicious use of agro-chemicals, irrigation and watershed management, agricultural value chains, digital and precision agriculture, organic and natural farming systems, and compliance with agricultural laws and regulations. The study material has been developed through a rigorous and consultative process involving scientists, academicians, extension professionals, and subject-matter specialists from leading national institutions, ensuring effective translation of scientific advancements and policy imperatives into field-level knowledge and strengthening the role of DAESI-trained input dealers as competent para-extension professionals.

Special emphasis has been placed on strengthening advisory competencies related to sustainability, responsible input use, farmer collectives, agri-entrepreneurship, business ethics, and government flagship schemes. The modular and outcome-oriented design of the revised curriculum enables systematic learning while equipping participants with practical skills to provide location-specific, need-based advisories across diverse agro-climatic regions.

I am confident that this revised curriculum will further enhance the technical proficiency, advisory effectiveness, and ethical standards of agricultural input dealers, thereby contributing meaningfully to sustainable agriculture, enhanced farm productivity, and improved farmer incomes. I sincerely appreciate the efforts of the Principal Coordinator (DAESI), Academic Associate (DAESI), authors, reviewers, and all stakeholders involved in revising this curriculum and trust that this publication will serve as a valuable learning resource for the participants across the country.
Happy reading…….

Dr. Sagar Hanuman Singh, IPoS
Director General, MANAGE



Dr. M. Srikanth, Director (ABM) &
PC (DAESI), MANAGE

PREFACE

The Diploma in Agricultural Extension Services for Input Dealers (DAESI) was conceived with the objective of equipping agricultural input dealers with scientific knowledge and practical competencies, thereby enabling them to support farmers with informed, responsible and farmer-centric advisory services. Over the years, the programme has clearly demonstrated its relevance and effectiveness by strengthening last-mile extension delivery mechanisms and enhancing the professional credibility of input dealers across diverse agro-ecological regions and farming systems.

The revised **DAESI course curriculum and study material**, organized into **16 comprehensive modules**, is the outcome of an extensive and systematic review process involving stakeholder consultations, expert deliberations, and critical assessment of emerging trends and challenges in Indian agriculture. The revision seeks to modernize and enrich the content by incorporating recent technological advancements, addressing climate change and sustainability concerns, and reinforcing the integration of theoretical concepts with practical, field-level applications.

The revised curriculum covers a wide range of subject areas, including agro-ecological situations, soil health and nutrient management, crop production technologies, weed and pest management, safe and judicious use of agro-chemicals, irrigation and watershed management, seed systems, farm mechanization, agricultural value chains, precision and digital agriculture, allied agricultural sectors, extension approaches, agri-entrepreneurship development, business ethics, statutory and regulatory frameworks, government support schemes, and organic and natural farming. Collectively, these modules address the technical, managerial, regulatory, and ethical dimensions essential for effective agricultural input advisory services. Designed in a reader-friendly and modular format, the study material facilitates progressive learning while also serving as a practical reference material for field-level problem solving.

We are grateful to Director General, MANAGE, for his kind support and valuable guidance in revising the syllabus of the DAESI programme. I also extend my sincere appreciation to the authors, reviewers, subject-matter experts, and DAESI implementing partners for their valuable contributions. It is hoped that this revised study material will further strengthen the DAESI programme and enable agricultural input dealers to function as effective, ethical, and farmer-centric extension service providers, thereby contributing to sustainable agricultural development and improved rural livelihoods.

Dr. M. Srikanth,
Director (ABM) &
Principal Coordinator (DAESI), MANAGE

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Module I: BASICS OF AGRICULTURE / AGRO ECOLOGICAL SITUATIONS

1.1. Overview of Agricultural Production Systems

Production system as a concept takes into account the components of farming, including livestock, horticulture and agroforestry. Here, the farm family is considered the centre holistically managing all components. In India, agricultural production systems are diverse and region-specific, tailored by agro-climatic conditions, resource availability, socio-economic factors, and cropping patterns. Broadly, these systems are classified into the following types:

I. Agricultural production system based on farming systems

1. Subsistence Farming

Subsistence farming as production systems where crops are grown for personal consumption rather than for sale, resulting in minimal or no surplus available for sale or trade. Key characteristics are:

- **Small landholdings**: Carried out in small farm areas
- **Focus on household consumption**: Their primary aim is to produce food to feed their family
- **Limited technology**: Minimal usage of modern machinery or chemicals
- **Diversified cropping**: Cultivation of diverse crops to ensure balanced diet and reduce the risk of crop failure
- **Low yields**: Yields are low due to minimal usage of technologies and resources

Predominantly practiced in Eastern India, parts of Central India and some parts of South India, where intensive subsistence wet paddy agriculture is common.

2. Commercial Farming

Agricultural production system focussed on producing crops and rearing livestock for sale in the market with the primary goal of generating profit. It involves large scale operations, high capital investment and use of several modern technologies. Key characters are:

- **Profit-oriented**: Mainly focussed on profit generation
- **Large-scale operations**: Extensive farms requiring significant land, labor and, capital
- **Modern inputs**: Utilize modern technologies, high yielding seeds, fertilizers, pesticides, irrigation systems and advanced machineries
- **Specialized production**: Often focus on specific crop or livestock for efficient production and marketing
- **Integration with market**: A well-developed transportation and communication network for connecting farms, processing industries and markets
- **Year-round production**: Aims at continuous production throughout the year
  Sugarcane in Maharashtra, Tamil Nadu, and cotton in Gujarat, wheat in Punjab, Haryana and Uttar Pradesh are few examples

3. Plantation Farming

Mono-cropping of perennial crops, primarily for export or industrial use examples are crops like, tea, coffee, rubber, coconut. Key features are:

- **Monocropping:** Focuses on one major crops, leading to specialized knowledge and infrastructure for that particular crop.
- **Large estates**: Vast tracts of land and significant capital investment for development
  Predominantly seen in Hilly regions of Assam, Kerala, Tamil Nadu, Karnataka focusses on Tea plantation, Rubber found mainly in Kerala, Tamil Nadu and Karnataka, Sugarcane grown in Uttar Pradesh, Maharashtra, Tamil Nadu, Karnataka and Andra Pradesh.

4. Mixed Farming

The integration of crop cultivation with livestock, poultry, or fisheries in the same farm. This approach aims to create a balanced ecosystem where different farm components support each other, allowing for the optimal use of resources and diversification of income. Key features:

- **Integration of crops and livestock**: Integrate both crop and livestock/poultry/psiculture. Eg: Paddy + fish, Crops+livestock+poultry
- **Resource exchange**: Recycling of resources,creating a circular flow of resources and enhance nutrient cycling eg- Crop residue as feed in turn cow manure as good source of nutrients for the crop
- **Diversified income**: Additional income generation through multiple enterprise. Widely adopted across India, especially in rainfed areas.

5. Organic Farming

According to Lampkin (1990), Organic farming is an agricultural production system which avoids or largely excludes the use of synthetic compounded fertilizers, pesticides, growth regulators and livestock feed additives. It envisages a comprehensive management approach to improve the health and productivity of the soil. In India organic farming is promoted under schemes like Paramparagat Krishi Vikas Yojana (PKVY). Major characteristics:

- **Reliance on available resources**: Sustainable use of local resources and minimal usage of purchased inputs
- **Improves soil health**: Ensuring the basic biological functions of soil-water-nutrients-humus continuum
- **Biodiversity**: Maintaining a diversity of plant and animal species as a basis for ecological balance and economic stability
- **Diversification**: Increasing crop and animal diversity in the form of polycultures, agroforestry systems, integrated crop/livestock systems etc. to minimise risk.

Practiced in Sikkim (India's first fully organic state), parts of Uttarakhand and Kerala

6. Integrated Farming Systems (IFS)

A holistic approach integrating various farm enterprises such as crops, livestock, aquaculture, agroforestry, and beekeeping, wherein recycling of by-products and wastes is an important component. Suitable for small and marginal farmers. Key features are:

- **Resource recycling:** A core principle in IFS. Example animal waste can be composted and used as fertilizers and in turn crop residues can be used as a feed for livestock.
- **Synergetic interaction:** Different components work together in this system to enhance overall productivity. For example: livestock manure improves soil fertility, which in turn increases crop yields.
- **Less reliance on external inputs:** IFS reduces the need for synthetic fertilizers through recycling of resources and utilization of natural materials.
- **Reduces environment impact:** Reduces the usage of synthetic inputs thereby minimizing pollution and environmental damage.
- **Food security:** By increasing food production and diversifying income sources, IFS can contribute to food security and improved livelihood.
- **Employment opportunities**: IFS provide consistent employment opportunities to farmers and their families

7. Homestead farming

It is a diverse sustainable farming system in which crops, trees and livestock are integrated within a farms residential area, primarily for household consumption and additional income generation. Key features are

- **Diversified production**: Creates a multi-tiered system including a variety of crops, trees and livestock's.
- **Household needs**: Primarily for the family's consumption, with any surplus sold for additional income
- **Optimization of resources**: Efficient use of available resources
- **Sustainability**: Promotes ecological balance and maintain biodiversity

8. Precision and Hi-tech Farming

It is a management approach to the cultivation of crops by considering spatially and temporal variations in soils, rainfall and adopting management techniques to reduce cost, efficient use of inputs and reduce environmental pollution. This system makes use of GPS, GIS, ICT, sensors, drones and data analytics using AI to optimize inputs. Major characteristics are:

- **Site specific management**: It tailors management practices to specific areas based on factors like soil types, crops and topography eg: Nitrogen application using sensors like GreenSeeker
- **Data driven decisions**: It relies on collecting and analysing data from various sources, including sensors, satellite imagery and weather forecasts to inform decisions about resource allocation.
- **Optimized inputs**: It aims at applying right amount of inputs at right time and right place**.** This help to reduce the wastage of resources

II. Agriculture production system based on dominant crops

Crop-based production systems focus on cultivating specific crops or combinations of crops based on agro-ecological zones, soil types, rainfall patterns, and socio-economic conditions. These systems aim to optimize land use and productivity by selecting appropriate crop combinations and management practices.

1. **Rice-Based Cropping System**
   Rice is grown in the high rainfall area or in areas where supplemental irrigation is available to ensure good yields. On an all-India basis, about 30 rice-based cropping patterns were identified in different states. Mostly practiced in Eastern India, Coastal Andhra Pradesh, Tamil Nadu, Kerala, West Bengal, Assam, Punjab, Haryana. Examples: *Rice–Wheat* (Uttar Pradesh, Bihar, Punjab), *Rice–Rice* (Kerala, Andhra Pradesh), *Rice-Jute (West Bengal)*

2. **Wheat-Based Cropping System**
   Wheat is grown mainly grown as Rabi crop in cropping sequences like Rice-wheat, Jowar-wheat, Pulse wheat, cotton -wheat etc. in different parts of the country under irrigated conditions. Rice-wheat system is most common. However, short duration crops like pulses are grown under rainfed conditions.
   On all India basis about, 19 cropping patterns are identified with wheat. Regions: Indo-Gangetic Plains (Punjab, Haryana, Uttar Pradesh, Bihar), Rajasthan ang Gujarat (Western region), Bihar and West Bengal (Eastern region). Examples: *Rice/maize/sorghum-Wheat (Uttar Pradesh, Punjab, Rajasthan, Jammu and Kashmir)*

3. **Pulses-Based Cropping System**
   Pulses are either intercropped or mixed with other crops and can be fitted in series of cropping system with cereals and other commercial crops. Regions: Madhya Pradesh, Maharashtra, Telangana, Rajasthan. Examples: *Rice-Rice-Greengram /Blackgram/Chickpea: Southern regions, Maize-Chickpea: North and Northwestern regions (Punjab, Haryana, J&K).*

4. **Groundnut-Based Cropping System**
   On the all-India level about 9 cropping patterns are identified for this crop. Regions: Andra Pradesh, Karnataka, Tamil Nadu, Maharashtra, Gujarat, Rajasthan, Maharashtra. Examples: *Groundnut–Sorghum/cotton (Gujarat)*.

5. **Cotton-Based Cropping System**
   Cotton is grown over 9.06 million ha in India. On the all-India basis, about 16 broad cropping patterns have been identified. Regions: Maharashtra, Madhya Pradesh, Andhra Pradesh, Gujarat, Telangana. Examples: *Cotton–Sorghum (*Maharashtra, Madhya Pradesh, Andhra Pradesh), *Cotton–Legume/Tobacco/Maize (Gujarat)*.

6. **Horticulture_Based Cropping Systems**
   This system refers to specific combination of crops and the management practices used over time on a given piece of land. Often multi-storey system is practiced in many areas. Regions: Across India depending on crop. Examples:
   Banana–Onion–Groundnut (Tamil Nadu), *Coconut- cocoa- pineapple (Kerala)*

III. Agricultural production system based on Agro-Ecosystems

Agricultural production systems in India vary significantly across agro-systems due to differences in climate, soil, topography and water availability. Under National Agricultural Technology Project, the country has been divided into five agro-ecosystems. On the basis of potentials and constraints, a number of production systems have been identified in each agro-ecosystem (See Table 1).

Table 1. Agro-ecosystem based dominant production systems

Eco-systems	Major characteristics	Dominant production system
1.Arid-agro ecosystem	Occupying nearly 19 per cent of the area. Includes both hot and cold arid regions	Agri-silvi-horti-pastoral production system Livestock and brackish water fish production system
2.Coastal Agro-ecosystem	With an estimated 1.2 million ha of brackish water area and 8129 km long coast line, the coastal agro-ecosystem forms a very valuable resource community	Fish and livestock production system Agri-horti-production system
3.Hill and Mountainous Agro-ecosystem	Covering the North Western and North Eastern Himalayan regions	Agri - horti - production system Livestock and fish production system
4.Irrigated Agro-ecosystem	Covers about 40–45% of the net sown area and contributes over 60% of food grain production A production system supported by artificial water application through canals, tube wells, tanks, etc. Predominant in Punjab, Haryana, Uttar Pradesh, Tamil Nadu, Andhra Pradesh	Rice-wheat production system Cotton-based production system Sugarcane – based production system Livestock – based production system
5.Rainfed Agro-ecosystem	Agricultural system that depends entirely on rainfall and does not receive any additional water at any stage of the crop through irrigation. It covers about 55–60% of India's net sown area and contributes nearly 40% of food grain production. Dominant in semi-arid and arid regions (Madhya Pradesh, Rajasthan, Maharashtra, Telangana, Karnataka, Chhattisgarh)	Rainfed rice production system Pulse-based production system Oilseed-based production system Cotton-based production system Coarse cereal-based production system

(Source:https://naarm.org.in/focarsrepository/files/3.%20Production%20Systems%20approach.pdf.)

Shaped by variations in climate, soil, water and socio-economic conditions agricultural production system in India is diverse and dynamic. From rainfed subsistence farming to highly intensive irrigated systems, from cereal-based cropping to high value horticulture and plantation crops, the country exhibits a wide range of production models. Agro-ecosystems spread across various agro-climatic zones. Within agro-ecosystems, various crop-based production systems exist. Majority of farmers still use traditional method of cultivation. While these methods continue to support the farmer's integration of modern approaches like IFS, organic farming, precision agriculture is needed. Identifying production system and applying it to suitable region is important for ensuring food security, environmental sustainability and improved livelihood opportunities.

1.2. A. Agro-ecological situation and Agro-eco system approach

India's agriculture is shaped by a wide range of ecological and climatic conditions. From the Himalayan hills to coastal plains and arid deserts, each region presents unique challenges and opportunities for farming to ensure sustainable and productive agriculture, it is essential to understand the agro ecological and agro climatic characteristics of each zone.

This chapter builds that foundation by guiding input dealers through the key concepts, components, and typologies of agro ecosystems across India. It emphasizes systems thinking, participatory management, and climate resilience as essential tools for para-extension work. The chapter also outlines India's classification into 15 agro-climatic zones (Planning Commission) and 127 agro-ecological zones (ICAR), demonstrating their relevance for crop planning, soil management, and irrigation strategies. Key topics include soil types, land use patterns, irrigation sources, groundwater potential, and zone-specific extension advisories. Supported by maps, tables, case studies, and embedded question banks, the chapter empowers input dealers to deliver localized, climate-smart, and scientifically grounded support to farmers across diverse agro-ecological settings.

I. Agro Ecology

1. Definition and Scope

Agro ecology is the science and practice of applying ecological principles to agricultural systems. It views farms as ecosystems and emphasizes the interactions between plants, animals, humans, and the environment. Agro ecology integrates:

- Ecological science (soil, water, biodiversity)
- Agronomic practices (crop rotation, mixed farming)
- Socio-economic factors (farmer knowledge, local resources)

It promotes sustainable, resilient, and locally adapted farming systems, moving beyond input intensive agriculture.

2. Sustainable Agriculture and Climate Resilience

Agro ecology aligns with India's goals for climate-smart agriculture, carbon farming, and sustainable food systems. It plays a vital role in:

- Reducing dependence on chemical inputs by enhancing natural processes
- Improving soil health and water conservation
- Supporting biodiversity and ecosystem services
- Building resilience to climate variability (droughts, floods, heat stress)
- Empowering farmers through participatory approaches and indigenous knowledge

3. Components of Agro Ecosystems

Agro ecosystems are dynamic systems shaped by natural elements and human activities. Understanding their components helps input dealers recommend appropriate technologies and practices. Agro ecosystems function best when these components are balanced and adapted to local conditions.

i. Biotic Components

These are living organisms that directly influence agricultural productivity:

- Crops: cereals, pulses, oilseeds, vegetables, fruits
- Livestock: cattle, goats, poultry, fish
- Soil organisms: earthworms, microbes, beneficial fungi and bacteria that aid nutrient cycling.

ii. Abiotic Components

These are non-living factors that determine the agro ecosystem's potential: Climate: rainfall, temperature, humidity, wind

Soil: texture, fertility, pH, organic matter

- Water: availability, quality, irrigation sources

iii. Human Interventions

These are management practices and technologies from human decisions:

- Farming practices: tillage, crop rotation, intercropping, mulching
- Inputs: seeds, fertilizers, pesticides, bio-stimulants
- Technologies: irrigation systems, farm machinery, mobile advisories

iv. Agro Ecosystem Typologies in India

India's diverse geography and climate give rise to various agro ecosystem types. Each has unique challenges and opportunities for input use and crop planning. Understanding these helps to offer location specific solutions on seeds, fertilizers, and water-saving technologies.

Table 2: Major Agro ecosystem types and case examples

Type	Example Regions/States	Key Features	Major Crops
Wetland	Tamil Nadu (Cauvery delta), Kerala (Kuttanad), West Bengal (Sundarbans)	Waterlogged soils, high rainfall or irrigation	Rice, banana, sugarcane
Dryland	Telangana, Karnataka (Raichur, Chitradurga), Tamil Nadu (Salem, Dharmapuri)	Low rainfall, poor soils, moisture stress	Millets, pulses, oilseeds
Rainfed	Madhya Pradesh, Chhattisgarh, Jharkhand	Monsoon-dependent, limited irrigation	Rice, pulses, maize
Hill	Himachal Pradesh, Uttarakhand, Nagaland, Meghalaya	Steep slopes, terrace farming, cool climate	Horticulture, spices, maize
Coastal	Odisha, Andhra Pradesh, Tamil Nadu (Nagapattinam), Gujarat (Saurashtra coast), Kerala	Salinity, cyclones, sandy soils	Rice, coconut, cashew, aquaculture
Arid	Rajasthan (Barmer, Jaisalmer), Gujarat (Kutch)	Very low rainfall, sandy soils	Pearl millet, cluster bean, livestock

4. Agro Ecosystem Approach: Principles and Practices

The agro-ecosystem approach promotes holistic and sustainable management of farming systems. It helps input dealers and farmers make informed decisions by considering ecological, economic, and social factors together. Agro ecosystem approach is not one-size-fits-all, but it evolves with local needs and conditions.

5. Systems Thinking and Landscape Level Planning

- Views farms as part of a larger landscape (watershed, village, region)
- Encourages integration of crops, livestock, trees, and water resources
- Promotes resource recycling and synergy between components

6. Participatory and Adaptive Management

- Involves farmers, input dealers, and extension agents in decision-making
- Encourages feedback-based learning and local innovation
- Adapts practices to changing climate, market, and policy conditions

7. Role in Climate Resilient Agriculture

Agro ecosystem management is central to building resilience against climate change. It helps farmers prepare for and adapt to weather extremes. Agro ecosystem strategies make agriculture not just productive, but also adaptive and regenerative.

8. Soil Health, Biodiversity and Water Use Efficiency

- Promotes organic matter buildup, cover cropping, and reduced tillage
- Encourages crop diversity and beneficial organisms
- Supports micro-irrigation, mulching, and rainwater harvesting.

9. Reducing Vulnerability to Climate Shocks

- Diversified cropping systems reduce risk from droughts, floods, and pests
- Agroforestry and mixed farming buffer income and ecological stress
- Early warning systems and advisories improve preparedness

10. Carbon Farming and Agroecological Intensification

- Practices like composting, tree planting, and reduced emissions contribute to carbon sequestration
- Agroecological intensification uses natural processes to boost yields sustainably
- Aligns with national missions like NMSA, PMKSY, and carbon credit pilots

1.2. B. Agro Climatic Zones of India - Soils, Land Use Pattern, Major Sources of Irrigation and Ground Water Potential

Agro climatic zones (ACZs) are regions classified based on climate, soil, and cropping patterns. This helps in planning agriculture according to local conditions and resource availability.

Definition: An agro-climatic zone is a geographical area with similar climate, soil type, and agricultural potential. It guides, crop selection and input use; irrigation planning; extension advisories and policy targeting.

1. Planning Commission's 15 Agro Climatic Zones

The Planning Commission (now NITI Aayog) divided India into 15 broad zones for regional agricultural planning based on climate, soil, and cropping patterns (Planning Commission, 1989). These zones group states or parts of states with similar agro-climatic features. Knowledge on this helps to regional agricultural planning and input targeting like zone specific seeds, fertilizers, and water-saving technologies.

Table 4: Overview of 15 agro climatic zones by planning commission

Zone No.	Zone Name	States Covered (Examples)	Dominant Crops
1	Western Himalayan Region	Jammu & Kashmir, Himachal Pradesh, Uttarakhand	Apple, barley, maize, vegetables
2	Eastern Himalayan Region	Assam, Arunachal Pradesh, Sikkim	Rice, maize, ginger, tea

3	Lower Gangetic Plains Region	West Bengal	Rice, jute, pulses
4	Middle Gangetic Plains Region	Bihar, Eastern Uttar Pradesh	Rice, wheat, sugarcane
5	Upper Gangetic Plains Region	Western Uttar Pradesh	Wheat, rice, sugarcane
6	Trans-Gangetic Plains Region	Punjab, Haryana, Chandigarh	Wheat, rice, cotton
7	Eastern Plateau and Hills Region	Odisha, Chhattisgarh, Jharkhand	Rice, millets, pulses
8	Central Plateau and Hills Region	Madhya Pradesh, Maharashtra (Vidarbha)	Soybean, wheat, pulses
9	Western Plateau and Hills Region	Maharashtra (Marathwada), Karnataka	Sorghum, cotton, pulses
10	Southern Plateau and Hills Region	Tamil Nadu, Andhra Pradesh, Karnataka	Millets, groundnut, pulses
11	East Coast Plains and Hills Region	Coastal Andhra Pradesh, Odisha, Tamil Nadu	Rice, sugarcane, coconut
12	West Coast Plains and Ghats Region	Kerala, Coastal Karnataka, Goa	Rice, spices, coconut
13	Gujarat Plains and Hills Region	Gujarat	Groundnut, cotton, bajra
14	Western Dry Region	Rajasthan (excluding southeast)	Pearl millet, pulses, guar
15	Island Region	Andaman & Nicobar, Lakshadweep	Coconut, rice, tuber crops

2. ICAR's 127 Agro Climate Zones

The Indian Council of Agricultural Research (ICAR), in collaboration with State Agricultural Universities, further refined these 15 zones into 127 Agro Climate Zones using the following parameters under National Agricultural Research Project (NARP) (ICAR, 1997).

- Climate (rainfall, temperature)
- Soil (type, depth, texture)
- Physiography (altitude, slope)
- Length of growing period (LGP)

This finer classification supports research and technology targeting, zone specific crop recommendations and climate resilient planning. The zones of each state are given below

Table 5: State wise Distribution of ACZs in India

State	No. of ACZ	State	No. of ACZ
Andhra Pradesh	7	Madhya Pradesh	12
Assam	6	Maharashtra	9
Bihar	6	North Eastern Hill Region	6
Gujarat	8	Orissa (Odisha)	9
Haryana	2	Punjab	5
Himachal Pradesh	4	Rajasthan	9
Jammu and Kashmir	4	Tamil Nadu	7
Karnataka	10	Uttar Pradesh	10
Kerala	8	West Bengal	6

Table 6: Comparison Summary of ACZ by planning commission and ICAR

Parameter	Planning Commission (15 ACZs)	ICAR (127 ACZs)
Purpose	Broad regional planning	Precise research and extension
Criteria	Climate, soil, cropping pattern	Climate, soil, physiography, LGP
Coverage	State-level grouping	District/block-level targeting
Use	Policy and schemes	Research, advisories, trials

3. AGRO ECOLOGICAL REGIONS (AER) in India

India is divided into 20 Agro-Ecological Regions (AERs) by ICAR–NBSS&LUP, each representing a unique combination of climate, soil, physiography, and length of growing period (LGP).

These regions guide land use planning, crop suitability, and agro-technology dissemination. The classification was developed by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP) under ICAR (Sehgal et al., 1992), using four integrated criteria:

- Climate (rainfall, temperature)
- Soil type (texture, depth, fertility)
- Physiography (terrain, slope)
- Length of Growing Period (LGP) – days suitable for crop growth

Table 7: Key Differences between ACZ and AER

Feature	Agro Climatic Zones	Agro-Ecological Regions
Defined by	Planning Commission & ICAR	ICAR-NBSS&LUP (National Bureau of Soil Survey & Land Use Planning)
Total Zones	127 zones (based on climate and administrative boundaries)	20 AERs subdivided into 60 AESRs (later to 110 → 127)
Primary Criteria	Climate (rainfall, temperature), cropping patterns	Climate + Soil + Physiography + Length of Growing Period (LGP)
Purpose	Macro-level planning, policy formulation	Micro-level land use planning, genotype suitability, agro-tech transfer
Granularity	Broader zones, often aligned with state/district borders	Finer subregions based on ecological homogeneity
Example	ACZ: Western Plateau & Hills Region	AESR: 10.3 – Cauvery Delta (Tamil Nadu)

- Agro-Climatic Zones are useful for broad policy and infrastructure planning, such as irrigation schemes or regional cropping strategies.
- Agro-Ecological Regions/Subregions are more relevant for precision agriculture, climate-resilient genotype selection, and region-specific extension advisories—especially critical for your DAESI curriculum and stakeholder outreach.

4. Agro-Ecological Sub Regions (AESR) by ICAR-NBSS&LUP

The Indian Council of Agricultural Research (ICAR, NBSS & LUP) developed a detailed classification of 127 Agro-Ecological Subregions (AESRs), each with a unique code grouped under their 20 AERs (ICAR-NBSS&LUP, 1999) to support precise agricultural planning and research. The purpose of finer classification is as follow

- To identify location-specific constraints and potentials
- To guide crop planning, input use, and technology dissemination
- To support climate-resilient and resource-efficient farming

i. Criteria used by ICAR

ICAR's AESRs are based on four scientific parameters:

1. Climate: Rainfall, temperature, humidity
2. Soil: Type, depth, texture, fertility
3. Physiography: Altitude, slope, terrain
4. Length of Growing Period (LGP): Number of days suitable for crop growth

ii. Structure of AESRS

Each AESR is coded and mapped at district or block level, making it useful for

- Agricultural universities and KVKs
- Input dealers and extension agents
- Policy makers and planners

Table 8: Representative list of AESR across India

AEZ Code	Region/State	Key Features	Major Crops
AESR 1.1	Western Himalayas (HP, UK)	Cold, high altitude, terrace farming	Apple, barley, vegetables
AESR 2.3	Kachchh & Kathiawar (Gujarat)	Hot arid, saline soils, low rainfall	Bajra, cluster bean, cumin
AESR 3.2	Northern Karnataka (Deccan Plateau)	Red loamy soils, moderate rainfall	Ragi, cotton groundnut,
AESR 4.4	Bundelkhand (MP, UP)	Shallow soils, low rainfall	Sorghum, pulses, oilseeds
AESR 5.3	Gujarat Plains (Central Gujarat)	Sandy loam, semi-arid	Groundnut, cotton, bajra
AESR 6.2	Southern Maharashtra (Deccan Plateau)	Deep black soils, semi-arid	Cotton, pigeon pea soybean,
AESR 7.4	Northern Telangana	Red and black soils, hot semi-arid	Cotton, maize, pulses
AESR 8.4	Cauvery Delta (Tamil Nadu)	Irrigated alluvial soils, long LGP	Rice, banana, sugarcane
AESR 9.2	Eastern UP Plains	Hot subhumid, alluvial soils	Rice, wheat, sugarcane
AESR 10.2	Malwa Plateau (MP)	Black soils, moderate rainfall	Soybean, wheat, gram
AESR 11.3	Chhattisgarh Plains	Red and yellow soils, subhumid	Rice, maize, pulses
AESR 12.2	Jharkhand Uplands	Lateritic soils, undulating terrain	Rice, millets, oilseeds
AESR 13.2	Bihar Plains	Moist subhumid, fertile alluvium	Rice, maize, lentil
AESR 14.1	Western Himalayas (Warm Subhumid)	Forested slopes, high rainfall	Maize, fruits & vegetables
AESR 15.2	Bengal Plains	Hot humid, alluvial soils	Rice, jute, mustard
AESR 16.2	Eastern Himalayas (Sikkim, Arunachal)	Perhumid, acidic soils	Tea, ginger, cardamom
AESR 17.3	Purvachal Hills (Nagaland, Manipur)	Hilly terrain, high rainfall	Rice, maize, tuber crops
AESR 18.2	Coastal Andhra Pradesh	Subhumid, deltaic soils	Rice, groundnut, sugarcane
AESR 19.2	Western Ghats (Kerala)	Perhumid, lateritic soils	Coconut, spices, rubber
AESR 20.1	Andaman Islands	Tropical, high humidity	Tuber crops, coconut, rice

These zones can be expanded into state-wise annexures or district-level maps for training and outreach. ICAR's AEZ maps are available through NBSS&LUP and can be used to develop zone-specific advisories and input packages. A zone wise advisory templated for the AESR is given below to develop location specific advisories based on AEZ characteristics.

Table 9: Zone-wise advisory template for AESRs

Parameter	Details
AEZ Code & Name	e.g., AESR 10.1 – Cauvery Delta
State/Region	Tamil Nadu, Karnataka, etc.
Physiography	Deltaic plains, plateau, hills
Climate Type	Humid, semi-arid, sub-humid
Rainfall Range (mm)	e.g., 800–1200 mm
Length of Growing Period (LGP)	e.g., >210 days
Dominant Soil Type	Alluvial, black, red, lateritic
Major Crops	Rice, banana, cotton, millets
Cropping System	Rice–rice, cotton–soybean, millet–pulse
Recommended Inputs	Seed varieties, fertilizers, bio-inputs
Irrigation Practices	Canal, tank, drip, sprinkler
Climate Risks	Drought, flood, salinity, heat stress
Extension Tips	Soil testing, water budgeting, pest alerts
Government Schemes	PMKSY, NMSA, RKVY, Soil Health Card

5. Soil Types across Zones

Soil is a key factor in determining crop suitability, fertilizer use, and water management. India has diverse soil types distributed across its agro-climatic zones, each with unique properties and constraints.

i. Soil Fertility Constraints

- Red and laterite soils: Low in nitrogen and organic carbon
- Black soils: Prone to cracking and waterlogging
- Desert soils: Poor in nutrients and water-holding capacity

Table 10: Major soil groups in India

Soil Type	Regions/States	Key Features	Suitable Crops
Alluvial	Indo-Gangetic plains (Punjab, UP, Bihar, West Bengal)	Fertile, loamy, good water-holding	Rice, wheat, sugarcane, pulses
Black (Regur)	Maharashtra, MP, Gujarat, parts of TN	Clayey, high moisture retention, rich in lime	Cotton, soybean, sorghum
Red	Tamil Nadu, Karnataka, Odisha, Chhattisgarh	Low fertility, porous, low in organic matter	Millets, groundnut, pulses
Laterite	Kerala, Odisha, WB, NE states	Acidic, low in nutrients, well-drained	Cashew, tapioca, pineapple
Desert (Arid)	Rajasthan, Gujarat	Sandy, low fertility, poor water retention	Bajra, guar, moth bean
Mountain/Forest	Himalayan states, NE hills	Shallow, acidic, rich in organic matter	Tea, fruits, spices

Table 11: Major soil types of ACZ

Zone	Soil Type	States	Key Crops
Western Dry (Rajasthan)	Desert/Sandy	Rajasthan	Pearl millet, Cluster bean
Trans-Gangetic (Punjab, Haryana)	Alluvial	Punjab, Haryana	Wheat, rice
Central Plateau (MP)	Black, red	MP, Chhattisgarh	Soybean, pulses
West Coast Plains (Kerala)	Laterite	Kerala, Goa	Coconut, spices

6. Land Use Patterns

Land use refers to how land is utilized for agriculture, forestry, settlements, and other purposes. Understanding land use helps in planning input supply, crop choices, and conservation strategies.

i. Major Land Use categories in India

- Net Sown Area: Land used for crop cultivation (approx. 140 million ha)
- Forest Area: Reserved and protected forests (approx. 24% of total land)
- Fallow Land: Temporarily uncultivated land (due to soil fatigue, water scarcity)
- Permanent Pastures and Grazing Land: Used for livestock
- Non-agricultural Uses: Urbanization, roads, industries

ii. Cropping Intensity and Land Utilization

- Cropping Intensity = (Gross Cropped Area / Net Sown Area) × 100
    - India's average: ~142%,
    - High in Punjab, West Bengal, TN (due to irrigation)
- Multiple Cropping: Growing more than one crop on the same land in a year
- Intercropping and Crop Rotation: Improve soil health and income

iii. Trends and Implications

- Decline in cultivable land due to urbanization
- Need for land-use planning and conservation agriculture
- Promotion of agroforestry, integrated farming, and fallow land reclamation

7. Irrigation Sources and Groundwater Potential

Irrigation is essential for stable crop production, especially in semi-arid and rainfed regions. India uses diverse irrigation sources but faces challenges in water availability and efficiency.

Table 12: Major irrigation sources (Example)

Source	Regions/States	Remarks
Canals	Punjab, Haryana, UP, Andhra Pradesh	Government-managed, linked to rivers
Tanks	Tamil Nadu, Telangana, Odisha	Traditional, community-managed
Tube Wells/ Bore Wells	Punjab, Gujarat, TN, MH	Major source in green revolution areas
Drip/Sprinkler	Maharashtra, Karnataka, Gujarat, Andhra Pradesh	Efficient, promoted under PMKSY

Table 13: Major irrigation sources of ACZ (Example)

Zone	Major Irrigation Source	Remarks
Cauvery Delta (TN)	Canal, tank	High irrigation intensity
Deccan Plateau (MH, KA)	Bore wells, drip	Semi-arid, groundwater stress
Eastern India (WB, Bihar)	Tube wells, rivers	High water table
Western Dry (RJ)	Wells, tanks	Low rainfall, water scarcity

8. Case Studies for successful Agro-Ecological Interventions

1. Tamil Nadu – Tank-fed Rice Ecosystem
    - Use of short-duration Rice varieties and SRI method
    - Improved water productivity and reduced input cost
2. Maharashtra – Cotton in Black Soils (Vidarbha)
    - Promotion of Bt cotton with drip irrigation
    - Reduced pesticide use through IPM kits
3. Odisha – Millet Revival in Red Soils
    - Community seed banks and organic inputs
    - Linked to PDS and nutrition schemes
4. Nagaland – Hill Agroforestry Systems
    - Integration of ginger, turmeric, and fruit trees
    - Soil conservation and income diversificatio

1.3. A. Weather Parameters/ Agro Meteorological Information and their Impact on Agricultural Production

Weather and climate are fundamental natural resources that significantly influence agricultural productivity and sustainability. The short-term variations in atmospheric conditions collectively termed as weather parameters, govern daily agricultural operations such as sowing, irrigation, fertilization, pest management and harvesting.

In the modern era, Agro-Meteorological Information Services integrate weather observations, forecasts and advisories to assist farmers in decision-making. The Gramin Krishi Mausam Sewa (GKMS) of the India Meteorological Department (IMD), in collaboration with Agricultural Universities and ICAR institutions, provides district-level weather forecasts and agro-advisories, helping farmers for mitigating weather-related risks and enhance productivity.

This chapter focuses on the basics of weather parameters, their measurement, agricultural significance and how agro-meteorological information can be effectively utilized for improving crop and livestock production.

1. Weather Parameters (Atmospheric Weather Variables)

Weather parameters are measurable elements of the atmosphere that determine weather and influence agricultural production. The major parameters include temperature, wind speed, atmospheric pressure, humidity, radiation, rainfall, and evaporation.

i. Temperature:

It is very important parameter. Temperature is the degree of hotness or coldness of a body or atmosphere, measured on a definite scale. It indicates the amount of heat energy present in the air and determines the thermal condition of the atmosphere.

Plant growth is profuse in certain range of temperature. This is known as cardinal temperature. Cardinal temperatures are the three critical temperature points (minimum, optimum, and maximum) that determine the rate of crop growth and development. The mean temperature of the Northern Hemisphere is approximately 15°C (59°F).

Temperature of the place depends upon latitude, longitude, time of the day at that place. Pressure and temperature are inversely related to each other.

Significance in Relation to Agriculture:

- Temperature influences seed germination, growth, flowering, and yield of crops.
- It determines crop distribution and growing seasons (Kharif & Rabi).
- It affects soil temperature, which controls root activity and nutrient uptake.
- It regulates evaporation, transpiration, and water requirement of crops.
- Extreme temperatures cause heat stress, frost injury, or crop failure.
- It helps in forecasting frost, heat waves, and growing degree days for crop planning.
- It affects livestock comfort, milk production, and feed intake.

Instruments Used for Measurement: Following instruments are used to measure temperature.

1. **Thermometer** – Measures air temperature Maximum thermometer used for measurement of maximum temperature of the day. Minimum thermometer is used for measurement of minimum temperature of the day. Dry bulb thermometer is used for measurement of actual temperature and Wet bulb thermometer is used for measurement of temperature of moist air.
2. **Soil thermometer** – Measures temperature at different soil depths
3. **Thermograph** – For continuous recording of temperature

Units of Measurement: Temperature is measured in degrees Celsius (°C), Fahrenheit (°F), or Kelvin (K) using a thermometer.

Scale	Symbol	Freezing Point	Boiling Point
Celsius	°C	0°C	100°C
Fahrenheit	°F	32°F	212°F
Kelvin (SI Unit)	K	273 K	373 K

Conversion:

- °C = (°F − 32) × 5/9
- K = °C + 273

ii. Wind: It is another important parameter of weather which play important role in weather forecasting**.**

Wind is the horizontal movement/flow of air from a region of high pressure to low pressure. It is caused mainly by differences in atmospheric pressure, which are created due to uneven heating of the Earth's surface. Wind speed increases at higher altitude.

Significance in Relation to Agriculture:

- Wind influences evapotranspiration and thereby affects crop water requirement.
- Strong winds may cause lodging of crops, breakage of stems and damage to fruits or greenhouses.
- It plays a key role in pesticide spraying and fertilizer application ideal under low wind speeds.
- Wind is important in frost prevention i.e. gentle wind reduces frost formation.
- Determines wind erosion risk in dry regions and helps in planning windbreaks or shelterbelts.
- Wind plays vital role in designing irrigation systems, greenhouses, and aeration in livestock sheds.

Instruments Used for Measurement: Following instruments were used to measure wind speed and direction

1. Anemometer – Measures wind speed
2. Wind Vane (Weather Vane) – Shows wind direction
3. Wind Recorder (Anemograph) – Records wind speed and direction continuously.

Units of Measurement: Wind speed is measured in meters per second (m/s) or kilometers per hour (km/h) and direction in degrees (°).

iii. Atmospheric Pressure

Atmospheric pressure is the weight exerted by the air column on a unit area of the Earth's surface. (in millibars or hPa). Atmospheric pressure is different at different levels of the atmosphere. At sea level, the atmospheric pressure is about 1013.25 millibars (hPa) this is the standard pressure. It results from the force exerted by the molecules of various gases and water vapour present in atmosphere. As we go higher in the atmosphere, air pressure decreases rapidly as density of the air is thin Mathematical representation of it is as follow,

$$\text{Pressure (p)} = \frac{\text{Force}}{\text{Area}}$$

Instruments Used for Measurement: Following instruments were used for measurement of Atmospheric Pressure

- Fortin's Barometer
- Kew Pattern Barometer
- Aneroid Barometer
- Barograph – for automatic and continuous recording of atmospheric pressure.

Units of Measurement: Atmospheric Pressure is measured in millibars (mb) or hectopascals (hPa) using a barometer.

Significance in Relation to Agriculture:

- Atmospheric Pressure governs weather and rainfall patterns, influencing crop growth and yield.
- It controls wind formation and monsoon circulation, essential for water availability and Kharif crop production.
- It helps in predicting frost, cold waves, cyclones and storms, enabling farmers to take preventive measures.

- It supports accurate weather forecasting for effective crop planning, irrigation, fertilizer application and harvesting.
-
- It ensures safety and efficiency in aerial spraying operations by understanding pressure variation with altitude.
- It affects livestock comfort and health, as sudden pressure changes influence animal respiration and behavior.

iv. Humidity

Humidity is the amount of water vapour present in the air. It indicates the moisture content of the atmosphere, which is an important factor influencing weather and plant growth. There are different measures of humidity. They are Absolute humidity, relative humidity, Dew point temperature and mixing ratio.

Significance in Relation to Agriculture:

- Humidity affects evapotranspiration, water requirement and irrigation scheduling of crops.
- It plays a vital role in plant growth, flowering and disease incidence (e.g., high humidity favours fungal diseases).
- Low humidity increases water loss from leaves, leading to wilting or heat stress.
- It influences drying and storage of harvested produce and grains.
- It is important for maintaining comfort and health of livestock in sheds.
- It is used to assess fog, dew and rainfall formation, which are crucial for weather forecasts.

Instruments Used for Measurement: Following instruments were used for measurement of humidity in the air.

1. Hygrometer – Measures relative humidity
2. Psychrometer (Dry and Wet Bulb Thermometer) – Determines relative humidity through temperature difference
3. Dew Point Hygrometer – Measures dew point temperature
4. Hair Hygrograph – Provides continuous record of humidity

Units of Measurement: Relative humidity is expressed in percentage (%) and measured by a hygrometer or psychrometer.

v. Solar Radiation

Solar radiation is the energy received from the sun in the form of electromagnetic waves (mainly shortwave radiation). It is the primary source of energy that drives atmospheric processes, plant photosynthesis and all-weather phenomena.

Significance in relation to Agriculture:

- Solar radiation is essential for photosynthesis, which drives plant growth and crop yield.
- It helps in estimating potential evapotranspiration (PET) and water requirement of crops.
- It determines temperature, evaporation and transpiration rates.
- It influences soil heating, seed germination and crop maturity.
- It affects microclimate within crop canopy and hence pest disease dynamics.
- It is used in solar energy applications like solar dryers, greenhouses and irrigation systems.
-

Instruments Used for Measurement:

1. Pyranometer – Measures total (global) solar radiation (direct + diffuse).
2. Pyrheliometer – Measures direct beam solar radiation from the sun.
3. Campbell–Stokes Sunshine Recorder – Measures duration of bright sunshine hours.
4. Net Radiometer – Measures net radiation balance between incoming and outgoing radiation.
5.

Units of Measurement: Solar Radiation is measured in watts per square meter (W/m^2) or megajoules per square meter per day ($MJ/m^2/day$) using a pyranometer.

vi. Rainfall

Rainfall is the precipitation of water droplets from the atmosphere to the earth's surface in liquid form. It occurs when moist air cools, condenses and the water droplets become heavy enough to fall due to gravity.

Significance in Relation to Agriculture:

- Rainfall is the main source of water for rainfed and irrigated farming systems.
- It determines crop selection, sowing time and growing season (Kharif/Rabi).
- It affects soil moisture, groundwater recharge and irrigation planning.
- Deficit rainfall leads to drought; excess rainfall causes waterlogging and crop loss.
- It influences fertilizer application, pest and disease occurrence and harvest scheduling.
- Long-term rainfall records help in climate classification, crop zoning and agroclimatic planning.

Instruments Used for Measurement:

1. Rain Gauge – Measures the amount of rainfall at a given location.
2. Automatic Weather Station (AWS) – continuous records rainfall electronically with time and intensity.

Units of Measurement: Rainfall is measured in millimeters (mm) using a rain gauge.

vii. Evaporation and Evapotranspiration

a. Evaporation:

Evaporation is the process by which water changes from liquid to vapour and enters the atmosphere from open water surfaces, soil and plant surfaces. It represents the loss of water to the atmosphere due to solar energy, temperature, wind and humidity.

Significance in relation to Agriculture:

- Evaporation determines crop water requirement and helps in irrigation scheduling.
- It is used to estimate evapotranspiration (ET) the combined loss of water from soil and plants.
- It influences soil moisture balance and drought assessment.
- It helps in design and management of irrigation systems.
- High evaporation rates can cause drought and soil salinity in arid regions.
- It is Important for water budgeting and hydrological studies in agriculture.

Instruments Used for Measurement:

1. Class 'A' Open Pan Evaporimeter – Measures daily evaporation from an open water surface.
2. Evapograph – Provides continuous record of evaporation.

Units of Measurement: Evaporation is measured in millimeters per day (mm/day).

b. Evapotranspiration (ET)

Evapotranspiration (ET) is the combined process of water loss from the soil surface by evaporation and from plants through transpiration. It represents the total water demand of the atmosphere for a given crop and environment.

Significance in Relation to Agriculture:

- Evapotranspiration determines crop water requirement and forms the basis for irrigation scheduling.
- It helps in water resource planning, management, and drought assessment.
- It Influences crop growth, yield and soil moisture balance.
- It is Important for designing irrigation systems and selecting suitable cropping patterns.

Instruments / Methods Used for Measurement:

1. Lysimeter – Measures actual evapotranspiration directly from cropped soil.

Units of Measurement: Evapotranspiration is measured in millimeters per day (mm/day) using a lysimeter or estimated by empirical methods.

Table 1. Summary of Weather Parameters and Their Agricultural Influence

Parameter	Definition	Key Agricultural Influence
Temperature	Degree of hotness/coldness	Germination, growth, flowering, yield
Wind Speed	Horizontal movment of air from high pressure to low pressure.	Pollination, transpiration, soil erosion
Atmospheric Pressure	Weight of air column	Rainfall, wind formation
Humidity	Water vapour content	Disease incidence, evapotranspiration
Radiation	Solar energy received	Photosynthesis, soil & air heating
Rainfall	Condensed water droplets	Water source for crops
Evaporation	Conversion of water to vapour	Irrigation need, water loss estimation

(Source: IMD, 2023; ICAR-CRIDA, 2022)

2. Agro-Meteorological Information and Its Impact on Agriculture

Agro-meteorological information refers to systematic collection, analysis, and application of weather and climate data for agricultural decision-making. It includes real-time weather observations, forecasts and advisories disseminated through GKMS and AMFUs.

Table 2: Major Agro-Meteorological Information Used

Parameter / Type	Example / Description	Use in Agriculture
Temperature	Maximum, Minimum, Mean	Crop suitability and phenology
Rainfall	Amount, distribution	Sowing, irrigation scheduling
Humidity	Morning/evening values	Pest and disease management
Solar Radiation	Sunshine hours	Photosynthesis and biomass
Wind	Speed & Direction	Pollination, lodging, pest spread
Evapotranspiration	Water loss estimation	Irrigation management
Soil Moisture & Temperature	Soil profile data	Seed germination, fertilizer use
Weather Forecast	Short to long-range	Risk management and planning

(Source: IMD-GKMS, 2023)

2. Application of Weather Parameters in Agro-Advisory Interpretation

Farmers can interpret advisories effectively when they understand the meaning of each weather parameter.

Weather Parameter	Possible Advisory Interpretation	Suggested Farmer Action
Rising Temperature	Heat wave likely	Provide irrigation, mulching, shade for livestock
Falling Temperature	Frost likely	Irrigate in evening, use smoke/fire in orchards
High Wind Speed	Dust storm/cyclone	Postpone spraying, support tall crops
High Humidity + Warm Temp	Fungal infection risk	Apply prophylactic fungicides
Predicted Rainfall	Wet spell ahead	Stop irrigation/fertilizer application
Dry Weather	Drought spell	Conserve soil moisture, apply mulch
Cloudy Days	Low radiation	Avoid spraying that requires sunlight
High Evaporation Rate	High water loss	Increase irrigation frequency

(Source: IMD Agro-Advisory Practices, 2023)

3. Latest Developments in Agro-Meteorology

- Establishment of Automatic Weather Stations (AWS) and Agro-AWS across India.
- Use of machine learning models for weather forecasting and yield prediction.
- Development of Decision Support Systems (DSS) integrating weather, soil and crop data.
- Expansion of block-level Agro-Advisory Services (AAS) for localized recommendations.
- Adoption of mobile apps (Meghdoot, Damini, Mausam) for real-time weather alerts.

Conclusion

Weather parameters form the basis of understanding atmospheric behaviour and its direct influence on agricultural production. Agro-meteorological information, when accurately interpreted and timely communicated, empowers farmers to make climate-smart decisions, minimize risks and optimize productivity. The integration of modern technologies such as IoT-based sensors, satellite remote sensing and AI-driven models has revolutionized agromet services, leading towards sustainable and resilient agriculture in the face of climatic variability.

1.3. B. Climate Change, Climatic Variability, Global Warming, Causes of Climate Change and its Impact on Regional and National Agriculture

Agriculture and climate are intricately linked, the former depends on stable climatic conditions, while the later is significantly influenced by agricultural activities themselves. In recent decades, human-induced changes, particularly through the burning of fossil fuels, deforestation and intensive agriculture, have altered the natural balance of the atmosphere.

Climate change is now one of the most pressing global challenges, threatening food security, water availability and rural livelihoods. The Intergovernmental Panel on Climate Change (IPCC, 2023) confirms that global average temperatures have risen by about 1.1°C above pre-industrial levels and the frequency of extreme weather events has increased substantially.

India's agriculture, being largely rainfed (≈ 60%), is highly sensitive to these changes. Understanding the causes, manifestations and mitigation measures of climate change, is therefore crucial for sustainable agricultural development.

1. **Climate, Weather and Climate Change**

- **Weather** refers to short-term instantaneous atmospheric conditions such as temperature, rainfall, humidity and wind occurring at a specific time and place.
- **Climate** is the long-term average of weather conditions for a region (usually 30 years or more).
- **Climate Change** refers to long-term changes in different weather parameters over decades or centuries.

2. **Climatic Variability**

Climatic variability means the natural fluctuations in climate that occur over months, years or decades. Examples include:

- Variation in monsoon rainfall from year to year.
- Occurrence of **El Niño** and **La Niña** events influencing Indian monsoon.
- Seasonal droughts or floods in different years.

Climatic variability is natural, while **climate change** refers to long-term shifts often driven by anthropogenic (human-induced) factors.

3. **Global Warming**

Global warming is the progressive increase in the Earth's mean surface temperature due to the accumulation of greenhouse gases (GHGs) in the atmosphere.

Major Greenhouse Gases (GHGs):

Gas	Source	Contribution to Warming
Carbon dioxide (CO_2)	Fossil fuel burning, deforestation	60%
Methane (CH_4)	Paddy fields, livestock, biomass burning	20%
Nitrous oxide (N_2O)	Fertilizer use, soil microbial processes	6%
Chlorofluorocarbons (CFCs)	Refrigerants, aerosols	10%

(Source: IPCC, 2023)

These gases trap outgoing longwave radiation, creating a "greenhouse effect" that warms the lower atmosphere.

4. Causes of Climate Change

i. Natural Causes

- **Volcanic eruptions:** It releases dust and aerosols. These release affects solar radiation.
- **Solar variation:** It changes in solar energy output which affect temperature in atmosphere.
- **Ocean currents:** They modify regional climate patterns (e.g., El Niño). Which decides monsoon pattern over Asian Countries.

ii. Anthropogenic (Human-Induced) Causes

- **Deforestation:** Cutting down of trees in massive amount reduces carbon sequestration and increases CO_2 concentration.
- **Industrialization:** cause to emissions of harmful toxic gases from factories and vehicles which causes serious health issues.
- **Intensive agriculture: It may cause methane** emissions from paddy fields and livestock.
- Misuse of fertilizer may generate nitrous oxide, a potent greenhouse gas harmful for Environment.
- **Urbanization:** Alters land use and local temperature through "urban heat islands."

Impact of Climate Change on Agriculture

Climate change affects agriculture directly through temperature and rainfall changes and indirectly through soil fertility, pest dynamics and water availability.

i. Impacts on Crops

- Altered growing seasons and shift in crop zones.
- Heat stress during flowering reduces grain yield in rice, wheat and maize.
- Changes in rainfall patterns lead to droughts or floods.
- Increased CO_2 concentration may increase biomass initially but not necessarily yield.

ii. Impacts on Soil and Water

- Increased evapotranspiration and reduced soil moisture.
- Enhanced soil erosion and nutrient leaching.
- Declining groundwater levels and irrigation efficiency.

iii. Impacts on Livestock

- Heat stress reduces milk yield, feed intake and reproductive efficiency.
- Increased spread of vector-borne diseases (e.g., bluetongue, foot-and-mouth disease).

iv. Impacts on Pests and Diseases

- Expansion of pest habitat and emergence of new pathogens due to warmer conditions. (Example: Early outbreak of aphids or late blight in potatoes under humid conditions.)

v. Impacts on Regional and National Agriculture

- In India, crop productivity of wheat and rice is projected to decline by 6–10% by 2030 (ICAR, 2022).
- Semi-arid regions such as Maharashtra face increased frequency of droughts, while coastal regions face salinity intrusion and cyclones.
- Extreme events like unseasonal rainfall and heat waves directly affect sowing and harvesting operations.

5. Mitigation and Adaptation Strategies

i. Mitigation (Reducing the Cause of Climate Change)

a. **Adopting Climate-Smart Agriculture (CSA):**
Integrated management of crops, livestock and resources to enhance resilience.

b. **Efficient Fertilizer Use:**
Site-specific nutrient management (SSNM) reduces N_2O emissions.

c. **Improved Water Management:**
Drip and sprinkler systems reduce water loss and methane emissions from flooded fields.

d. **Agroforestry and Afforestation:**
Enhances carbon sequestration.

e. **Renewable Energy Adoption:**
Use of solar dryers, solar pumps and biogas systems on farms.

ii. Adaptation (Adjusting to Climate Change Effects)

a. **Crop Diversification:**
   Shifting to short-duration and drought-tolerant varieties.
b. **Weather-Based Agro-Advisories:**
   Using real-time weather forecasts to plan sowing, irrigation and spraying.
c. **Soil and Water Conservation:**
   Contour bunding, mulching and water harvesting.
d. **Early Warning Systems:**
   Alerts for droughts, floods or heat waves through GKMS and DAMINI app.
e. **Insurance Schemes:**
   Crop and weather-based insurance to reduce financial risks.

Latest Developments in Climate Change and Agriculture

- **ICAR-NICRA (National Innovations on Climate Resilient Agriculture)** (2011) project focuses on developing resilient technologies and contingency crop plans.
- **IPCC AR6 (2023)** emphasizes the need for limiting warming to 1.5°C through immediate emission reduction.
- **Remote sensing and AI-based climate modeling** enhance regional-level forecasting.
- **Carbon farming and regenerative agriculture** are gaining prominence as mitigation tools.

Table 1. Major Greenhouse Gases and Their Sources

Gas	Source	Agricultural Contribution
CO_2	Fossil fuel burning, deforestation	Machinery use, residue burning
CH_4	Livestock, paddy cultivation	Enteric fermentation, rice fields
N_2O	Fertilizer use	Denitrification in soils
CFCs	Industrial cooling	Minor agricultural use

(Source: IPCC, 2023)

Conclusion

Climate change poses both challenges and opportunities for global and Indian agriculture. While it threatens crop yields and food security, adaptive and innovative practices offer pathways for resilience. Shifting from conventional to climate-smart, low-emission agriculture through precision farming, agroforestry, efficient irrigation, and renewable energy can mitigate adverse effects.

Understanding the interlinkages between agricultural practices and climate is essential for building a sustainable and climate-resilient agricultural future.

Annexure I: Major Indian Initiatives for Climate-Resilient Agriculture

Program	Implementing Agency	Objective
NICRA	ICAR	Climate-resilient technologies and adaptive farming
NMSA	MoA&FW	Sustainable agriculture under the National Action Plan on Climate Change
GKMS	IMD	Weather-based agro-advisories
PMFBY	GoI	Weather-based crop insurance
SAPCC	State Governments	State-level adaptation and mitigation planning

1.4. Components of IFS / Agroforestry and Its Advantages - Site Specific Development of IFS Model for Different Agro-Climatic Zones in Rainfed, Irrigated and Irrigated Dry Conditions

Integrated farming system is a resource management strategy to achieve economic and sustained production to diverse requirement of farm household while preserving resource base, ensuring environmental quality and maintaining desired level of biological diversity.

The word integrated is derived from the "Latin" word "integrare" which means to make whole (that means to complete) by addition of parts or to combine the parts to make whole. Eg: Crop, livestock and fish are the subsystems, they function independently. However the products are additive i.e. output of one subsystem in an IFS which other wise may have been wasted becomes an input to another subsystem which will result in greater efficiency of the output of desire products. Integration of various farm enterprises like cropping system, animal husbandary, fishery, forestry etc., may be for optimal utilization of resources which will bring prosperity to farmers.

Integrated Farming System according to Dr. Jayanthi 2008: It is a judicious (meticulous) mix of one or more enterprises with cropping in which there is a complementary effect through effective recycling of wastes or residues and encompasses additional source of income to the farmers.

The systems of farming and type of cultivation will vary according to various conditions like climatic condition, soil type irrigation potential available in a particular locality / place.

1. Principles of integrated farming system

- Minimization of risk
- Recycling of waste and residue
- Integration of two or more enterprises
- Optimum utilization of all resources
- Maximum productivity and profitability
- Ecological balance
- Generation of employment potential
- Increased input use efficiency
- Use of end products of one enterprise as input in other enterprise

2. Components of Integrated farming systems

- Field crops
- Crop production
- Vegetables
- Fruit cultivation
- Poultry farming
- Livestock integration
- Duckery
- Aquaculture
- Agroforestry
- Bee- keeping
- Mushroom cultivation
- Bio-gas plant

Normally there are three types of farming:

1) Wet land farming
2) Garden land farming or irrigated farming
3) Dry land farming.

3. Advantages of Integrated Farming Systems / benefits of IFS.

- Productivity: IFS provides an opportunity to increase production per unit area by virtue of intensification.
- Profitability: B: C ratio increases.

- Sustainability: Increase by way of effective utilization of bioproducts.
- Balanced food: because of linkage of components may produce different sources of nutrition.
- Environmentally safety : waste materials are used more efficiently
- Recycling of farm wastes.
- Income round the year – eg : vegetable, eggs, mushroom production
- Adoption of new technology – because of linkage of different components availability of cash round the year will give a short of individual farmer to think.
- Solves energy crisis
- Solves fodder crisis
- Create employment generation to rural youth avoiding migration to urban areas
- Provides opportunity for agro circuited industry
- Improve the standard to living
- Avoid degradation of forestry
- Solve fuel and timber crisis.
- Maintenance of good soil health.
- Increase in input efficiency.

Table 1: Characteristic features of Farming Systems

Features	Wet land farming	Garden land farming	Dry land farming	Rain fed farming
1. Farming duration	9-12 months	9-12 months	<6 months	6-8 months
2. Source of water	River, Lake, Pond	Well	Rainfall < 800 mm	Rainfall >800 mm
3. Climate	Arid to humid	Arid to humid	Arid to semiarid	Sub humid to humid
4. Irrigation	Natural Flow(canal)	Lift irrigation	No irrigation	Supplemental irrigation
5. Water management	Management of excess water Eg: Drainage	Economical use of water (WUE)	Water Conservation	Disposal of excess water during high rainfall period.
6. Fertilizer Management	Liberal use	Liberal use	Limited use	Adequate
7. Objective	Maximization of yield	Yield maximization	Sustainable yield	Yield maximization
8. Constraint	Drainage, water logging, salt formation	Salt affected land	Soil erosion due to undulating lands	Water erosion

4. Different forms of Integrated farming system

Crop based farming system, Livestock based farming system, Agro-forestry based farming system, Horticulture based farming system and Fishery based farming system

Selection and adoption of high income generating IFS depends on environment condition of the locality and other available resources. IFS can be categorized based on the zones and irrigation availability as\

i. IFS for irrigated situation

- *Crop husbandry+ Dairy+ Biogas+ Vermicomposting
- Crop husbandry+ Dairy+ Bee keeping
- Crop husbandry+ Sericulture+ Vermicomposting
- Crop husbandry+ Poultry+ Sheep

ii. Transition, coastal and hilly situation

- Crop husbandry+ Dairy+ Poultry
- Crop husbandry+ Fish
- Crop husbandry+ Mushroom+ Piggery
- Crop husbandry+ Fish+ Poultry
- Crop husbandry+ Fish+ Duckery
- Paddy+ Fish+ Azolla+ Duckery

iii. Dryland situation

1. Crop husbandry+ Horticulture (fruit)+ Sheep/ Goat
2. Crop husbandry+ Sheep/ goat+ Agro forestry
3. Crop husbandry+ Piggery+ Biogas
4. Crop husbandry+ Dairy+ Sheep/goat+ Poultry+ Agro forestry

*crop husbandry includes field crops, horticultural crops (fruits and Vegetables) and plantation crops

5. Integrated Farming System Model for Sustainable Production and Income

- Area = 1 ha
- Five blocks in one ha - each block 20 guntas

i. Block (20 guntas) (Agri + Horti system) - sustainable annual income and nutrition

20 plants of horticulture fruit crops – mango, cashew, sapota and including
One tree each of bela, jamun, guava and emblica.

In dryland horticulture small fruit plants like sithapal, Rampal, kavale and kare are Interspaced
Food crops like fingermillet / millets/, field bean, soybean and redgram are cultivated in rotation
Forage crops are introduced after six years in dryland horticulture

- **II & III Block (20 + 20 guntas) – Improved crops and Cropping Systems for Food Security**
  Suitable crops and crop varieties in rotation-
  Fingermillet+redgram/fingermillet+ field bean/niger

- **IV Block (20 guntas) – Forage production and commercial crops**
  10 guntas for forage crops Co-4, Co-5, Napier,
  10 guntas for Seri Suvarna mulberry production

- **V Block (20 guntas) – Vegetables, Flower crops and Farm pond**
  Chrysanthemum, crossandra,
  Vegetables – chilly, brinjal, guards, beans, clusterbean, tomato and bhendi etc.
  Banana and drumsticks are interspaced on upstream of the bunds in the lower end

- **Livestock components** – for sustainable income, manure production, employment generation and upscaling water productivity

- Two -three milching animals, Rabbits (5+1), Backyard poultry-local birds (10+1), Sheep/goats(8+2), Piggery (9+1)

Fisheries – Assured water availability - Composite fish culture (150-200 fingerlings)

- Surface feeder –Catla catla, silver carp,
- Column feeder- Rohu
- Bottom feeder- Mrigal and common carp
- Aquatic plants- Grass carp

Bee keeping - 6 bee units

Biogas – recycling animal waste for sustainable and self sufficient energy production

- Animal waste 50-60 kg per day
- 2 cu. m biogas unit

Compost and vermicompost production – effective and efficient use of farm waste, production of manures and reducing cost of production

- Biogas slurry and farm waste
- 3-4 ton of vermicompost
- 10-15 tons of compost

Farming System Research for different agro climatic zones in India

- High altitude cold deserts : Pastures with forestry, goats, rabbits, and settled agricultural crops like millets, wheat, barley, and fodders
- Arid and desert region : Animal husbandry with the camels, sheep and goats, and growing with fodder and field crop
- Western and central Himalayas : Horticultural crops as a major component and agriculture mainly on the hill terraces and slopes with maize, rice, wheat, pulses and fodder crops
- Eastern Himalayas : Primitive crop husbandry with rice, millets, pulses etc. Agro forestry system are also common. Piggery and poultry are the chief livestock activity
- Indo-Gangetic plains : Intensive crop husbandry like rice-wheat-maize/mustard/pulses and livestock, dairy, cattle and buffaloes.
- Central and Southern Highlands : Cotton-sorghum-millets/pulses with dairy cattle, sheep and goats and poultry are the secondary livestock and animal husbandry enterprises
- Western Ghats : Major activity on plantation crops, cultivating rice and pulses are the secondary agricultural activity. Cattle, sheep and goats are the livestock components which in most parts, are maintained as large herds.
- Delta and Coastal plains : Rice cultivation with other enterprises like fishery, poultry and piggery, etc., capture fisheries of marine ecosystem is a specialized enterprise







Module II: SOIL HEALTH MANAGEMENT

2.1 Soil Profile, Types and Characteristics

Soil, soul of infinite life is a natural body and an important medium for plant growth. It is formed on the surface of earth due to weathering of rocks and minerals. It takes thousands of years to form one-inch-thick layer of soil. Buckman and Brady defined soil as "a dynamic natural body on the surface of the earth in which plants grow, composed of minerals and organic materials and living forms".

Soil a three-phase system comprising of mineral matter, organic matter, water and air. The type of soil, its composition, properties etc, depend on the soil forming factors and processes that has occurred. Thus, **soil profile** is a historic record of the soil forming processes. It is the vertical section through soil having differentiated layers called horizons. It consists of different horizons called "O, A, E, B and C" horizons. A typical soil profile shows a very thin organic horizon rich in organic matter, an upper mineral horizon that supports plant growth, a leached elluvial horizon, a dark coloured illuvial horizon, a partially weathered unconsolidated parent material and bed rock at the bottom.

Study of soil profile help us understand the genesis of soil, type of soil that is formed, its properties, like depth, texture, structure etc of solum, soil constraints if any and suitability to crops.

The study of soil profile also helps in knowing the soil type of a given region. The soils are characterized by their properties, their origin, effect of climate etc. Thus, the soils differ from region to region supporting diversified crop production. Considering the overall characteristics, the following major types of soils are found in India. The soil type and its characteristics, land use, major constraints and their distribution are given in Table 2.1.1.

Table. 2.1.1: Soils of India and its distribution

Sl. No.	Soil Type & Characteristic	Land Use	Constraints	Distribution
1	**Alluvial Soil –** Highly Fertile & Productive soils	Supports cultivation of wide variety of crops - Rice, Wheat, Bajra, Sugarcane, Cotton, Mustard, Potato vegetables and Jute.	1. Very Low Water Holding Capacity. 2. Low in humus, nitrogen and phosphorus.	Accounts for 23.4% of country's soil cover. Indo-Gangetic plains, Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, West Bengal & Brahmaputra Plains.
2	**Black Soil** – 1. Highly Clayey soils with swelling & Shrinkage property 2. Very high cation Exchange &	Supports cultivation of Jowar, Bajra, Cotton, Sugarcane, Groundnut, MINER Millets, Maize,	1. Highly sticky & Plastic soils 2. Has high concentration of Iron, Lime, Calcium, Magnesium	Accounts to 24.12% Gujarat, Maharashtra, Telangana, Karnataka, Tamil Nadu

	Water Holding Capacity (CEC & WHC) 3. High percent Base Saturation	Pulses, Oilseeds, Wheat, Chilli.	3. Low in Nitrogen, Phosphorus and Organic matter.	
3	**Red Soil** – Less Fertile, Good drainage, mildly acidic to neutral Soils	Supports Miner millets, Groundnut, Chilli, Tobacco, Potato & Vegetables.	Rich in Iron but little humus, Low in Nitrogen, Phosphorus, Potassium, Organic matter & other basic cations.	Accounts to 29.08% Tamil Nadu, Karnataka, Maharashtra, Jharkhand, Chhattisgarh, Andhra Pradesh, Odisha, West Bengal & North eastern states.
4	**Laterite Soil** – 1. Hard brick like, 2. Rich in Iron & Alluminium 4. Moderate to Highly acidic	Useful for both Rice and Plantation crops	1. Extremely low in calcium & Magnesium 2. Low in Phosphorus	Accounts to 4.3% soil cover. Karnataka, Kerala, Tamil Nadu, Odisha, Assam, Parts of Maharashtra, Madhya Pradesh, West Bengal.
5	**Desert Soil** – Highly Sandy with poor soil structure	With irrigation suitable for drought resistant crops Barley, Millets	1. Very low in fertility, 2. Very low Water Holding Capacity and very high drainage 2. Deficient in Organic matter, nitrogen and almost all the plant nutrients.	Covers around 4.32% Rajasthan, Gujarat, Southwestern Punjab and Southwestern Haryana.
6	**Forest and Mountain Soils** 1. Hilly Terrain 2. Extreme weather condition	Suitable for Tea, Coffee, Cocoa & Spices, Wheat & Maize in tropical region and temperate fruits, Teak, Pine Tree in Himalayan region	1. Acidic, Rich in organic matter but lack Potash, Phosphorus and Lime 2. Very Shallow soils at higher altitude.	Covers approximately 8.67% Western ghats, in Karnataka, Kerala and Tamil Nadu, North eastern states, Himalayan states like Jammu and Kashmir, Himachal Pradesh and Uttarakhand.
7	**Saline and Alkaline Soils** –	Cotton, Jowar, Barley, Sugarcane, Salt tolerant crops like Sugar beet, Mustard, Berseem & various grass species	Less Productive, High Salt content, problematic soils	Accounts for 2.1% - (7 million ha). Uttar Pradesh, Punjab, Haryana, Rajasthan, Gujarat, Parts of Maharashtra, Andhra Pradesh, Telangana, Karnataka
8	**Peat and Marshy Soils** – High organic matter and Nitrogen content	Supports Paddy, Jute, Spices and Rubber in Malabar region	1. Poor in phosphorus and Potash 2. Ill- drained, high-water table, Highly acidic	covers 2.17% Kerala, West Bengal (Sunderbans), Odisha, Tamil Nadu, Uttarakhand

			(Peat Soils), very high soluble salt content (Marshy Soils)	

2.2. Soil Properties

A soil is termed as a good soil based on the ease of tillage operations, its ability to supply water & nutrients for good plant growth and in turn crop yield. The goodness of soil is reflected by its properties. These properties include physical properties – the conditions that the soil offer while working, the chemical properties – the reactions it supports in terms of nutrient supply and biological properties – that modify these physical and chemical properties.

Thus, a soil having good physical condition possess the ideal chemical and biological environment and supports plant growth and development at optimum levels.

2.2.1. Physical Properties

The physical properties of soil include soil texture, structure, density, porosity, consistency, temperature, colour and water content. which depend on the amount, size, shape, arrangement and mineral composition of its particles, kind and amount of organic matter, volume and form of its pores and the way they are occupied by water and air at a particular time.

1. **Soil Separates**

The mineral portion of soil volume is composed of three important components, viz. sand, Silt and Clay. The particle size of sand is 2.0 mm to 0.02 mm, silt – 0.02 mm to 0.002mm and clay - < 0.002 mm.

2. **Soil Texture**

The relative proportion of sand, silt and clay in a given soil is called soil texture. The soil texture influences porosity, permeability, infiltration, shrink-swell rate, water holding capacity, susceptibility to erosion etc. ease of tillage and combinedly influence soil fertility. For ex: a coarse sandy soil has sufficient aeration for good root growth, easily wetted but, it dries rapidly and easily lose plant nutrients through leaching. Whereas a clayey soil (> 35% clay) is rich in clay closely packed together leaving very little pore space, this condition makes soil difficult to wet, drain and till.

Based on the percentage of sand, silt and clay the soils are classified into 12Textural classes from sandy soils to clayey soils. Soils having almost equal proportion of sand, silt and clay exhibiting light and heavy properties as seen in 'Loam soils'. Soil texture is an innate property of the soil and does not change with agricultural activities.

3. Soil Structure

Soil particles do not exist as individual particles, but are bound together in varying degree into aggregates. The arrangement of primary soil particles and their aggregates into a well-defined pattern is called soil structure (Fig. 2.2.1a & 2.2.1b). The naturally occurring aggregate is called 'Ped'.

Types of soil structure

Platy – The aggregates are flattened, compressed arrangement of peds. It is normally inherited from parent material and is present in A horizon.

Prismatic – Vertical arrangement of particles giving a flat pillar like shape. It may be ***Columnar*** when top is round. Normally found in sub surface layers.

Blocky- Aggregates possess cube like shape. They are angular when having sharp edge and sub angular it is found in sub surface region.

Granular & crumb – spheroidal peds of generally found in 'A' horizon along with organic material. It is considered ideal structure.

Various factors like climate, organic matter content, adsorbed cations, tillage operations, soil organisms etc affect the formation of soil aggregates and their stability.

How to improve Soil Structure?

Soil structure is the most important physical property in relation to plant growth as it influences the functional properties like aeration, water holding capacity etc. The Soil structure can be improved by adopting various management practices like;

a. **Tillage:** Intensive cultivation practices spoil the soil structure. Tillage operations at optimum soil moisture is favourable. Even minimum tillage and zero tillage operations promote stable soil aggregation.
b. **Vegetation:** Grassland and forest soils have highly stable soil aggregates.
c. **Cropping and manurial practices:** Cultivation of grass / Fodder crops green manure crops result in improved soil structure. Crop rotation with legumes promotes good soil structure besides improving soil fertility.
d. **Liming in acidic soils:** Application of lime neutralizes acidity and improves the soil structure due to addition of calcium and magnesium.
e. **Drainage in Saline and Sodic Soils**: Drainage helps to leach out the accumulated salts and increased concentration of Calcium ion promotes flocculation and thereby aggregation is improved.
f. **Addition of Organic manure:** Addition of organic manure encourages formation of granular structure. Various compounds released during decomposition of organic matter and the synthesized humus binds the soil particles into stable aggregates.

4. Densities of Soil

Density of soil is the weight per unit volume of soil expressed in grams per cubic centimeter.

Density (D) = Mass of Soil (M) / Volume (V) gm/c.c of soil

a. **Particle density** – it is the weight of soil solids per unit volume. Generally, the normal soils have a particle density of 2.65 grams per cubic centimeter.

Particle Density = Weight of soil solids / Volume of Soil Solids = gm / c.c.

b. **Bulk density** – it is the mass of unit volume of oven dry soil (including soil and pore volume). It is always less than particle density and normally varies from 1.0 to 1.6 grams per cubic centimeter.

Bulk Density = Oven Dry weight of Soil / volume of soil (Pore volume + Solid particle volume) in gm/c.c.

5. Soil Porosity

It is the portion of soil not occupied by soil particles or organic matter. Under field conditions these pore spaces are occupied by air and water. This includes ***i. Macro pores*** – the large sized pores and ***ii. Micro pores*** – small sized pores.

6. Soil Consistency

It is one of the dynamic properties indicating behaviour of soil under stress influenced by soil moisture levels wet, moist and dry.

The bulk density, porosity and consistency are influenced by the soil texture and structure. These properties indicate the degree of compactness permitting the entry and movement of air and water through the soil. These properties can be managed better by addition of organic matter and adopting suitable cropping practices.

7. Soil Air

It is the exchange of gases between the soil pores and atmosphere. A well aerated soil is one which has sufficient amount of pore space for ready movement of useful gases in and out of the pore space. The soil air quality is expressed in terms of Oxygen Diffusion Rate (ODR), which is an index of the rate of oxygen diffused through the water film to the roots. ODR is an indication of relationship between plant roots and soil, soil moisture, aeration status and biological activity in soil which ultimately influence plant growth by affecting various physical and chemical properties of the soil.

8. Soil Water

Soil water is the water that is present between the soil particles and moves through the soil It is the solvent in which nutrients get dissolved and move. For optimum water use it is very important to know how water moves into and through the soil, how it is stored in soil, how plants absorb it and how nutrients are lost from soil.

Water which is available for plant uptake is present and moves through small pores is called ***Capillary water***. It is held in micropores of soil at a water potential between -1/3 bar and -31 bar. Water which is not available for plant uptake is ***Unavailable water.*** It moves down through larger pores, hence called ***Gravitational water.***

It is held at a potential greater than -1/3 bar. Water present as thin film of vapour and also is not available for plants is ***hygroscopic water***. It is held by soil at a suction more than -31 bar. A representative cultivable soil has 50% pore space in which 25% is occupied by soil air and 25% is occupied by soil water.

All these physical properties influence soil air and water, their movement, and availability which is of great importance in terms of soil fertility. Addition of organic matter and adopting suitable cropping systems and cultural practices help in conserving the soil.

9. Soil temperature

Solar radiation is the greater and major source of soil heat. Soil has a temperature ranging between 20^0 C to 60^0 C. The soil temperature is affected by soil texture, structure, moisture, colour, vegetation cover, season, climate and compactness of soil.

Soil Temperature affects a) Germination of seed b) soil aggregation c) microbial activity in soil d) decomposition of organic matter in soil e) absorption of water, availability of nutrients, root growth etc.

Soil temperature can be managed by regulating the amount of water, draining out excess water from waterlogged soils, addition of water in case of dry soils, use of various kinds of mulches etc.

10. Soil Colour

It is the colour of soil that is visible and is influenced by the presence of organic matter, iron compounds, silica, lime and other salts, drainage conditions, degree of oxidation etc. Soil colour is indirectly an indicator of various soil properties. It is represented by Hue, value and Chroma which indicate dominant spectral colour, lightness or darkness of the colour and purity/ strength of the colour respectively. For ex; Munsell's colour chart showing 2.5YR 5/6 indicates a Hue of 2.5 YR, Value 5 and Chroma 6 and is interpreted as Weak red colour soil.

2.2.2. Soil Chemical Properties

The chemical properties of soil are the soil reaction referred to as soil pH, salt content, soil nutrients essential for plants, nutrient holding capacity referred to as exchange capacity, nutrient uptake, soil – water – plant relations, and nutrient use efficiency.

a. Soil Reaction (pH)

Soil reaction is the most important factor expressed in terms of pH for evaluating soil production potential for most crops. It is an indicator of **soil acidity** or **alkalinity** and **nutrient availability** for plant uptake. The pH scale ranges from **0-14** (practically from **3-11**). Soils having **pH less than 6.5 are termed acidic** (Slightly acidic – 6.5 – 6.1, moderately acidic – 6.0 – 5.1, strongly acidic – 5.0 -4.1, very strongly acidic – 4.0 – 3.0 & extremely acidic - < 3.0) and **soils with pH more than 7.5 are termed as alkaline** (slightly alkaline – 7.6 – 8.0, moderately alkaline – 8.1-8.9, strongly alkaline – 9.0 – 9.9, very strongly alkaline – 10.0 10.9 & extremely

alkaline - >11.0). Most of soil nutrients are available for plant uptake in pH range of 6.5 – 7.5 which is called neutral range.

b. Soil Conductivity

It is the ability of soil water to conduct electricity expressed as deci Siemen per meter (dSm^{-1}) or milli Mhos per centimeter ($mMhos\ cm^{-1}$). It is the measure of total dissolved salts present in soil. It is a key indicator of soil salinity and nutrient availability.

c. Soil Nutrients Essential for Plants

The nutrient elements which are very much essential for plant to complete its life cycle are called essential nutrients. The nutrients present in the soil along with applied nutrients through manures and fertilizers are made available for plant uptake by the soil.

d. Ion Exchange capacity

Nutrients are absorbed by the plants in ionic forms. These ions are held and released into the soil solution for plant uptake. The capacity of the soil to hold and release these nutrients is called ion exchange capacity. It is one of most important chemical property related to soil fertility and hence plant nutrition. Two types of ion exchange are CEC and AEC (for positive ions, and negative ions respectively).

e. Nutrient Uptake

Plant nutrients prior to uptake by plants move near the plant roots by mechanisms called Mass flow, diffusion and root interception. All these processes act simultaneously in soil in fulfilling the nutrient requirement of plant near root zone. But, most of the nutrients, quantity wise move through the soil solution and taken up by the plants through the mechanism of Mass Flow.

f. Nutrient Transformations

Availability of plant nutrients depend on the biochemical reactions that take place in soil leading to release of nutrients in the form suitable for plant uptake. When soil physical conditions are favourable, i.e proper gaseous exchange take place, it enhances the activity of microorganisms, the nutrient cycles are completed releasing the nutrients for plant uptake.

2.2.3. Soil biological properties

The presence of soil microorganisms, small and large animals in soil is an indication of biological activity in the soil.

It is the most living thing in soil dependent on soil organic matter content. These organisms help in improving the structure, aeration, and nutrient cycles promoting nutrient release for plant uptake.

Soil organic matter

It is the organic compounds from plant, animal and microbial material in both living and dead conditions. The organic matter under goes decomposition dynamically by these soil organisms resulting in formation of humus.

Addition of organic matter every year and decomposition thereafter at various levels aid in improving soil carbon pool that enhances plant growth. Addition of humus increases the water and nutrient holding capacity and in turn increases nutrient availability to plants.

An important aspect which draws attention is that, due to extended and continued erosion, the fertile top soil is completely eroded along with the removal of the finer particles exposing bare gravelly structures in some regions. This leads to altering the native soil texture itself. Thus it is very important to understand the soil and its properties to manage them by adopting suitable practices. Date back in 15th Century our famous saint Purandara Dasaru said **"Manninda *Kaya, Manninda – meaning what comes from soil goes back to soil"***. The cycle should go on and on to conserve this precious natural resource otherwise it may be lost forever. A quote by F.D. Roosevelt ***"A Nation that destroys its Soils, destroys itself"*** highlights the importance of conserving our natural resource - Soil and in turn strengthening nation.

Soil Quality Indicators

Soil Health Management emphasizes on maintaining favourable soil physical condition. The first step towards management is assessing the soil quality. Some of soil quality indicators are listed in the table. 2.3.1.

Table 2.3.1: Soil quality indicators

Quality Indicator	**Parameter**
Physical Indicator	Texture, Aggregate Stability, Bulk Density, Infiltration, Available Water Capacity
Chemical Indicator	Soil pH, electrical Conductivity, Available nutrients
Biological Indicators	Soil Respiration, Earthworm enumeration, Microbial Population, enzyme activity

Generally, these indicators are tested in laboratory which are time consuming. Some of these like soil texture, earthworm load can be assessed at field level, enabling a farmer/an extension person to get basic onsite information about soil property. These tests are presented in pictorial format for better understanding.

Scan this QR code for Annexures 1 & 2 to know about these simple and easy field test methods.

Apart from these tests, general field observations like the feel when walked bare footed, crust formation, smell of the soil, soil colour assessment in wet and dry condition help in qualitative assessment of soil condition.

Every farmer wishes to maintain a healthy soil as it supports healthy crop growth and higher yield. Assessment of the functional indicators of soil at field level and advising suitable management practices including cropping and manurial practices help a farmer to improve his soil health. Field assessment tests become a handy tool for an extension worker.

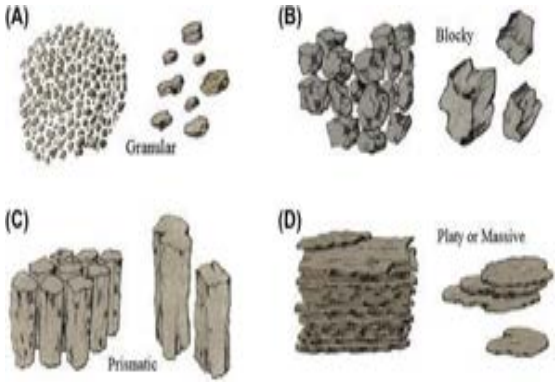


Fig. : Types of Soil Structure

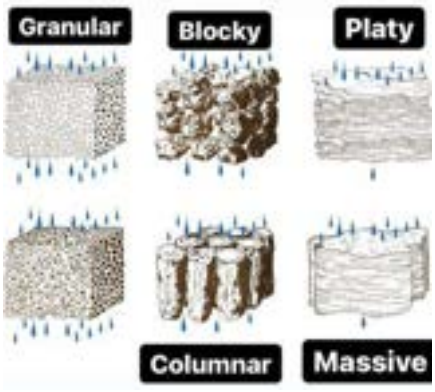


Fig.: Permeability of water through Soil

2.1. A. Importance of Soil Testing / SHC, Method of Soil Sampling, Interpretation and Farm Advisory, Based on Soil Test Results

Fertile soil plays a critical role in promoting plant growth and improving crop productivity. To complete their life cycle and sustaining crop production, plants require 17 essential elements. Of which, carbon, hydrogen and oxygen are obtained from air and water while the rest 14 from soil only. Hence, it is very essential to assess the fertility status of soil. Major techniques include nutrient deficiency symptoms of plants, plant analysis, biological tests and soil analysis.

Soil testing is a chemical method to estimate the nutrient supplying capacity of soil. The data are useful for recommending the type and amount of fertilizers and other amendments needed for increased and profitable crop production. It helps to evaluate the nutrient status of an area and also to compare the fertility levels of different areas. The nutrient status of soils may vary with the season and crops grown. Fertilizers help to replenish the nutrients removed by the crop during its growth period. Soil test based fertilizer recommendation is a scientific management method for obtaining effective and economic fertilizer use. Through soil testing, it is possible to determine the nutrient status of soil before the crop is planted.

Major benefits of soil testing include:

- Balanced fertilizer application
- Ensuring cost effectiveness
- Reducing pest and disease incidence due to imbalanced fertilizer use
- Maintaining soil health
- Avoiding environmental pollution due to overuse of fertilizers
- Improved crop yield and productivity
- Supports long term planning for sustainable farming practices

1. Soil Sampling

The most critical aspect of soil testing is obtaining a soil sample that is representative of the entire area under investigation. It is essential that the field be sampled properly. If the sample does not represent the field, it is difficult to provide a reliable fertilizer recommendation. Soils collected from different parts of the field should be thoroughly mixed to get a homogenized soil sample. Intensive soil sampling is the most efficient way to evaluate the soil variability. Variations in slope, colour, structure, crop growth and management practices should be considered and separate set of composite samples should be collected from such areas. Usually surface soil samples (0-15 cm) are collected. Complete information about the site *viz.*, slope, drainage, soil depth, cropping history, fertilizer and cultural practices, is essential for fertilizer recommendation.

Tools for sampling

- Soil tubes/ Augers/ Spades/ Power driven samplers
- Buckets
- Cloth bags/ Plastic bags

Collection of Soil Samples

Soil samples should be collected in a scientific manner to get precise results and appropriate fertilizer recommendation. In levelled lands, one composite sample may be sufficient while in slopy areas, more number of samples may be needed depending on the degree of slope. Soils from 10-12 sites may be mixed thoroughly to get a representative sample. Usually, soils are collected from plough layer *ie.* 15 cm depth and 15-20 cm away from the crop basin. For larger and perennial trees, soils are collected farther away outside the basins. For eg. 75 cm away from the basin for banana and 2m for coconut. In the case of line- planted crops, samples are collected from the space between the planting lines. Before collection of soil samples, all weeds, dried leaves and other debris from the collection site are removed and the surface is cleaned. Then a V- shaped cut of 15cm deep is made using a spade. Soil of 2-3 cm thickness is scraped out from both the sides of the V cut. It is better to traverse the field in zig-zag manner prior to sampling and identify the selection sites.

Steps in Soil Sample Collection:



Pooling of soil sample



Quartering of soil sample



Discarding opposite corners

Preparation of Soil Sample

The soil samples collected from the different sites are pooled together and a representative sample is obtained by way of a process called '*quartering*'. For that, the collected samples are spread on a plastic sheet and mixed thoroughly. Dried leaves, twigs, small gravel pieces, if any, are removed and formed into a heap. The uniformly mixed sample is then cut into four equal parts by drawing lines horizontally and vertically.

The diagonally opposite two halves are discarded and the remaining portion is again mixed thoroughly. Quartering is continued till a representative sample of 500 g is obtained.

The sample thus obtained is allowed for shade drying on a clean surface. Never allow the sample to dry under direct sunlight. The dried sample is collected in cloth or plastic carry bags and send to soil testing laboratories for further analysis. Detailed information about the farmer and field *viz.*, name and address of farmer, area of field, survey number, crops grown, crops planning to be cultivated etc. should be given along with the soil sample. There is a prescribed format in all soil testing laboratories and it should be properly filled up. In areas where intensive cropping practices are carried out, it is better to collect soil samples annually, while for mono-cropped areas, once in three years.

Areas to be avoided for Soil Sample collection

- Sites near manure pits or compost pits.
- Recently fertilized areas
- Sites near roads, paths or buildings
- Areas near fences or field boundaries
- Areas where fertilizer bags have been kept
- Very near to root zone areas

Soil test results give an indication of the pH and nutrient status of the soil and management practices to be adopted to improve the productivity of the soil. Soil testing facilities are available with

State Agriculture departments, Agricultural Universities, KVKs and Central Institutes. Based on the available nutrient status of soils, they are categorized to low, medium and high classes and accordingly, modifications in the fertilizer recommendations are made.

2. Concept of Soil Health Card

Soil health is defined as the continued capacity of soil to function as a vital living ecosystem sustaining the life of plants, animals as well as human beings. It is an integration of all the soil properties *viz.*, physical, chemical and biological. Healthy soils can improve crop productivity with minimum external inputs, enhance nutrient recycling, enhance water infiltration and retention, reduce runoff and act as carbon sinks. The soil samples collected should be analysed for various physical, chemical and biological attributes to provide correct soil interpretation results to the farming community. "All fertile soils need not be productive" because productivity is the actual crop yield which is influenced by many other factors besides the availability of soil nutrients (soil fertility).

The concept of Soil Health Card (SHC) was introduced by Govt. of India in 2015, which is a document given to farmers containing detailed assessment of their soils based on 12 key parameters *viz.*, pH, EC, organic carbon, available N, P, K, S (major nutrients), Fe, Mn, Zn, Cu and B (micro nutrients). The card suggests recommendations for fertilizer use and soil amendments, enabling farmers to optimize nutrient application, improve crop yields, reduce input costs and adopt sustainable farming practices.

Major benefits include:

- Enables the farmers to take judicious decisions on fertilizer use and crop choices
- Regulates over use of fertilizers
- Reduces input cost
- Improves crop productivity and more sustainable yield
- Protects the ecosystem from unwanted pollution
- Maintains long term soil health
- Provides a valuable record to monitor soil health over time

Soils of Kerala, in general, are acidic and shows deficiencies of Ca and Mg. Hence, in preparation of soil health cards in these areas, 14 parameters are analyzed.

2.2. B. Problematic Soils and their Management

Soil is the loose weathered natural material on the surface of Earth that supports plant life and helps build strong structures like buildings, rocks etc. But all soils do not behave in the same manner. In general, the soils require good management practices to maintain their productive manner in long run. Some soils may require special management techniques as they possess serious constraints that limit their use for construction or agriculture purposes. Such soils are referred as ***problem soils*** and they need proper reclamation measures for raising crops.

Based on the nature of problems, soils are grouped into:

- Soils that face climatic problems
- Soils with physical problems
- Soils with chemical problems
- Soils with biological problems
- Soils that face problems due to anthropogenic reasons

Classification of problem soils based on the Nature of problems

Nature of problem	Major soil groups	Salient features

Climatic	Cold soils	Reduced weathering and slow soil development; poor soil fertility; accumulation of undecomposed organic matter
	Dry soils	Extreme dryness leading to soil cracking and destruction of soil structure; heavy salt accumulation; high bulk density
Physical	Steep soils	Shallow depth; weakly developed; intense leaching and poor fertility
	Shallow soils	Limited soil depth; imperfect drainage and low water holding capacity; severe erosion
	Imperfectly drained/ Slowly permeable/ Submerged soils	Water logging; poor drainage and anaerobic condition; leaching of nutrients; low organic matter decomposition and microbial activity; redoximorphic features
	Highly permeable soils	Rapid infiltration; low moisture retention; low fertility; poor structural stability
	Soil surface crusting	Formation of thin dense layer; low infiltration rate and hydraulic conductivity; restricted gaseous diffusion
Chemical	Acid soils	Low soil pH; high exchangeable acidity; imbalance of nutrients; low fertility
	Acid sulphate soils	Presence of sulphuric horizon; very low pH (3.5 or even less); toxic levels of Al, Fe, S, Mn and soluble salts; both acidity and salinity problems have to be addressed.
	Red soils	Accumulation of iron oxides; low in nutrients like N, P, K; low in organic matter
	Laterite soils	High Fe and Al oxide content; low fertility and CEC; highly weathered; lateritic hardpan restricts root growth, drainage, & infiltration
	Salt affected soils	Plant development severely affected; osmotic and nutritional stress leading to decline in crop yield; loss of soil biological activity; poor soil structure
Biological	Low carbon soils	Insufficient organic carbon content; poor nutrient availability; reduced WHC
	Biologically less active soils	Reduced abundance of soil microorganisms; lack of nutrient turnover; reduced fertility
Anthropogenic	Eroded soils	Loss of top soil; reduced organic matter and soil fertility; degradation of soil structure
	Contaminated soils	Presence of toxic substances; risk to ecosystem; reduced soil microbial activity
	Mine- degraded soils	Loss of soil structure; release of toxic metals and pollutants; soil erosion; biodiversity loss

i. Soils with Climatic problems

Major soil groups under this class are cold soils and dry soils. The major limitations are due to extreme climate events *viz.*, coldness and dryness. In India, cold soils are seen in north- western Himalayas, covering Ladakh and Gilgit districts. The native vegetation is mainly sparse forest trees. Major fruits cultivated- Apple and apricot.

Dry soils are mainly found in arid and semi- arid regions, where water deficit prevails throughout the year. In India, these soils are seen in hot arid ecoregions at Kachchh and Kathiawar Peninsula, Gujarat, Northen Plains and Deccan Plateau. Extreme dryness may result in cracking of soils and disrupts soil structure. In addition to high deficit in water, these soils also experience salinity problems.

Management

- Provision of mulches to regulate soil temperature. It provides a congenial environment for the plant roots.
- Adjust planting time to safeguard the crops from extreme climate events.
- Use of cold tolerant crops in cold regions and drought tolerant in dry soils.
- Use of soil amendments or conditioners to overcome salt accumulation, subsoil acidity and nutritional imbalance
- Application of organic manure to improve soil structure and thereby enhance retention of soil moisture.

ii. Soils with Physical problems

Steep Soils

Found in areas with >30 % slope. In India such soils are seen in Eastern Himalayas, West Bengal, northern parts of Assam, Arunachal Pradesh, Sikkim and Western Ghats in Kerala, Karnataka and Maharashtra. The soils are very shallow and are more prone to erosion and landslides. Because of severe leaching of nutrients, the fertility status of these soils is very poor.

Soil acidity is another limitation of these soils. Crops like tea, apple, pear, rubber, pineapple etc. are cultivated in these soils with proper management practices.

Management:

- Appropriate soil conservation methods like contour bunding, strip cropping, relay cropping etc.
- Erosion resistant crops like vetiver, cover crops, groundnut etc.
- Use of geotextiles, crop covers etc.
- Application of soil binding or cementing agents



Contour bunding



Stone embankment

iii. Shallow Soils

These soils have a depth less than 50 cm of solum and are found in hill tops and along the slopes. Root penetration is much restricted in these soils leading to poor crop growth. Nutrient availability and water holding capacity are Very low. Presence of hardpan beneath the soil surface resulting in imperfect drainage and severe erosion. Seen in western Himalayas, Central Kathiawar Peninsula, south western Maharashtra, and north Karnataka.

Management

- Planting shallow rooted crops
- Application of organic manures/ amendments/ fertilizers to maintain soil fertility
- Adopt slope protection measures
- Permanent grass cover over soils
- Scientific irrigation practices
- Promote erosion resistant crops

iv. Imperfectly drained / slowly permeable/ submerged soils

Soils which remain in waterlogged condition for major period are included under this category. They are usually found in backwater areas, depressions, coastal areas, rivers, deltas etc. In India, such soils are seen in north-eastern Uttar Pradesh, northern Bihar, Assam, West Bengal, and Kerala. Poor drainage may be due to high clay content, shallow water table, presence of hardpan, or poor physical condition. Rice is the main crop and in reclaimed areas, others like coconut, banana, vegetables, and tuber crops are cultivated. Water logging along with salinity are the major constraints here. Leaching of nutrients is a common phenomenon here. The submerged condition creates anaerobic condition, slowing down organic matter decomposition and low microbial activity.

Management

- Select crops that can tolerate waterlogged condition
- Application of organic manure/ soil amendments/ conditioners- Lime to correct soil pH; gypsum for sodic soils and leaching with good quality water for salt affected soils
- Use of biofertilizers like Azospirillum, Azotobacter, and PGPR mix I etc.
- Slow release fertilizers- neem coated urea, rock phosphate etc.
- Surface as well as sub surface drainage
- Suitable planting methods like planting on ridges, mounds or broad beds, formation of ridges and furrows etc.

v. Highly permeable soils

This group includes sandy soils with >70% sand and <18% clay, seen along coastal areas, river deltas, and in desert belts. These soils are widely distributed in Rajasthan, Gujarat, Haryana, and Punjab. All the states with coastal belts have these soils. Since these soils are very loose and poorly structured, they have large number of macropores and have very high infiltration rate and hydraulic conductivity.

Other constraints include low moisture retention, poor water holding capacity, low nutrient status, and poor organic matter content and less anchorage to the crops grown.

Management

- Application of organic manures- FYM, compost, coir pith compost, vermicompost etc.
- Crop rotation with green manure crops like sunnhemp, daincha, sesbania etc.
- Provide mulching
- Split application of fertilizers and frequent irrigation

vi. Soils with Surface Crusting

Such soils are generally found in arid and semiarid regions. Surface crusting refers to the formation of specific modifications or thin, dense and relatively hard layer on the top soil caused by the impact of rainfall or irrigation and the following drying process. The soils having weakly aggregated soil structure are more prone to the dispersing effect of rain drops and formation of clay crust on the surface. Crusting prevents the germination of seeds and proper root growth. It accelerates surface runoff and causes poor infiltration.

Management

- Incorporation of organic manure like FYM, compost or green manure to improve soil physical properties
- Retention of crop residues on surface as protective cover
- Light harrowing after rainfall to break the crust
- Application of binding agents like polysaccharides or biochar to enhance aggregation
- Soil amendments like gypsum or lime based on soil pH

Vii Soils with Chemical problems

a. Acid Soils

These soils are characterized by preponderance of H^+ ions. H^+ found in soil solution and Fe^{3+} and Al^{3+} found in soil solution are largely responsible for soil acidity. About 30 % of Indian soils are acidic in nature, covering 49 million ha of land. In India they are mainly distributed in Assam, West

Bengal, Meghalaya, Andhra Pradesh, Telangana, Karnataka and Kerala. Under high rainfall areas, most of the bases will be leached out, resulting in the accumulation of Fe and Al in the soil which are acidic in nature. Plant growth will be much restricted in high acidic conditions due to restrictions in the availability of essential plant nutrients and increase in the availability of toxic elements. Microbial activity will be much affected under acidic conditions- inhibiting the survival of useful bacteria, legume nodulation and N fixation.

Management

- Addition of amendments especially, liming materials- calcite, dolomite, quick lime etc.
- Acid tolerant crops- cassava, pineapple, banana
- Application of organic manures like FYM, vermicompost, green manures etc. will improve the physical, chemical and biological properties of soil
- Application of ash, rice husk etc.

b. Acid Sulphate Soils

These soils are unique soils containing iron sulphides or pyrites that have formed naturally in water logged conditions like estuaries, wetlands and shallow groundwater. Upon oxidation through drainage or mining, pyrites oxidises to produce sulphuric acid. This leads to the development of extreme acidity, pH may even reaches upto 2.5, and creates a sulphuric horizon. Results in the mobilization of more metal elements and toxicity of Fe, Al, Mn, S, etc.

This badly affects root development and plant growth. Another major problem is salinity as most of these soils are located in back water areas or very near to saline water bodies. Hence, rice varieties that are tolerant to both acidity and salinity are to be cultivated.

Management

- Keep the soils in flooded condition as long as possible
- Shallow surface or subsurface drainage to facilitate leaching of soluble salts
- Application of liming materials
- Application of FYM, compost, rice husk or biochar
- Adopt rice- shrimp cropping sequence
- Soil test based fertilizer application
- Cultivation of tolerant rice varieties

c. Laterite Soils

In India, these soils are found in the southern, south eastern and north eastern states- Kerala, Karnataka, TamilNadu, Orissa, Assam and Deccan Hills. The term laterite was first coined by Dr. Francis Hamilton Buchanan (1807) for ferruginous soft materials which irreversibly hardens on exposure to air. Laterite soils are formed by intense leaching of bases and desilication followed by residual accumulation of Fe and Al oxides. Formed under humid tropical climate experiencing alternate wet and dry spells. These soils are characterized by low organic matter content, low fertility, deficiency of P, K, Ca, Mg, S, Zn and B, low CEC, and toxicity of Fe, Al and Mn.

Management

- Liming
- Judicious application of manures and fertilizers
- Adoption of suitable soil conservation measures against erosion
- Breaking of hardpans or deep ploughing
- Crops tolerant to acidity- pineapple, banana, cashew, vegetables, coconut etc.

d. Red Soils

In India, red soils are mainly found in Andhra Pradesh, Karnataka, Maharashtra, Orissa, Goa, NE region and Kerala (southern parts of Thiruvananthapuram district and certain pockets in Palakkad district). They are found in tropical and subtropical regions, particularly in areas with moderate to low rainfall and are characterized by their reddish colour, due to iron oxide accumulation. These soils are nutritionally poor and

low in organic matter content. They usually require fertilization to maintain soil productivity. Well drained soils, but chances of erosion problems are there. Red soils can develop a cemented lateritic hardpan just below the surface, which can impede root growth, water infiltration, and air circulation

Management

- Add organic matter, lime, and fertilisers to improve fertility and text
- Efficient irrigation techniques like drip irrigation or mulching, to conserve soil moisture.
- Use terracing, cover crops, or contour planting to prevent soil erosion in hilly regions.
- Use mechanical methods or organic amendments to break up hardpans and improve root growth.

e. Salt affected Soils

These soils contain considerable amount of soluble salts like chlorides, sulphates and carbonates of Na, Ca and Mg. in Inia about 6.727 m.ha is salt affected of which 2.965 m.ha is saline and the remaining is sodic. Major states include Gujarat, Uttar Pradesh, Maharashtra, West Bengal, and Rajasthan.

Classification of salt affected soils

Characteristics	Saline soils	Sodic/ alkali soils	Saline- sodic soils
Ph	<8.5	>8.5	8 – 8.5
EC	>4	<4	>4
ESP	<15	>15	>15
Main chemical problem	Excess soluble salts	Excess exchangeable Na	Both soluble salts and exchangeable Na

P is commonly deficient in these soils because it is tied up with Ca or Mg as insoluble phosphates. Availability of micronutrients like Fe, Mn, Zn, Cu and B are affected and hence, plant growth may be limited.

Management

- Application of amendments like gypsum
- Improved agroforestry techniques
- Cultivation of salt resistant crops
- Maintain high water content in soil

vii. Soils with Biological problems

Biological problems in soil often result from unhealthy soil management practices due to poor management, environmental stress, or inherent soil characteristics. These soils often suffer from a decline in microbial populations, nutrient cycling, and organic matter content, which are essential for maintaining soil fertility, structure, and overall ecosystem health. Major risks include:

- Soils with low organic matter and
- Soils with low biological activity

These soils are marked by low organic carbon content and significant reduction in microbial populations, which impacts nutrient cycling, organic matter decomposition, soil structure, and water retention. These soils have poor physical properties like low aggregate stability, infiltration and drainage.

Management

- Addition of organic inputs
- Crop rotation and organic mulching
- Reduced tillage
- Application of biochar
- Inoculation with beneficial microorganisms
- Reduce compaction and improve soil aeration

viii. Soils with problems due to anthropogenic reasons

Various anthropogenic activities and over exploitation of natural resources have resulted in soil degradation and reduction in agricultural productivity. It can be the loss of organic matter, decline in soil fertility, degradation in soil structure, erosion, adverse changes in soil salinity, acidity or alkalinity and the effects of toxic chemicals, pollutants or excessive flooding.

a. Eroded Soils

Soil erosion, either water or wind, removes the fertile surface soil exposing the subsurface strata. The transported soils get deposited in reservoirs and reduces their water holding capacity. Wind erosion is more prominent in areas having sandy soils with low organic matter content. These soils are characterized by weak structure, low water holding capacity, changes in texture, low organic carbon and poor fertility.

Management

- Soil and water conservation measures- check dams, contour trenches, terracing, contour bunding
- Maintain vegetative cover by palnting grass or cover crops
- Agroforestry
- Mulching
- No tillage or minimum tillage

b. Contaminated Soils

The soils get contaminated by different types of materials released from the agricultural, industrial and developmental activities. The major contaminants include agrochemicals (fertilizers and pesticide residues), industrial effluents and automobile emissions. Results in the accumulation of toxic materials that are hazardous to plants and animals. In long run, it will affect soil microbial activity, biodiversity and alter soil chemistry. Contaminants may bioaccumulate in food chain causing ecological and health problems.

Management

- Addition of amendments- organic manure/ compost
- Prevention of pollution following strict guidelines
- Land use planning
- Bioremediation techniques including phytoremediation

c. Mine degraded Soils

Mining activities often disrupt topsoil, destroy soil structure leading to poor water infiltration and root penetration. The landscape will be undulating / slopy with coarse textured materials ends up on the lower slopes. Mining releases heavy metals and other pollutants leading to contamination of soils. Soils are with low nutrient reserves. These soils are highly prone to erosion hazards.

Management

- Addition of soil amendments
- Reintroduce topsoil and maintain vegetation to restore fertility and prevent erosion
- Enforce strict environmental regulations for mining

2.3. Crop nutrition- Essential elements -Importance of major, secondary and micro nutrients.

Macro-Micro Nutrient deficiencies + Toxicity and their symptoms

Objectives

After studying this unit, the participants will be able to:

- To know the nutrients required for plant growth.
- To develop the skills to advise farmers by checking the deficiency / Toxicity symptoms.

Crop nutrients are essential chemical elements that plants absorb from the soil, air or water and are vital for their growth, development & reproduction. These nutrients can be natural or added through fertilizers. Proper nutrient management improves soil fertility and crop yield. In plants deficiency refers to the lack of essential nutrients, hindering growth and development, while toxicity occurs when a nutrient is

present in excess amount, also causing detrimental effects on plant health. Essentially, plant need a 'Just right amount of nutrient-not too much, not too little.

1. **Types of Nutrients**

Autotrophs like plants can produce their own food through photosynthesis, while heterotrophs like animals cannot produce their own food & obtain it by consuming other organisms or organic matter. While soil provides the majority of nutrients, plants also obtain carbon (C) from carbon dioxide in the air and hydrogen (H) from water which are essential components for photosynthesis.

Type	Sub-category	Examples	Key Role
Macro Nutrients	Primary Nutrients	Nitrogen (N), Phosphorus (P), Potassium (K)	Growth, roots, flowers, fruit quality
	Secondary Nutrients	Calcium (Ca), Magnesium (Mg), Sulphur (S)	Cell wall strength, chlorophyll, protein
Micro Nutrients	Trace Elements	Fe, Zn, Mn, Cu, B, Mo, Cl, Ni	Enzymes, photosynthesis, reproduction

2. **Importance and Role of Nutrients**

- Nutrients regulate **plant growth**, **flowering**, **fruiting**, and **resistance to diseases**.
- Deficiencies affect plant health, reduce yields, and cause visible symptoms.

3. Deficiency Symptoms:

Macro Nutrients Deficiency

Understanding these symptoms helps in early correction.

i. **Nitrogen:** Yellowing of old leaves, poor growth.

ii. **Phosphorus:** Purplish leaves, slow root development.

iii. **Potassium:** Leaf edge burning, weak stems.

iv. **Calcium:** Tip burn, blossom end rot in tomato.

v. **Magnesium:** Yellow between veins in older leaves.

vi. **Sulphur:** Yellowing of young leaves.

Micronutrient Deficiencies:

i. **Zinc:** Short plants, small leaves (Little leaf).

ii. **Iron:** Yellowing in young leaves.

iii. **Boron:** Cracked fruits.

iv. **Molybdenum:** Whiptail in cauliflower.

v. **Copper:** Curling and dying back of shoots.

vi. **Manganese:** Interveinal chlorosis (yellowing beteen leaf veins while veins remains green).

vii. **Chlorine:** Cloristic (yellowed) leaves, leaf spots, brown edges, wilting and stunted growth.

viii. **Nickel:** Yellowing of older leaves, necrotic (dead) leaf tips and inhibited growth.



Remedial Measures

Proper diagnosis, through continuous monitoring of crop growth is the key for initiating remedial measures.

Method	Description
Soil Testing	Analyze soil nutrients and plan inputs accordingly
Fertilizer Application	Use correct fertilizers in right doses
Foliar Spray	Spray micronutrient solution on leaves
Organic Amendments	Add FYM, compost, green manures
pH Management	Lime for acidic, gypsum for alkaline soils
Petiole Testing	Analyse nutrients content of the petioles at any stage of growth and guides precision nutrient management strategies especially in fruit crops.

3. **Farmer Awareness Tools**

- **Charts/Posters**: Visual tools showing symptoms
- **Demonstrations**: Compare healthy vs. deficient plants
- **Mobile Apps/Videos**: Local language learning aids

- **Field Schools**: Group learning with practical exposure
- **Soil Testing Campaigns**: Farmer participation encouraged

4. **Integrated Nutrient Management (INM)**

Definition: Balanced use of chemical fertilizers, organic and bio fertilizers to maintain soil fertility and crop productivity

Components:

Component	Function
Chemical Fertilizers	Quick nutrient supply (e.g., Urea, DAP)
Organic Manures	Improve soil health and microbial life
Biofertilizers	Live microbes that fix nitrogen or solubilize phosphorus
Green Manuring	Adds organic matter and improves soil structure
Soil Testing	Site-specific nutrient recommendations

Benefits of INM:

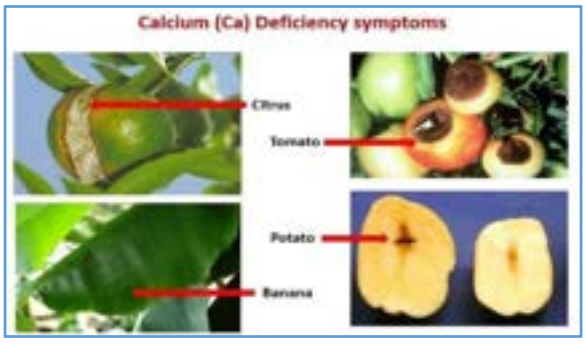
- Higher and sustainable yields
- Lower costs and eco-friendly practices
- Balanced nutrient supply
- Improved soil structure

Conclusion

Soil nutrients are essential for healthy crop growth and better quality yields. Balanced and timely supply of macro and micro nutrients ensure proper plant development and resistance to stress. Recognizing deficiency /toxicity symptoms and following soil test- based nutrient management, including the use of fertilizers, biofertilizers, and organic manures, is the key to maintain soil fertility and achieving sustainable agriculture production cycle.



N-Yellowing of old leaves, Poor Growth



P- Purplish discoloration of leaves, dying of tips of older leaves

2.4. Manures and Fertilizers- Classification-Nutrient Content-Nutrient Use Efficiency- Factors effecting nutrient use efficiency

Present agriculture is generally chemically intensive where using more doses of chemicals for nutrient management to get maximum production per unit area without caring about natural resources and ecosystems. Even though we are using fertilizers to meet nutrient requirement of crops, nutrient use efficiency of fertilizers are very low because of improper management practices.

The word "Manure" is originated from the French word "MANOEUVRER" which refers to "work with soil". Manures are the substances which are organic in nature, capable of supplying plant nutrients in available form, bulky in nature having low analytical value and having no definite composition and most of them are obtained from animal and plant waste products.

A fertilizer can be defined as a mined or manufactured material containing one or more essential plant nutrients in potentially available forms in commercially valuable amounts.

Major sources of manures are cattle shed wastes, human habitation wastes, poultry litter, slaughterhouse wastes, byproducts of agro industries, crop wastes, weeds, green manure crops etc., The use of chemical fertilizer is increasing day-by day for the sake of increasing production. By excess use of it, the fertility of soil and health also deteriorate. Therefore the use of organic manure is one of the alternative ways for enhancing production and improving the soil health.

Differences between Manures and Fertilizers

Manures	Fertilizers
• Organic in nature	• Inorganic in nature
• Slow acting	• Quick acting
• Having low analytical value	• Having high analytical value
• Having no definite chemical composition	• Having definite chemical composition
• Obtained from plant , animal and human resources	• Mined or manufactured
• Improves physical properties of soils	• Don't improve the physical properties of soils
• Supply almost all major, minor and • Micronutrients.	• Supply one or very few plant nutrients.
• Derived from French word • 'MANOEUVRER' to work with soil	• Derived from Latin word Fertil (means • Fertile)
• Bulky in nature	• Non-bulky in nature

A. Bulky organic manures:

The bulky organic manures are organic in nature and required in huge amounts. All these bulky organic manures are bulky in nature and supply i) plant nutrients in small quantities and ii) organic matter in large quantities. Bulky organic manures contain nutrients in small quantities, therefore large quantities of these are needed. Besides the major nutrients, they also contain traces of micro-nutrients. Bulky organic manures increase organic matter content and hence improve the physical properties of soil. This effect is very important in case of most of our arable land. Such manures increase the humus content of soil and consequently water holding capacity of sandy soils also increased and the drainage of clayey soils is improved. Bulky organic

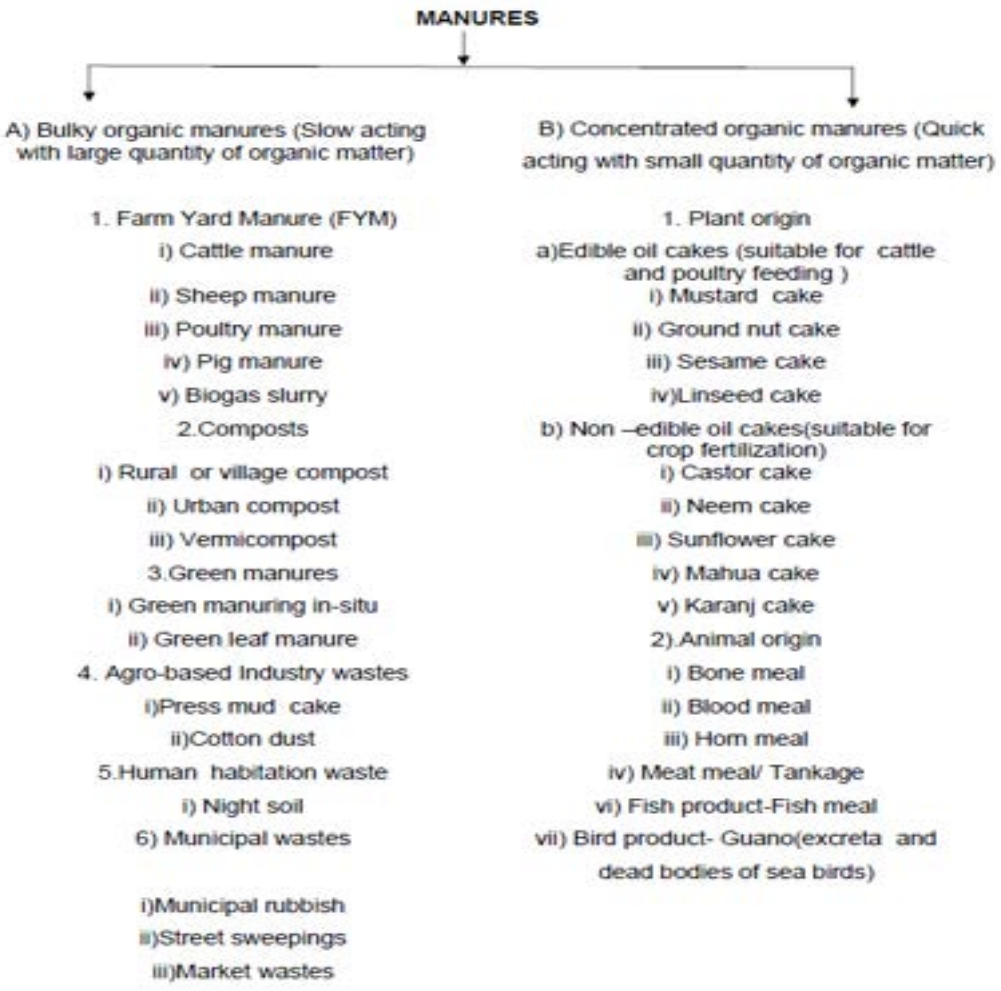


Fig. 1. Classification of organic manures

Manures provide food for soil microorganisms. This increases the activity of microbes which in turn help to convert unavailable plant nutrients into available form.

Eg. FYM, Composts, Green manures, Sewage sludge. Of the various bulky organic manures FYM, Compost and Green manures are widely used.

B. Concentrated organic manures:

Like bulky organic manures, these organic manures contain plant nutrients and considerable amount of organic matter. They have direct effect on plant growth. Nitrogen content is higher in concentrated organic manures and varied from 2.5 per cent in mahua cake to 7.9 per cent in decorticated safflower cake. In addition to nitrogen all the oil cakes contain P_2O_5 (0.8 to 2.9 %) and K_2O (1.2 to 2.2%) since they contain nitrogen in relatively large quantities, they are usually classified as organic nitrogenous manures. By virtue of this high nitrogen content they enrich the nitrogen status of soil.

Fertilizer:

A commercial fertilizer is defined as a material containing at least one of the primary nutrients in assemble or available form to plants in known amounts.

Elements essential for plant growth:
Macronutrients: N, P, K, Ca, Mg and S

Micronutrients: Fe, Zn, Cu, Mn, Mo, B, Cl, etc.
Primary nutrients: N, P and K
Secondary nutrients: Ca, Mg and S

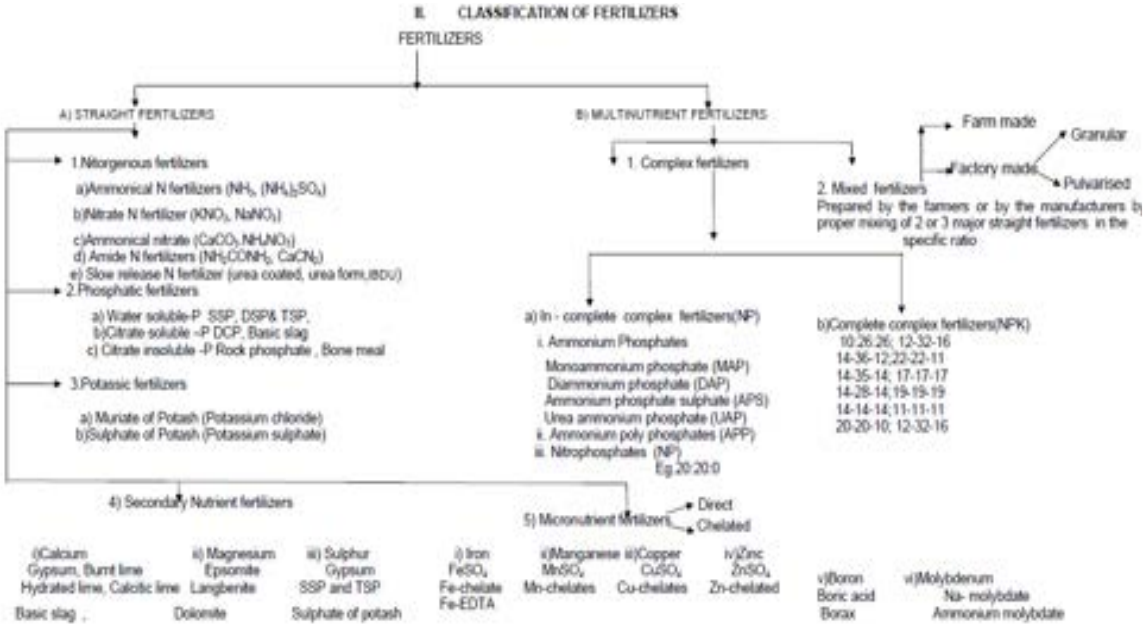


Fig. 2. Classification of Fertilizers

A. Straight Fertilizers:

Straight fertilizers are chemical substances that contain only one nutrient element in absorbable form by plants. The straight fertilizers include 1) Nitrogenous, 2) Phosphatic and 3) Potassic fertilizers.

Nitrogenous Fertilizers:

Nitrogenous fertilizers are chemical substances that contain the nutrient element nitrogen in absorbable form by plants chiefly as ammonium (NH_4^+) or nitrate (NO_3^-) or which yield these from after conversion.

Table 1: Classification of nitrogen fertilizers

S. No.	Chemical Form of Nitrogen	Fertilizer	Chemical formula	N Content (%)
1	Ammonium [NH_4^+]	a) Gaseous ammonia	NH_3	82
		b) Ammonia water	NH_3 ,NH_4 OH	24
		c) Ammonium sulphate	$(NH_4)_2$ SO_4	21
2	Nitrate [NO_3^-]	a) Calcium nitrate	$Ca(NO_3)_2$	16
		b) Sodium nitrate	Na NO_3	16
		c) Ammonium sulphate nitrate	$(NH_4)_2SO_4$+ NH_4NO_3	26
3	Ammonium Nitrate [NH_4^+] +[NO_3^-]	a) Ammonium nitrate	NH_4 NO_3	35
		b) Calcium ammonium nitrate	NH_4 NO_3 + $CaCO_3$	25
4	Amide [-NH_2]	a) Urea	$CO(NH_2)_2$	46
		b) Calcium cyanamide	$CaCN_2$	22

Phosphatic Fertilizers:

Phosphate fertilizers are chemical substances that contain the nutrient element phosphorus in the form of absorbable phosphate ions (anions) or that yield such phosphate anions after conversion.

Table 2: Classification of phosphatic fertilizers based on the relative solubility

S. No.	Fertilizer	Nutrient content (%)
I. Water soluble phosphorus fertilizers		
1	Single super phosphate	16-18% P_2O_5
2	Double super phosphate	32 % P_2O_5
3	Triple super phosphate	46-48% P_2O_5
4	Ammonium phosphate	20% N and 20% P_2O_5
II. Water insoluble but citrate soluble phosphorus fertilizers		
1	Basic slag	14 to 18% P_2O_5
2	Dicalcium phosphate	34-39 % P_2O_5
III. Water and citrate insoluble phosphorus fertilizers		
1	Rock phosphate	20 to 40 % P_2O_5
2	Raw bone meal	20 to 25% P_2O_5
3	Steamed bone meal	22% P_2O_5

2. Potassic Fertilizers:

The term potash generally refers to any salt used to provide fertilizer potassium. The large deposits of potassium salts are in North America (Canada, USA), USSR, West Germany, East Germany and France in that order.

Table 3: The important potassic fertilizers

S. NO.	Fertilizer	Chemical formula	Nutrient content (%)
1	Muriate Of Potash (MOP)	KCl	60 of K_2O & 47 of Chloride
2	Sulphate of Potash (SOP)	K_2SO_4	50 of K_2O &18 % S

B. Secondary Nutrient Fertilizers (Ca, Mg & S):
Calcium Fertilizers:

Nearly all multi nutrient liquid fertilizer formulations and more than 50 per cent multi nutrient solid fertilizers are almost devoid of calcium. Of the different sources, the Gypsum has been gaining importance for crops such as legumes. Global reserves of Ca are considerably large since whole mountain ranges consist of lime stone.

Table 4: Important calcium sources & nutrient content

S. No.	Source	Formula	Ca (%)
1	Burnt lime	CaO	70
2	Hydrated lime	$Ca(OH)_2$	50
3	Calcite lime	$CaCO_3$	36
4	Dolomitic lime	$CaCO_3$ $Mg\ CO_3$	17
5	Basic slag	$[CaO]_5\ P_2O_5\ SiO_2$	29
6	Gypsum	$CaSO_4\ 2H_2O$	22
7	Calcium nitrate	$Ca(NO_3)_2 2H_2O$	20
8	Single Super phosphate	$Ca(H_2PO_4)_2\ CaSO_4$	20
9	Triple super phosphate	$Ca(H_3PO_4)_2$	13
10	Rock phosphate	$Ca_5(PO_4)_3F$	33
11	Calcium chloride	$CaCl_2$	36

Magnesium Fertilizers:

In multi nutrient fertilizers, finely ground dolamitic limestone is used as filler and it is a incidental supplier of Mg.

Table 5: Important calcium sources & nutrient content

S. No.	Source	Formula	Mg (%)
1	Magnesium oxide	MgO	45
2	Dolamite	$CaCO_3$ $MgCO_3$	12
3	Kiserite	$MgSO_4\ H_2O$	18.2
4	Langbeinite	$K_2SO_4\ 2MgSO_4$	11.2
5	Magnesium sulphate	$MgSO_4\ 7H_2O$	10.5

Sulphur Fertilizers:

Plants take sulphur in the form of sulphate [SO_4^{2-}] ion. Sulphur fertilizers predominantly contain sulphate, some of which are easily soluble and some are slightly soluble.

Gypsum [$CaSO_4\ 2H_2O$] is a calcium sulphate because it's slight solubility in water which is slow acting. Elemental sulphur is also an important sulphur fertilizer with strong acidifying action. It can be used either directly or as an additive to other solid fertilizers.

Eg: Sulphur coated urea.

Table 6: Important sulphur sources & nutrient content

S. No.	Source	Formula	S (%)
1	Ammonium sulphate	$(NH_4)_2\ SO_4$	23
2	Potassium sulphate	K_2SO_4	18
3	Magnesium sulphate	$MgSO_4$	13
4	Super phosphate	$Ca(H_2PO_4)_2\ CaSO_4$	12
5	Gypsum	$CaSO_4\ 2H_2O$	18
6	Aluminiumsulphate	$Al_2(SO_4)_3 18H_2O$	14

C. Micronutrient Fertilizers:

Higher green plants are known to require micronutrients viz., Fe, Mn Cu, B, Mo, Cl etc., .

Table 7: Important micronutrient sources & nutrient content

Micronutrients	Formula	Content (%)
Iron		
1. Ferrous sulphate	$FeSO_4\ 7H_2O$	20
1. Fe-chelate	Fe-EDTA	5
2. Fe-Chelate	FeEDHA	6
Manganese		
1. Manganoussulphate	$Mn\ SO_4\ 4\ H_2\ O$	24
2. Manganous sulphate (Monohydrate)	$Mn\ SO_4\ \ H_2\ O$	32
3. Mn -chelate	Mn-EDTA	13
Zinc		
1. Zinc sulphate	$ZnSO_4\ 7H_2O$	23
3. Zinc sulphate (Monohydrate)	$ZnSO_4\ H_2O$	36
4. Zn-chelate	Zn-EDTA	14
Copper		
1. Copper sulphate	$Cu\ SO_4\ 5H_2O$	25
2. Copper sulphate (Monohydrate)	$Cu\ SO4\ H_2O$	36
Boron		
1. Borax (Na-tetra borate)	$Na_2B_4O7\ 10H_2O$	11
2. Borax anhydrous	$Na_2\ B_4O_7$	22
3. Boric acid	H_3BO_3	18
Molybdenum		
1. Sodium molybdate	$Na_2MoO_4\ 2H_2O$	40
2. Ammonium molybdate	$(NH_4)_6MoO_4$	54
3. Molydenum trioxide	MoO_3	66
4. Calcium molybdate	$CaMoO_4$	48

Multi nutrient fertilizers:

The major plant nutrients supplied by fertilizer are nitrogen, phosphorus and potassium. The fertilizers that contain these three plant nutrient elements N, P, K is designated as complete fertilizers according to fertilizer technology. However, scientifically, such fertilizers are called as multi nutrient fertilizers.

Multi nutrient fertilizers can be classified into two categories

Complex Fertilizers

The fertilizers containing two or more major plant nutrients, which are in chemical combination are called as complex fertilizers .They are solids and homogeneous in nature that each fertilizer granule is guaranteed to contain two or more major plant nutrients in a specified ratio .

Classification of Complex Fertilizers:

The complex fertilizers being produced in India can be classified into

A) Incomplete Complex Fertilizes: Contain only two major nutrients such as N and P_2O_5 in chemical combination. They are of two types

I. Ammonium phosphates: May be present in the combination of mono or diammonium salt or mixture of two. Most of these formulations are in granular form

Eg. MAP 11:46, DAP18:46, AP 16:20 and UAP28:28:0

II. Nitrophosphates eg. 20:20:0, 24:24:0

B) Complete Complex Fertilizers: Contains all the three major nutrients in chemical combination. E.g. 17:17:17 and 19:19: 19

Mixed Fertilizers:

Mixed fertilizers are simply physical mixture of solid fertilizers materials containing 2 or more major plant nutrients .Each individual particle of this blend represents only one of the ingredients of the mixture.

Sources of Mixed Fertilizers:

Compatibility of Mixed Fertilizers: Some fertilizers should not be mixed together in one stock tank because an insoluble salt might form very quickly.

Examples of compatible fertilizers are

Ammonium nitrate+ urea

Calcium nitrate + ammonium nitrate, etc.

Examples of incompatible fertilizers are mixing fertilizers that contain calcium with those that contain phosphate or sulphate.

Calcium nitrate+ ammonium sulphate.

Nano-fertilizer:

Nano-fertilizer may be defined as the nano-particles, which can directly supply essential nutrients for plant growth, have higher nutrient use efficiency and can be delivered in a timely manner to a rhizosphere target.Nanofertilizers are nutrient carriers with nano dimensions of 1- 100 nm.

1 Nanometer = 10^{-9} m = 1 billionth of a meter

Example: Nano urea- 4 % nitrogen,
Nano urea plus-20% N,
Nano DAP- Nitrogen (8.0% N w/v) and Phosphorus (16.0% P_2O_5 w/v) etc,

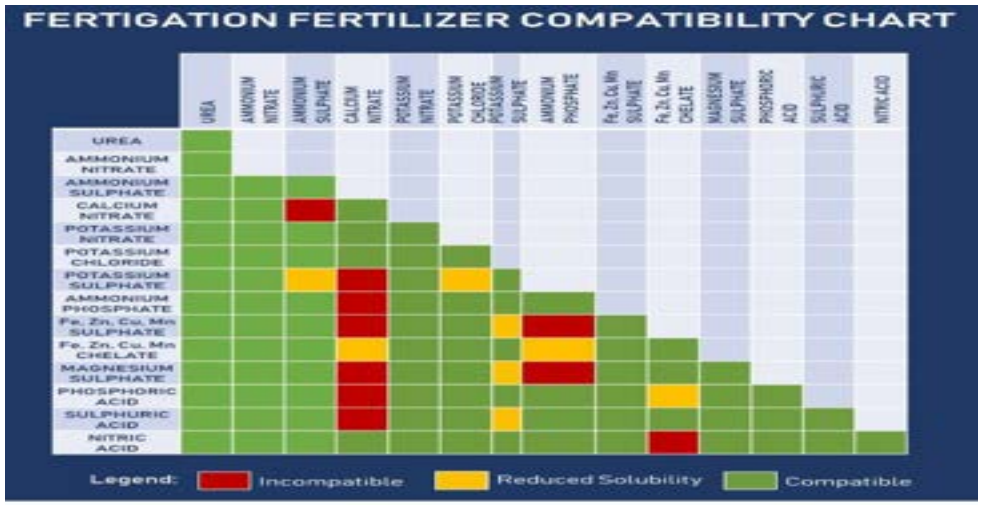


Fig. 3. Compatibility of fertilizers for mixing

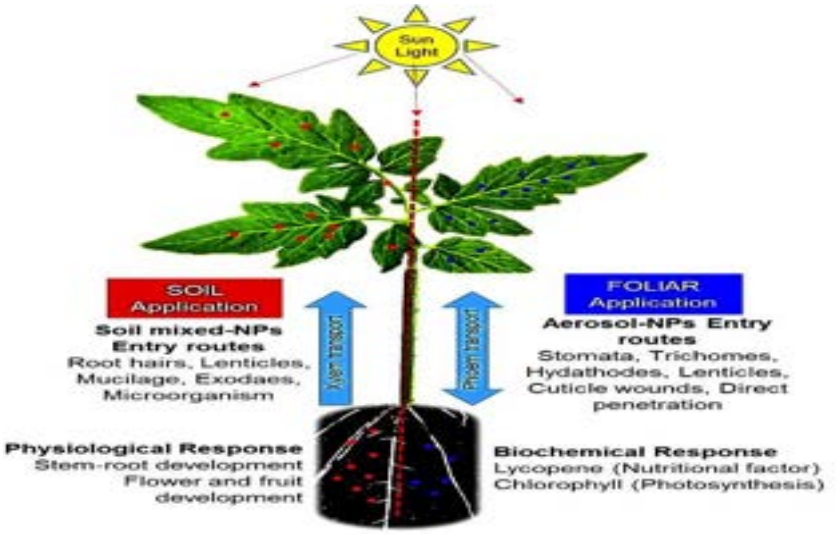


Fig. 4. Transport route of nano fertilizer

Advantages of Nano fertilizers over traditional fertilizers:

- They increase soil fertility, yield and quality parameters of the crop.
- They are nontoxic and less harmful to environment and humans.
- They minimize cost and maximize profit.
- Nano particles increase nutrients use efficiency (80-100 times less requirement to chemical fertilizers) and minimizing the costs of environment protection.
- Improvement in the nutritional content of crops and the quality of the taste.
- Enhance plants growth by resisting diseases, improving stability of the plants by anti-bending and provide 10 times more stress tolerant by deeper rooting of crops.

- Also suggested that balanced fertilization to the crop plant may be achieved through nanotechnology.

Unique features of Nano-fertilizers include:

- Smaller size and higher surface area
- Ultrahigh absorption rate
- Slow, targeted and efficient release of plant nutrients
- Increase in NUE
- Reduce adverse effects on the environment compared to application of conventional mineral fertilizers
- The application of nano-urea can save up to 12.4-41.7 per cent of nitrogen application to the soil.

Water soluble fertilizers:

- Water soluble fertilizers are fertilizers(may be liquid or solid) that can be dissolved in water and are applied to the crop in irrigation water (fertigation)
- Contains fertilizers which are readily available for plant uptake
- Examples :-
- Urea Phosphate 17:44:0
- Urea Phosphate with SOP 18:18:18
- Sulphate of potash 0:0:50

Advantages:

- Easy to apply and provides even feeding
- Nutrients are readily available for plant uptake., (Reduces the preparation phase)
- Highly reliable for supplying both macro and micro nutrients
- Increase yield and improves quality of the product
- Often effective when roots are unable to absorb nutrients due to fixation, losses, leaching etc.
- No risk of burning a plant as long as label directions are followed

Disadvantages:

- They are relatively expensive
- They must be reapplied often (their nutrients in solution leach through root zone more rapidly).

Nutrient Use Efficiency (NUE):

Nutrient use efficiency is a measure of how well plants use the available nutrients. It can be defined as the crop yield per unit input applied. In other words, it refers to the fraction of nutrients removed by crops from the fields.

Similarly, Fertilizer use efficiency refers to the crop yield obtained per unit quantity of fertilizer applied. Agronomic efficiency (AE) is calculated in units of yield increase per unit of nutrient applied. It more closely reflects

The direct production impact of an applied fertilizer and relatesdirectly to economic return. NUE not only depends on the ability to efficiently take up the nutrient from the soil, but also on the transport, storage, mobilization, usage within the plant, and even on the environment.

Nutrient use efficiency is defined as the extent to which the nutrients and management practices interact to give a specified yield level.

$$\text{NUE (\%)} = \frac{\text{Yield with applied nutrient} - \text{Yield without applied nutrient}}{\text{Amount of nutrient applied}} \times 100$$

Factors affecting NUE

a. Soil factors: The most important factors are soil physical conditions, soil fertility and soil reaction. On soils with poor physical condition, plant growth will be poor due to impeded drainage, restricted aeration and unfavourable soil temperature due to which the nutrients will not be used efficiently. Coarse textured soils are usually poorer in available nutrients than fine textured soils. On such soils nitrogen and potassic fertilizers should be more frequently applied than in fine textured soils. The higher the fertility status of the soil, the lower is the response. Soil reaction is an important consideration in the selection of right type of P fertilizers. The higher the organic matter status, the more is the nutrient use efficiency.

b. Climatic factors: include temperature, rainfall and its distribution, evaporation, length of day and growing season. Rate of nitrification is slower in cooler climate than in warmer climate, hence more amounts of fertilizers should be added in cool climate. Higher amount of fertilizers are required in high rainfall region due to leaching to obtain an expected yield potential. In arid regions, soil moisture is a limiting factor to get higher nutrient use efficiency. The higher the light intensity, the better is the nutrient use efficiency.

c. Crop factors: CEC of plant roots influences the fertilizer responsiveness of the crop. A large ramifying root system of the plant absorbs nutrients more efficiently. The time of application of fertilizer should match the pattern of nutrient uptake to increase nutrient use efficiency. For legumes N fertilizer may be reduced as they can fix atmospheric N to increase N use efficiency.

d. Agronomic factors: include selection of fertilizer responsive crops and varieties, timely sowing, proper spacing, proper dose, time and method of fertilizer application to increase the yield and thereby increasing NUE.

Reasons for low Nutrient Use Efficiency:

- Continuous use of fertilizer N alone or with inadequate P and K applicationleading to mining of native soil P and K
- Continued practice of intensive cropping systems like 'rice-wheat' with highyielding varieties even under recommended NPK use, impoverishing soils ofsecondary and micro nutrients especially S, Zn, Mn, B and Fe.
- Use of high analysis fertilizers and inadequate addition of organic manuresresulting in widespread deficiencies of S and micronutrients.
- Fertilizer application mostly not based on soil-test values Inappropriate time and method of fertilizer application
- Excessive use of irrigation in rice-wheat cropping system, sugarcane and otherheavily fertilized crops leading to leaching of nitrogen and other plant nutrients.

Table 8: Nutrient use efficiency of nutrients

Nutrient	Efficiency (%)	Cause of low efficiency
N	30-50	Immobilization, volatilization, denitrification, Leaching
P	10-20	Fixation in soils Al – P, Fe –P, Ca – P
K	70- 80	Fixation in clay – lattices
S	8-10	Immobilization, Leaching with water
Micronutrients (Fe, Mn, Cu, Zn, B)	1-2	Fixation in soils

Methods to enhance Nutrient Use Efficiency

Use efficiency of any nutrient can be increased by achieving potential yields of crops by optimizing the factors of crop production.

i. Selection of suitable crops and varieties, which are input responsive recommended for the region.
ii. Sowing or planting the crops at optimum time.
iii. Maintaining optimum plant population.
iv. Use of organic manures and bio fertilizers to supplement nutrients and also to bring ideal conditions for crop growth.
v. Inclusion of legumes in the cropping system as intercrop.
vi. The crops should be irrigated at least to save life at critical growth stages.
vii. Fertilizer scheduling must be based on soil test values to prevent nutrient deficiencies or luxury consumption.
viii. P and K fertilizer and part of N fertilizer should be applied as basal and N in splits doses; for light textured soils K also should be applied in splits.
ix. Band placement of fertilizers preferable to prevent losses. (Especially P to reduce fixation).

x. Under moisture stress condition, foliar application of urea at 2% concentration is effective.
xi. Micronutrient deficiencies should be corrected instantly.
xii. $ZnSO_4$ should be applied as package once in two seasons @ 25-50 kg/ha.
xiii. Problem soils must be ameliorated by taking reclamation measures.
xiv. Zinc and iron fertilizers should not mix and apply with phosphate fertilizers.

NUE of individual nutrients also can be increased by following the above management practices along with some specific measures as follows

Nitrogen Use Efficiency: can be increased through

- Split application of nitrogenous fertilizers to prevent losses due to leaching.
- The use of slow release nitrogenous fertilizer like urea formaldehyde, sulphur coated urea, Neem coated urea etc.
- Use of nitrification inhibitor (Eg: N-serve) to retard the conversion of NH_4^+-N to NO_3^{2-} N to prevent leaching and make it available to crops for quite longer period.
- By the integration of inorganic N with organic sources the soil physical condition can be optimized besides adding nutrients to the soil.

P use efficiency: can be increase by decreasing P fixation and balanced application of the nutrients. P fixation can be reduced by judicious application of organic manures, application of P fertilizer by placement, inoculation (either seed or soil) with phosphorus solubilising bacteria like *Pseudomonas, Bacillus megathrium var. phosphaticum.*

K use efficiency: can be enhanced by preventing leaching loss either by split application on light soils, applying organic manure and balanced application of nutrients.

Conclusion:

Balanced application of fertilizers, Split application of nitrogenous fertilizers, and basal application and band placement of phosphatic fertilizer will improve the nutrient use efficiency of fertilizers.
Coated urea and nitrification inhibiters application will improve nitrogen use efficiency.
Application of PSB will solubilize the soil native P and improve PUE.
Nano fertilizers and water soluble fertilizer have more NUE as compared to conventional fertilizers.

2.5. Compost – Preparation of Compost from Agricultural Wastes – Urban Compost Preparation - Vermicomposting – Preparation snd Properties

Soil health is the foundation of successful farming, much like the heart is to the human body. When soil becomes weak, overused, or chemically imbalanced, crop growth declines. Excessive use of chemical fertilizers may give short-term results, but they gradually reduce the natural fertility of the soil, disrupt soil organisms, and contribute to long-term degradation. One of the simplest and most natural ways to restore soil health is composting.

Composting is a traditional agricultural practice known since ancient times, where organic waste is transformed into nutrient-rich material that benefits the soil. Unlike directly adding raw plant or animal waste—which decomposes at varying rates and often has minimal or even harmful effects on the soil—composting converts such materials into a stable, humified product. The term "compost" is derived from the Latin word *"componere"*, which means "to put together," signifying the process of combining various organic materials to create a balanced and effective soil amendment.

1. **What is Compost and Why is it Important?**

Compost: Compost is a product of decomposition of plant and animal wastes with various additives .The compost had the largest variation of all organic material ranging from neglected garbage dumps to carefully composted and treated substances with high fertility.

Composting: Composting is a process of converting organic matter into manure in a short time by accelerating the fermentation process under controlled conditions. The organic material that is usually handled for composting are waste vegetative material such as spoiled straw, peanut hulls, saw dust, dried leaves etc., stubbles, chilli plants, cotton stalks, tobacco stems, weeds, municipal rubbish etc., according to availability.

2. **Detailed Methods of Composting**

Over the last century, many composting methods have been designed to suit different farming conditions, waste types, and available resources. While all aim to convert organic matter into stable, nutrient-rich compost, each varies in materials, starters, aeration techniques, and time required. Below is a detailed explanation of the ten main composting systems.

i. ADCO Process

The ADCO (Agricultural Development Company) process originated in England during the First World War (1914–1918). Developed at Roth Amsted Experimental Station by Hutchinson and Richards, it uses straw and other farm residues as the basic raw material. The straw is spread in layers, each sprayed with a solution of ammonium sulphate and broadcast with powdered limestone. This layering continues until a heap of convenient height is formed. Over three months, fermentation breaks down the material into a product similar to farmyard manure, known as "synthetic FYM." The process was patented, and commercial starters such as ADCO Accelerator were sold with full usage instructions. This method is reliable, relatively fast, and suitable where chemical starters are readily available.

ii. Activated Compost Process

Developed by Fowler and Ridge in 1922 at the Indian Institute of Science, Bangalore, this method accelerates composting by using biological starters such as cow dung, urine, night soil, sewage sludge, or a combination. Raw materials like straw and crop residues are mixed with these inoculants to ensure every part of the heap comes in contact with them. The heap, about three to four feet high, is kept moist with regular sprinkling of dung-urine slurry and turned frequently. High internal temperatures develop within a week, speeding up microbial activity. Fresh raw material can be added during the process, provided it is mixed with starters. Compost is usually ready within five to six weeks, making this one of the fastest traditional methods.

ii. Indore Process

The Indore process, created by Sir Albert Howard and Ward at the Indian Institute of Plant Industry, Indore, is a well-known aerobic method. A large pit, about 30 feet long, 14 feet wide, and 3 feet deep, is prepared with sloping sides. Organic matter such as crop residues, weeds, and cotton stalks is laid in 3-inch layers. Over each layer, a mixture of urine-soaked earth and wood ash is sprinkled, followed by a 2-inch layer of cattle dung. This is repeated until the pit is filled, rising about 3 feet above ground level. Aeration is improved with vertical vent holes or perforated pipes. Moisture is maintained by watering twice daily. The heap is turned three times: after 15 days, 30 days, and at two months. Compost matures in three to four months, producing humus-rich material ideal for soil improvement.

iii. Bangalore Process

Designed by Dr. C.N. Acharya in 1949, the Bangalore process combines aerobic and anaerobic decomposition. Organic matter is layered in a pit (20 x 4 x 3 feet) with farmyard manure or litter as starters, and each layer is moistened with water or dung-urine mixture. A top layer of earth mixed with bone meal or oil cakes is applied, improving nutrient content. After a week of aerobic decomposition, the heap is plastered with moist clay, sealing in heat and creating anaerobic conditions. Cracks in the plaster are sealed to maintain the environment. This process requires fewer turnings, conserves more nitrogen, and produces compost in about five months, making it relatively low-labor compared to purely aerobic methods.

iv. Coimbatore Process

The Coimbatore process uses semi-aerobic fermentation and was developed for efficient nutrient conservation. Organic matter is spread in a pit (12 x 6 x 3 feet) to a depth of 9 inches, moistened, and treated with about 1 kg of powdered bone meal. Over this, an emulsion of cattle dung and water is sprinkled. These layers are repeated until the heap is 2 feet above ground level, and then plastered with mud to create semi-aerobic conditions for about six weeks. Afterwards, the plaster is removed, and the heap is allowed to decompose aerobically for another 6–8 weeks. Total decomposition takes 3–4 months, resulting in nutrient-rich compost with high phosphorus content due to the bone meal.

vi. Rain-water Composting

This method is adapted for dry areas with limited water availability. Compost heaps are prepared just before the rainy season using the usual layering method of green and dry organic matter. The heap is left uncovered to absorb rainfall, which provides the necessary moisture for decomposition. Turning is done during rainy breaks to maintain aeration. With about 400 mm of seasonal rainfall, compost is typically ready by the end of the rainy season, making this method cost-effective where irrigation water is scarce.

vii. Rural Compost

Rural composting is a traditional and simple method widely used by farmers. It uses locally available materials such as crop residues, green weeds, sugarcane trash, and animal dung. Pits (commonly 3 x 6 x 3 feet) are dug in elevated, well-drained areas. Layers of green material about 12 inches thick are alternated with 3-inch layers of dry material. Bone meal or ash may be sprinkled to neutralize acids formed during decomposition. Each layer is moistened with dung slurry or water, and the heap is built up about a foot above ground level, then covered with earth. Turning is done periodically, and the composting period can range from three months to a year, depending on the materials used.

viii. Urban Compost

Urban composting uses municipal refuse such as street sweepings, market waste, and night soil as raw materials. Since putrefactive fermentation can produce foul odors, copper sulphate is sprinkled between layers to suppress smell. In one method, refuse and night soil are mixed in a 4:1 ratio, layered with copper sulphate (1 kg per 400 kg of material), moistened, and turned every fortnight. Compost is ready in about two months. Another method involves filling pits with alternating layers of refuse and night soil, covering with soil, and allowing decomposition for about five months. Urban composting not only recycles waste but also improves sanitation in cities.

ix. Mechanical Composting

Mechanical composting is used in large cities to process high volumes of waste quickly and hygienically. Waste is sorted, shredded, and mixed mechanically, with controlled moisture and aeration. The system reduces human contact with waste, controls odor, and allows recovery of recyclable materials like metal and glass. Large-scale plants, such as those in Tel Aviv and Bangkok, can handle hundreds of tonnes daily, producing high-quality compost within a few weeks. Mechanical composting is cost-effective at scale and produces consistent, pathogen-free compost.

x. Vermi compost

Vermicomposting means using earthworms to make compost. Special types of worms like Eisenia foetida (red wigglers); eat waste materials such as vegetable peels, crop residues, and cow dung. The worms digest this waste and release it as small, dark granules called vermicast. This vermicast is very rich in nutrients and is excellent for improving plant growth. Vermicompost not only adds nutrients like nitrogen, phosphorus, and potassium to the soil but also improves the soil structure. It makes the soil soft, porous, and better at holding water. This helps plant roots grow easily and reduces the need for chemical fertilizers. The microbes present in Vermicompost also protect plants from some soil diseases.



3. Step-by-Step Guide to Making Vermicompost

i. **Choose a Suitable Location**

Select a shaded and cool place, such as under a tree, a shed, or a roofed area.
Ensure the site is not waterlogged; proper drainage is essential.
Vermicomposting can be done on bare ground, cemented floors, or inside pits/tanks.

ii. **Size of the Pit or Bed**

For small farmers, a common pit size is **10 feet long × 3 feet wide × 1.5 feet deep**.
The size can be adjusted depending on the amount of organic waste available.
For household use, even a small box, barrel, or container can be used.

iii. **Prepare the Base**

Spread a 2–3 inch layer of dry soil or sand on the floor.
This layer helps with drainage and prevents water stagnation, which could harm the worms.

iv. **Add Bedding Material**

Bedding is the most important foundation layer in vermicomposting. It provides a soft, moist, and comfortable environment for earthworms to live and move, just like soil in their natural habitat. The bedding should be loose, organic, and able to hold moisture while allowing enough air to pass through. This helps worms breathe properly and prevents bad smells.

v. Common bedding materials include:

a. **Dry Leaves**: Easily available on farms, they decompose slowly and keep the bed airy. Dry leaves also act like a natural blanket for worms.

b. **Sugarcane Trash**: After harvesting sugarcane, the leftover stalks and trash can be cut into small pieces and used. They provide bulk and porosity.

c. **Straw or Husk**: Paddy straw, wheat straw, or groundnut husk are excellent bedding materials. They are light, fibrous, and help in water retention.

d. **Shredded Paper or Cardboard**: Waste paper (without glossy ink) and cardboard can be shredded and used as bedding. They absorb moisture well and are a good recycling option, especially in urban areas.

e. **Coconut Coir / Coir Pith**: A by-product of coconut processing, coir is soft and holds water effectively. It is one of the best bedding materials for small-scale vermicomposting.

f. **Partially Decomposed Farmyard Manure (FYM)**: Adding a thin layer of old, half-decomposed manure makes the bedding richer and helps worms adjust quickly.

g. **Add Organic Waste**
Put a layer of semi-decomposed organic material like cow dung, vegetable peels, fruit scraps, crop residues, or farmyard waste. Avoid adding meat, oily food, plastics, or citrus fruits, as they may harm worms.

h. **Introduce Earthworms**
After 2–3 weeks (when the initial heating of waste reduces), release worms into the bed.
Common species: *Eisenia foetida* (red wigglers) or *Eudrilus eugeniae*.
For a 10 × 3 ft. bed, about **2,000–3,000 worms** are sufficient.

i. **Maintain Moisture and Temperature**
Keep moisture around 60–70%. The bed should feel damp but not soggy.
Sprinkle water regularly, especially in summer.
Cover the bed with a straw mat, old sack, or gunny bags to protect worms from heat, rain, and predators.
Ideal temperature: **18–35°C.**

j. **Care and Feeding**
Keep adding small amounts of organic waste once or twice a week.
Always cover fresh waste with a thin layer of soil or old compost to avoid flies and odor.
Do not overload the bed; let the worms finish earlier waste before adding new.

k. **Harvesting Vermicompost**
After **45–60 days**, most of the waste will be converted into dark, earthy-smelling compost.
To separate worms, shift compost to one side and add fresh waste on the other. Worms will migrate, making collection easier.
Dry the harvested Vermicompost in shade (not direct sunlight) and sieve it if needed.

l. **Storage and Use**
Store Vermicompost in a cool, dry place.
Apply about **2–3 tonnes per acre** for field crops, or **250–500 g per plant** for vegetables and fruits.

Vermicompost improves soil structure, increases water-holding capacity, and provides balanced nutrients to crops.



Stage	Action
Bin setup	Drill holes, place bin in a shaded area
Bedding	Use shredded paper/cardboard soaked with water
Soil layer	Add clean soil for worm habitat
Adding worms	Introduce red worm species gently
Feeding	Use appropriate kitchen scraps—bury under bedding
Maintenance	Keep moisture and air circulation in check
Harvesting	Separate finished compost from worms after 8–12 weeks

Tips for Success:

Tip	Why It's Important
Avoid plastic, meat, and dairy	These harm worms and cause bad smell
Keep moisture balanced	Worms need moist conditions to survive
Shade and cover	Protects worms from sun and heat
Use only soft organic waste	Helps worms digest and convert faster

4. **How Compost Helps the Soil**

Compost plays a very important role in keeping soil fertile and productive. It supplies essential nutrients such as nitrogen, phosphorus, and potassium, which are required by plants for healthy growth. In addition to nutrients, compost improves the soil texture, making it lighter and easier for roots to spread and absorb water. It also increases the soil's ability to hold water for a longer time, which keeps plants moist even during dry periods. Another major benefit of compost is that it supports millions of helpful organisms such as microbes, fungi, and earthworms. These living organisms improve soil structure naturally and help protect plants from diseases. By using compost regularly, farmers can reduce their dependence on chemical fertilizers, save money, and protect the environment from pollution.

5. **Benefits of Using a Vermicompost Pit**

A Vermicompost pit is especially useful because it is easy to build, requires little management, and operates at low cost. Within just two months, it produces high-quality compost that is rich in nutrients and

safe for crops. At the same time, it helps reduce the burden of waste disposal on farms and households. By using Vermicompost regularly, farmers can improve soil health, increase crop yields, and maintain long-term productivity of their fields.

Summary

Soil health is the foundation of good farming. Composting is a natural method of recycling waste materials such as crop residues, cow dung, and kitchen scraps into valuable organic fertilizer. The process improves soil fertility, enhances its ability to hold water, and reduces the dependency on chemical fertilizers. In this paper, simple methods of making compost at home or on the farm have been explained, along with their role in improving soil health. Composting is an effective and eco-friendly way to grow better crops, save money, and protect the environment.

2.6. A. Biofertilizers – Classification with Examples – Constraints for Use in Agriculture – Bio Fertilizers Used for Different Crops/Situations

Modern agriculture faces the challenge of producing more food sustainably. Farmers need inputs that are both effective and eco-friendly. Biofertilizers and Plant Growth Regulators (PGRs) are tools that help improve crop productivity without harming the environment. This chapter is designed in simple language for agro-input dealers, helping them understand the basics, uses, and benefits of these inputs.

1. Bio-fertilizers

Biofertilizers are natural substances containing beneficial microbes. These microbes promote plant growth by increasing the availability of nutrients in the soil, especially nitrogen and phosphorus.

i. Importance

- Improve soil fertility and texture naturally
- Enhance water-holding capacity and aeration
- Increase crop yields by 20–30%
- Reduce dependence on chemical fertilizers
- Eco-friendly and minimize groundwater pollution
- Cost-effective for small and marginal farmers
- Improve nutrient uptake through microbial action
- Support long-term soil sustainability and biodiversity

ii. Types and Functions

Type	Microorganism Examples	Function
Nitrogen-fixing	• Rhizobium, Azotobacter, Azospirillum	• Converts atmospheric nitrogen (N_2) to ammonia (NH_3)
Phosphorus Solubilizers	• Bacillus, Pseudomonas, Aspergillus	• Converts insoluble phosphates to available form
Phosphate Mobilizers	• Mycorrhizae fungi (VAM)	• Mobilize bound phosphate from distant soil zones
Potassium solubilizers	• Frateuria aurantia	• Solubilize potassium-bearing minerals
Zinc solubilizers	• Bacillus spp., Pseudomonas spp.	• Convert unavailable Zn to absorbable form
Cyanobacteria (BGA)	• Nostoc, Anabaena	• Fix nitrogen in paddy fields (aquatic environments)

iii. Methods of Application

Seed Treatment: Seeds are coated with biofertilizer before sowing.

Soil Application: Mixed with compost or FYM and broadcasted in the field.

Root Dipping: Seedlings are dipped in a biofertilizer slurry before transplanting.

Foliar Spray: Used occasionally in liquid form for foliar application.

iv. Storage and Precautions while using Bio-Fertilizers

- Check expiry date and microbial count on label
- Do not mix with chemical fertilizers or fungicides
- Apply in moist soil for better microbial colonization

- Ensure correct combination for crop-specific use
- Store in shade and cool environment
- Use immediately after opening the packet
- Avoid exposure to direct sunlight and high temperature

2.6. B. Bio fertilizers – Storage, shelf life and marketing. Factors influencing the efficacy of Bio fertilizers.

Storage of Bio fertilizers

Bio fertilizers contain living microorganisms, so their effectiveness depends on keeping these organisms alive during storage. When storage conditions are poor, the microbial population declines quickly, reducing the product's usefulness.

Importance of Proper Storage

Proper storage helps keep beneficial microorganisms alive, preserves product quality, prevents contamination, and extends shelf life.

Ideal Storage Conditions

Bio fertilizers are best stored between 4°C and 25°C, as extreme temperatures can harm or slow microbial activity. They should be kept away from direct sunlight because UV rays damage cells. A cool, dry environment prevents excess moisture and contamination, while good ventilation helps avoid heat build up and maintains stability.

Packaging

They are typically packed in LDPE bags, bottles, or sachets. The packaging should protect against moisture, contamination, and physical damage, while still allowing limited gas exchange to support microbial survival.

Handling and Transportation

Careful handling is important—avoid dropping, crushing, or stacking heavy loads on the packages. Transport them in covered vehicles to protect from heat and sunlight, and avoid leaving them in unfavourable conditions for long periods.

Shelf Life of Bio fertilizers

Shelf life refers to how long bio fertilizers retain enough living microorganisms to remain effective.

a. General Shelf Life

Carrier-based bio fertilizers usually last 3–6 months, while liquid forms last 6–12 months and may extend up to 18 months under ideal conditions.

b. Factors Affecting Shelf Life

Shelf life is influenced by the type and quality of carrier material, moisture content, storage conditions, initial microbial population, and the quality of packaging and sealing.

c. Signs of Reduced Effectiveness

Indicators include a drop in microbial levels, unusual odor or color, clumping or drying, and poor performance in the field.

Marketing of Bio fertilizers

Effective marketing supports wider adoption among farmers.

a. Distribution Channels

These include agricultural input dealers, cooperatives, Farmer Producer Organizations (FPOs), and government or extension agencies.

b. Promotion Strategies

Awareness can be improved through demonstrations, field trials, farmer training, and by highlighting

benefits like cost-effectiveness and environmental safety. Inclusion in government support schemes also encourages use.

c. Constraints in Marketing
Challenges include limited shelf life, low awareness among farmers, competition from chemical fertilizers, and inconsistent product quality.

Factors Influencing the Efficacy of Bio fertilizers

The effectiveness of bio fertilizers in the field depends on several interacting factors.

a. Microbial Factors
These include the efficiency, adaptability, viability, and survival capacity of microbial strains.

b. Soil Factors
Soil pH, fertility, organic matter, moisture, aeration, and native microflora all influence performance.

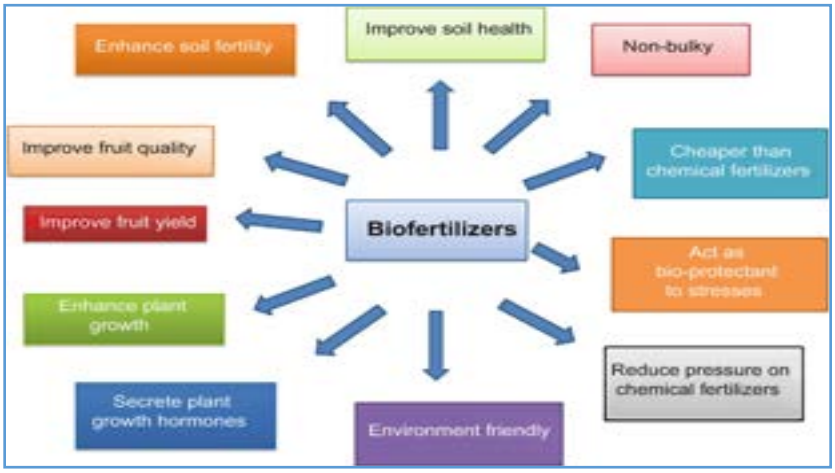
c. Environmental Factors
Temperature, climate, rainfall, irrigation, sunlight, and drying conditions play important roles.

d. Agronomic Practices
Application method, timing, dosage, and compatibility with other inputs affect outcomes.

e. Crop Factors
Crop type, variety, root activity, and management practices also impact effectiveness.

Conclusion

Maintaining proper storage conditions is essential for preserving the quality of bio fertilizers. Along with managing shelf life and improving marketing, creating favourable environmental and farming conditions helps maximize their effectiveness. Increasing farmer awareness and strengthening quality control can further support their use in sustainable agriculture



2.6. C. Plant Growth Regulators (PGRs)

Plant Growth Regulators are organic chemical substances, other than nutrients, that influence physiological and developmental processes in plants. They act as growth promoters or inhibitors depending on the need.

Naturally synthesized in plants (Phytohormones)

Artificially synthesized to mimic natural hormones

i. Types and Uses

Type	Functions	Example
Auxins	Promote rooting, prevent fruit drop	Planofix
Gibberellins	Increase fruit size, break dormancy	GA3
Cytokinins	Promote cell division, delay aging	Cytozyme
Ethylene	Uniform ripening, promote flowering	Ethrel
ABA	Induce dormancy, stress resistance	ABA

ii. Applications of PGRs in Agriculture

- Enhancing fruit size, color, and quality
- Improving seed germination and plant vigour
- Preventing lodging in cereals (with CCC or paclobutrazol)
- Regulating plant height for easier harvesting
- Inducing early or synchronized flowering
- Delaying senescence and improving shelf life
- Improving drought or salinity tolerance

iii. Combined use of Bio-Fertilizers and PGRs

- The synergistic application of both inputs is a modern practice in integrated nutrient management (INM). The combination offers:
- Better plant vigor and productivity
- Enhanced nutrient absorption and root development
- Improved yield quality and fruit setting
- Shorter time to flowering or fruiting
- Increased hormonal activity and stress resilience

Example Combinations

PSB + Gibberellic Acid (GA3) → Accelerated plant growth, earlier flowering

PSB + Triacontanol → Improved fruit size, sugar content, and quality

Azotobacter + Cytokinin spray → higher seedling vigor and tillering in cereals

Feature	Bio-fertilizers	Plant Growth Regulators (PGRs)
Nature	Microbial (living organisms)	Chemical (natural/synthetic hormones)
Main Action	Enhances nutrient availability	Regulates growth and development
Examples	Rhizobium, PSB, Mycorrhiza	Auxins, GA, Cytokinins, ABA, Ethylene
Application	Soil, seed, root treatment	Foliar spray, seed treatment
Eco-Friendliness	Highly eco-friendly	Depends on type and dose
Result Time	Slower, but long-term effect	Faster, short-to-medium term
Use in Organic	Fully compatible	Limited (only natural PGRs allowed)

Conclusion

Biofertilizers and PGRs are essential tools for modern farming. Biofertilizers improve soil and nutrient supply, while PGRs enhance plant development and productivity. When used correctly, they reduce chemical dependency, support sustainable farming, and increase farmer incomes. Agro-dealers should promote proper usage among farmers.

2.7. Integrated Nutrient Management

Integrated nutrient management is a practice where all sources of nutrients namely organic, inorganic (chemical fertilizer), Bio fertilizer can be combined and applied to soils so that crop growth is enhanced and we can get good yield with quality product. Besides, it keeps the soil in healthy condition. In INM it integrates/combines the objectives of production with ecology and environment, that is, optimum crop nutrition, optimum functioning of the soil health, and minimum nutrient losses or other adverse effect on the environment. Integrated Nutrient Management (INM) has to be considered an integral part of any sustainable agricultural system.

In the early 1990s, however, fertilizer became the target of criticism, mainly because of heavy use in the developed countries, where it was suspected of having an adverse effect on the environment through nitrate leaching, eutrophication, greenhouse gas emissions and heavy metal uptakes by plants.

1. Goals/ Objectives of INM:

i. To Maintain Soil Productivity
ii. To ensure productive and sustainable agriculture.
iii. To reduce expenditure on costs of purchased inputs by using farm manure and crop residue, etc.
iv. To utilize the potential benefits of green manures, leguminous crops and bio-fertilizers.
v. To prevent degradation of the environment.
vi. To meet the social and economic aspiration of the farmers without harming the natural resource base of agricultural production.

2. Concepts of Integrated Nutrient Management:

i. Regulated nutrient supply for optimum crop growth and higher productivity.
ii. Improvement and maintenance of soil fertility
iii. Zero adverse impact on agro – ecosystem quality by balanced fertilization of organic manures, inorganic fertilizers and bio- inoculant
iv. Improve the stock of plant nutrients in the soils
v. Improve the efficiency of plant nutrients, thus, limiting losses to the environment.

3. Components of INM:

i. Soil Source:

Mobilizing unavailable nutrients and to use appropriate crop varieties, cultural practices and cropping system.

ii. Mineral Fertilizer:

Super granules, coated urea, direct use of locally available rock phosphate in acid soils, Single Super Phosphate (SSP), MOP and micronutrient fertilizers.

iii. Organic Sources:

Byproducts of farming and allied industries. FYM, droppings, crop waste, residues, sewage, sludge, industrial waste.

iv. Biological Sources:

Microbial inoculants substitute 15 - 40 Kg N/ha.

4. Strategies in INM:

Besides use of inorganic fertilizers as the major approach, others include incorporation of farmyard manure (FYM), composts, green manure, crop residues, crop rotation, biofertilizers and so on**.**

5. Approaches / Strategies in INM:

Besides use of inorganic fertilizers as the major approach, others include incorporation of farmyard manure (FYM), composts, green manure, crop residues, crop rotation, biofertilizers and so on.

i. Balanced fertilization:

Improved crop nutrition aims at maintenance of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of various plant nutrients in an integrated manner. Balanced dose of N, P and K is usually applied to the soil in the ratio of 2:1:1 or 3:1:1 (N: P_2O_5: K_2O). However, imbalanced one viz., high available N possibly shifts the balance between the vegetative and reproductive growths towards excessive vegetative development, thus delaying maturity, reducing yield and promote disease & insect damage.

Study reveal that basal placement of P within the active root zone is advocated for less surface contact & less fixation over broadcasting on top soil or splitting. Water-soluble sources of P are more efficient over others especially when P is applied through foliage, and P with N increases use efficiency of N. Yet, antagonistic effect of P on Zn, Fe and Cu is noticed.

ii. **Incorporation of animal manure:**

Although the manure is the source of all nutrients, crop response is more evident in presence of fertilizers.

- Besides improvement in yield and soil properties, soil microflora is also improved following FYM or INM practice.
- Significantly greater populations of actinomycetes, fungi, Rhizobia and bacteria is seen in the INM plots compared to that in mineral fertilizer plots which may, in part, attributed to higher moisture holding capacity and favourable environment under it.

iii. Incorporation of Green manure:

- With the increase in usage of fertilizers and intensification of agriculture, alternative source of organics besides FYM like green manure (GM), crop residues/ wastes etc. have been increased.

- Although N additions through GM is in the range of 30-40 kg ha^{-1}, yet this practice is not prevalent even in rainfed areas because of unavailability of sufficient soil moisture and no direct visual/ economic benefits.

iv. Incorporation of Crop residues:

The bulk of available crop residues constitute cotton stalks, wheat straw and mustard residues in the Northern India, cotton and pigeon pea stalks in central India, and cotton, legume & rice straw in the Southern India. Usually these are poor for quality composting because of their high lignin content, wide C/N ratio, and low nutrient especially N content causing N immobilization and often allelopathic effect on the applied crop.

Since there is very little turnaround time between harvest and sowing of the crops in cropping systems and inherent deterrent nature due to residues in field operations, management of residues poses a stupendous task. Thus, a majority of crop residues are burnt resulting in health and environmental problems in addition to loss of N, P, S and B. On the other hand, restoration of soil fertility is possible by incorporating the crop residues since the practice itself conserves/sequesters carbon as residue having wider C/N ratio possibly leaves more carbon in the soil.

v. Rotational cropping:

More often ignored in an INM strategy, crop rotation is a very important tool in sustaining nutrient supply. Legumes in rotation restore soil fertility in more than one-way viz, some of the N fixed isleft in the soil after harvest, improvement in soil properties, lesser disease andpest problem and better weed control. Legumes rotation can fix atmospheric N to an extent of135-488 kg ha^{-1}.

vi. Biochar:

Biochar is obtained through pyrolysis of agricultural or other lignocellulosic biomass at temperatures ranging from 350°C to 700°C.Biochar addition to soils has positive effects on water-holding capacity as well as C sequestration However, biochar properties vary widely depending on feedstock and production conditions.

a. **Advantages:**

- Biochar addition to soils has positive effects on water-holding capacity as well as C sequestration
- Improvement of microbial habitat
- Moisture and nutrient retention
- Affinity to adsorb contaminants there by keeping out harm's way for plants
- "Limit effect" to balance acidic soil towards a neutral pH
- Increased Soil fertility and WHC.

6. Bio-fertilizers:

Bio-fertilizers or bio-inoculants are productions containing living organisms such as nitrogen fixers or phosphorus solubulizers which are useful for agricultural production.

Biofertilizers play a significant role in improving soil fertility and plant growth.

- by fixing atmospheric nitrogen both in association with plants and without plants
- solubilize insoluble soil phosphates into soluble phosphates there by increasing the availability of phosphorus
- Secrete growth promoting substances and supplies to the inoculated plants.

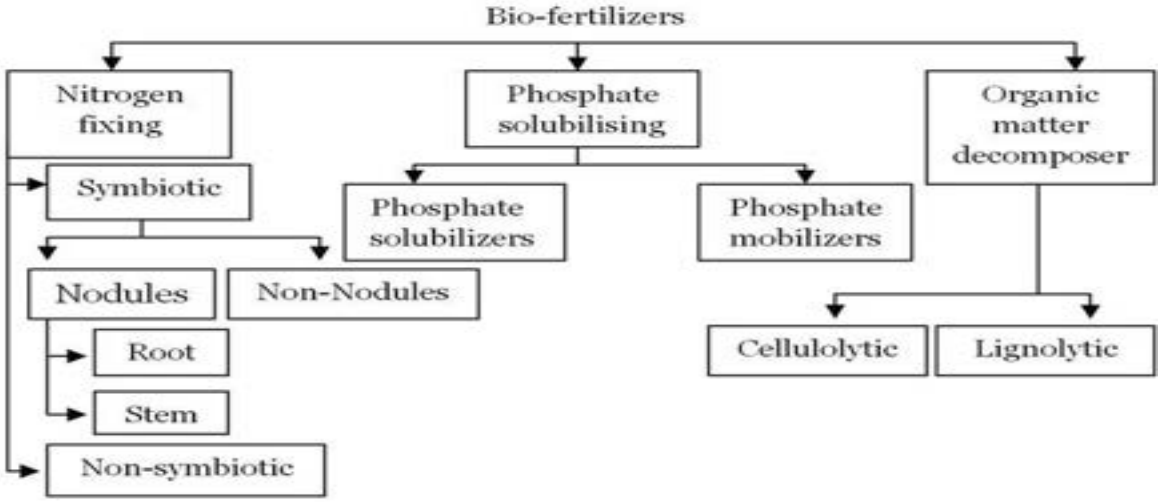


Fig. 5. Classification of bio fertilizers

i. Rhizobium inoculant:

Belongs to the family Rhizobiaceae and symbiotic in nature. Rhizobium establishes symbiotic relations with pulses and other legumes and can fix 50 to 100 kg N ha^{-1} by which application of chemical nitrogen fertilizers could be reduced and supplemented nearly 80-90 per cent of nitrogen requirement of crop is met by nitrogen fixation in root nodules of legume crops.It is used for pulse legume crops like chick pea, red gram, chickpea, lentil, black gram etc., and oil seedlegumes like soybean and groundnut and forage legumes like besrseem, lucerne and pillipesara. On average yield increase was 15-30 % due to rhizobium inoculation.

ii. Azotobacter inoculant:

Azotobacter belongs to the family Azotobacteriaceae, which is a chemoautotrophic in nature, free living, non-symbiotic in nature and is recommended for application to non-legume crops. It grows best in neutral to alkaline soils.By the application of Azotobacter to various crops, the amount of recommended doses of nitrogenous fertilizers can be reduced by 10-20%. It produces plant growth promoting substances like vitamins of B group , Indole acetic acid, Gibberellic acid by which plants grow quickly and healthy. This biofertilizer is recommended for rice, wheat, millets and other cereals, vegetables, sunflower, mustard, tobacco, sugarcane, cotton etc., and also fruit crops.

Method of usage: It is carrier based biofertilizer (lignite / peat). Azotobacter can be applied by seed inoculation, seedling inoculation, or by broad casting in the field after mixing with FYM or with well decomposed compost.

Seed inoculation: Seed is treated with Jaggery to make it sticky and then treated with biofertilizer and shade dried. Seedling inoculation: Make slurry of biofertilizer and dip the roots in it. The recommended dose of Azotobacter is 2-3 packets /ha.

iii. Azospirillum Inoculant:

It belongs to the family spirillaceae, chemoautotrophic and associative in nature. It is an associative nitrogen fixing organism was found to be beneficial for sorghum, wheat, maize, barley, fodder grasses and minor millets. Yield increase was 15-30 %.By the application of this fertilizer nitrogen saving is 20-30 kg /ha.It also produces growth regulating substances.

iv. Azolla [Botanical name is *Azollapinnata*]:

It belongs to the family Azollaceae. Azolla is a water fern.It is considered as aquatic weed commonly found in floating in idle ponds, tanks shallow ditches and canals. Azolla is associated with rice field. A blue green algae (BGA) Anabaena azollae living in the epidermal cavity of lower side of the leaf of Azolla. The symbiotic association of *Azollapinnata* and *Anabaena azollae* is termed as Azolla Anabaena complex. This algae fixes atmospheric nitrogen for Azolla and in exchange, the plant provides shelter andfood to the algae. As this complex fixes atmospheric nitrogen, it has great potentiality for use, in agricultural field as biofertilizer and can be used as an alternative to nitrogen fertilizers. It is recommended as green manure because of its large biomass and high N content (4-6%N) for sub merged rice fields.

v. Blue green algae or Cyanobacteria:

BGA is phototrophic in nature. These are photosynthetic, prokaryotic microorganisms and capable of fixing molecular nitrogen. BGA are found to grown in a paddy filed and marshland. It is used as bio fertilizer for irrigated rice crop. The rice field ecosystem provides an environment favorable for the growth of BGA with respect to their requirements viz., light, water and temperature. Nitrogen fixation by BGA have been estimated to be 25-30 kg N/ha. Yield increases by 10-15 %. BGA has some species viz., Nostoc, Anabaena, Olocia, Calothrix, Tolipothix etc., They fix nitrogen in the presence of sunlight .They also contain growth promoting substances like auxin, Indole acetic acid and Gibberellic acid. Recommendation: application of 10 kg /ha flakes of BGA. It is applied 10 days after the transplanting of rice crop.

vi. Mycorrhizae:

Mycorrhizae means the association between higher plant root and fungi. These are obligate symbiotic .They are ubiqutous in nature and with very few exceptions found on a wide range of plant species. They form vesicular – arbuscular – mycorrhizal (VAM) symbiosis. VAM fungi infects and spreads inside the root by providing an aseptate mycelium. Vesicles which are sac like structure provided by these fungi are known to store phosphorus as phospholipids. Arbuscules formed inside the cortical cells are attributed to help in the exchange of nutrients. Common genera that form VAM associations are Glomus, Gigaspora, Enterospora etc.

It is recommended for forest trees, forage grasses, maize, millets, sorghum and barely and also leguminous crops. Mycorrhizae can substitute up to 560 kg phosphorous fertilizer per hectare for citrus.

vii. Phosphate solubilizing microorganisms

Phosphorus is present in soils in both organic and inorganic forms and most of which is insoluble and unavailable to plants. Several soil bacteria particularly those belonging to the genera Pseudomonas and Bacillus and fungi belonging to the genera Pencillium and Aspergillus possess the activity to bring insoluble phosphates in the soil to the soluble forms by secreting organic acids such as acetic acid, propeonic acid etc., These acids lowers the pH and bring about the dissolution of the bound phosphate forms .

a. Constraints in usage of Bio-fertilizers

- Farmers acceptance
- Difficult to demonstrate striking increase in yield due to biofertilizers unlike chemical fertilizers
- Strains fail to establish if the soil moisture in the surface in the surface zone
- Fungicide treatment is a problem in crops like groundnut
- Inoculants manufacturing is for below the requirement
- Availability of quality of inoculants is another problem
- Seed inoculation is no more suitable when seeds are sown on dry soil under
- When seeds are coated with toxic chemicals and pesticides

- Soil containing higher number of ineffective native rhizobia
- Seeds have fragile seed coat

- When seed coat is toxic to rhizobia .In such situation soil inoculation with granulated inoculant is followed in USA, New Zealand, and France etc. Granulated inoculation is prepared using grains of sand, gypsum, peat etc.,
- Problem like transport form the manufacturing center.

b. Advantages:

- Enhances the availability of applied as well as native soil nutrients
- Synchronizes the nutrient demand of the crop with nutrient supply from native and applied sources.
- Provides balanced nutrition to crops and minimizes the antagonistic effects resulting from hidden deficiencies and nutrient imbalance.
- Improves and sustains the physical, chemical and biological functioning of soil.
- Minimizes the deterioration of soil, water and ecosystem by promoting carbon sequestration, reducing nutrient losses to ground and surface water bodies and to Atmosphere.

7. Common constraints in INM:

- Availability of organic manures like FYM / Compost in sufficient quantity is less due to decrease in the cattle population with farming community
- Application of bulky organic manures involves high labour and transport cost thus involving high expenditure.
- Availability of green manure seeds in time.
- Growing green manure crop for in situ application involves both time and money apart from the loss of cropping season. In addition it requires optimum moisture at the time of incorporation.
- The bio-fertilizers may not be available in time.
- Lack of knowledge among the farming community regarding the benefits /usage of bio-fertilizers
- Farmers are not having proper understanding of importance of balanced nutrition and sound knowledge on fertilizer use efficiency.
- Lack of soil test base fertilizer applications
- Increasing cost of the chemical fertilizers
- Scarcity of ground water resources
- Problematic soils.

Conclusion:

The wide spread nutrient deficiencies or toxicities are deteriorating the soil health day by day. Due to this there will be low productivity & profitability in growing crops, majorly by the low nutrient use efficiency. A judicious use of chemical fertilizers in combination with naturally available organic sources gives a breakthrough effect in maintaining the soil health and sustaining the environment. Thus, the adoption of INM practices involving organic manures, bio-fertilizers and amendments in cropping system enriches the soil fertility status; ultimately improves growth and yield of crop and the quality of food as well.

Module III: Crop Production Technologies of Major Local Crops

3.1. A. Wheat

Wheat (*Triticum aestivum* L.) is locally known as *Gehun*/ *Kanak* belongs to family Poaceae. Wheat is the second most important food crop of India, which contributes nearly one-third of the total food grains production. In India, the crop is cultivated in 31.83 million hectares to produce the all-time high production of 113.29 million tonnes with a record average national productivity of 3559 kg/ha and highest productivity was recorded from Punjab (5045 kg/ha) followed by Haryana (4723 kg/ha) during 2023-24 (ICAR-IIWBR, 2024). In India, the production of wheat has been increasing consistently in the recent past, despite the adverse effects of climate change. In areas where wheat is the staple cereal food, it is eaten in the form of '*chapaties*'. In the areas where rice is the staple cereal food, wheat is eaten in the form of *puries* or in the form of *upma* (cooked from *suji* or *rawa*) or sweet *puwas* etc. In addition to this, wheat is also eaten in the form of *Dalia, halwa*, sweet meats etc. In most of the urban areas of the country the use of wheat bread, flakes, cakes, and biscuits is increasingly getting popular.

1. Classification of Indian Wheat

Wheat is an annual plant of *Grammeae* family. It belongs to genus *Triticum*. Perival (1921) classified 12 cultivated species into three distinct groups; deploids (Einkorn Wheat), tetraploids (Emmer, Durum, Persian, Poulard and Polish wheat) and hexaploids (Common, Club, Spelt, Shot, Macha and Vavilovii wheat), with 7, 14 and 21 pairs of chromosomes, respectively in their cells. Only spring-type wheat varieties are grown in the country, though these are raised in winter.

Although as many as 12 species of wheat have been described and recognized, only a few are of agricultural importance. They are discussed as under:

Common bread wheat (*T. aestivum)* is the most important hexaploid wheat species with 42 chromosomes, occupying more than 90% of the total wheat area in the country. It is grown all over India from the sea-level up to an elevation of 3,500 m in the Himalayas. Mexican dwarf wheat developed by incorporating dwarfing gene Norin 10 was introduced in India by Dr. N.E. Borlaug (Noble Leurate).

Macaroni wheat (*T. durum)* is the second most important species, occupying nearly 10% of the wheat area. The durum wheat is good for making suit, semya, sphagetti.

Emmer wheat (*T. dicoccum*), is grown on a very restricted scale in Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu. It is preferred for several south Indian dishes, which use granular form of wheat.

2. Climatic requirement

Wheat crop has wide adaptability. It can be grown not only in the tropical and sub-tropical zones but also in the temperate zones and the cold tracts of the far north, even beyond the 60 degree north latitude. Wheat can tolerate severe cold and snow in spring. It can be cultivated from sea level to as high as 3300 meters. In India wheat is a winter season (*rabi*) crop. The sowing is done in autumn and harvesting in summer. The high temperature at both ends of the crop season determine the duration available for cultivation, which ranges from 100 days in south to more than 145 days in north-western plains and 180 days in the hills.

The best wheat are produced in areas favored with cool, moist weather during the major portion of the growing period followed by dry, warm weather to enable the grain to ripen properly. The optimum temperature range for ideal germination of wheat seed is 20 to 25^{0}C though the seeds can germinate in the temperature range of 3.5-35^{0}C. Early seeding severely restricts tillering capability, crop duration and yield potential of most varieties. During the heading and flowering stages, excessively high or low temperature and drought are harmful to wheat crop. The temperature conditions at the time of grain filling and development are very crucial for yield. Temperature above 25°C during this period tends to depress grain weight. When the temperatures are high, too much energy is lost through the process of transpiration (Chhidda Singh *et al*., 2020; Bhullar and Salaria, 2024).

3. **Soil requirement**

Wheat is a widely adaptable crop and can be grown in a variety of soils but the ideal soil for wheat cultivation is the clay loam or loam soil having a good structure and moderate water holding capacity. Soil should be neutral in its reaction *i.e.* the pH of soil should range from 6.5 to 7.5. *Durum* wheat is considered more suitable for cultivation in heavy and black soils, whereas *aestivum* wheat is grown in all types of soils.

4. **Crop rotations**

In India many rotations of crops involving wheat are feasible. In the irrigated areas a variety of crops like paddy, jowar, bajra, maize, cotton, toria, arhar, moong, urd, etc are grown in rotation with wheat.

5. **Field preparation**

Wheat crop requires a well pulverized but compact seedbed for good and uniform germination. After the harvest of previous crop, the field should be ploughed with disc or mould board plough. Where tractor is available, one deep ploughing followed by 2-3 harrowings with disc or tines harrow and 2-3 planking with heavy wooden planks should be carried out to prepare a well pulverized seed bed.

6. **Selection of seed:**

Only use healthy seeds of recommended varieties should be selected for sowing. There should not be any mixture of seeds of other varieties of wheat or weeds in it. The seed should be obtained/purchased from a reliable source. Always use certified seeds. If the seed is untreated, it should be treated before sowing.

7. **Varieties**

The selection of a suitable variety is the first and primary aspect of production technology. The contribution of other inputs will depend on the genetic potential of the improved variety. Wheat is grown in different growing conditions viz. irrigated or rain-fed, timely or late sown and problematic soils having salinity and alkalinity. For better productivity, suitable variety for the growing conditions must be selected. At present, a wide range of improved varieties are available for use under various situations *viz.*, timely and late sown, irrigated, rainfed and salinity-alkalinity conditions (Anuj Kumar *et al*., 2014; Bhullar and Salaria, 2024).

Wheat varieties released for different zones of India
North Western Plains Zone

Early sown, high fertility, irrigated conditions: DBW 370 (Karan Vaidehi), WH 1270
DBW 327 (Karan Shivani), DBW 332 (Karan Aditya)
Timely sown, irrigated conditions: WH 1105, PBW 826, DBW 222 (Karan Narendra), HD 3226, HD3386
Late sown, irrigated conditions: WH 1124, JKW261 (Birsa Gehun-4)

Very late sown, irrigated conditions: HI 1621, HD 3271

Timely sown, restricted irrigation conditions**:** WH1402**,** HI1654, HI1653, HD 3369, HUW 838, DBW 296, NIAW 3170, HI1628, HD3237, HI1620

Biofortified Wheat Varieties for North Western Plains Zone

Timely sown, high fertility, Irrigated conditions: DBW 371, DBW 372
Timely sown, Irrigated conditions: PBW 872, DBW 303, DBW 187
Late sown, irrigated conditions: PBW 771, PBW 752, PBW 757
Very late sown conditions: HD 3298

North Eastern Plains Zone (NEPZ):
Timely sown, irrigated conditions: PBW 826, DBW 222, HD3388
Late sown, irrigated conditions: DBW 316, PBW 833
Very late sown, irrigated conditions: HI1621, HD 3271
Timely sown, restricted irrigation: HD 3293, DBW 252

Central Zone:

Timely sown, High Fertility, Irrigated conditions: HI 1650, HI 1636, GW 513, NWS 2194, Gujarat Wheat 547
Late sown, irrigated: CG1029, HI1634
Bread wheat for Timely sown, restricted irrigation: CG1036, HI1655
Durum wheat for Timely sown, restricted irrigation: HI8830, DDW55, HI8823, UAS466
Peninsular Zone (PZ):

Durum wheat for timely sown, irrigated: HI8826, MACS4100
Bread wheat for timely sown, restricted irrigation: MP1358, NIAW3170, NIAW 4028, MP(JW) 1378
Durum wheat for timely sown, restricted irrigation: NIDW1149, GW1346

Northern Hills Zone (NHZ):

Timely sown, rainfed conditions: VL 2041

8. **Sowing time**

Sowing time is an important non-monetary input that affects the wheat productivity. The time for wheat sowing varies from region to region. It depends mostly on soil, temperature, irrigation facilities, harvesting of previous crop and duration of the wheat varieties. Normally wheat is sown when the average daily temperatures fall to around 22-23°C, which happens only in November in most wheat-growing areas. Sowing wheat while the temperatures are high (around 25°C) results in poor germination reduced tillering and early onset of flowering, thereby exposing the floral parts to cold damage. All these factors depress the crop yields (Chhidda Singh *et al*., 2020). However, sowing of long duration/ high yielding varieties can be commenced from the last week of October to avoid the impact of terminal heat stress. Under rainfed conditions, sowing the crop in last week of October is suitable. First fortnight of November is optimum time of sowing of wheat in NHZ, NWPZ and PZ and Middle of November is optimum in NEPZ and CZ (Pannu *et al*., 2022; Bhullar and Salaria, 2024).

9. **Seed rate**

Seed rate requirement is dependent on seed size, germination percentage, time and method of sowing, moisture content in the soil at the time of sowing. For varieties with the medium sized grains (38 to 44 g for 1,000 seeds) a seed rate of 100 kg/ha is recommended. For bold seeded varieties (around 45 g or more/1,000 seeds) a seed rate of 125 kg/ha is optimum. For late-sown and mild salinity condition, 25% higher seed rate (125-150 kg/ha) is recommended (Pannu *et al*., 2022; Bhullar and Salaria, 2024).

10. **Method of sowing**

In wheat growing areas the sowing of wheat should be done with the help of seed- cum -fertilizer drill. For proper germination the seed must be placed in moist soil. Sowing with seed-drills, place the seed at a uniform depth, gives a more uniform stand and leads to early emergence of vigorous seedlings. Seeds of semi dwarf varieties can be sown to a depth of 5-6 cm. For irrigated timely sown wheat, a spacing of 20 cm between the rows is considered optimum. For irrigated late-sown conditions, the row spacing is reduced to 18 cm (Anuj Kumar *et al*., 2014; Bhullar and Salaria, 2024).

11. **Nutrient Management**

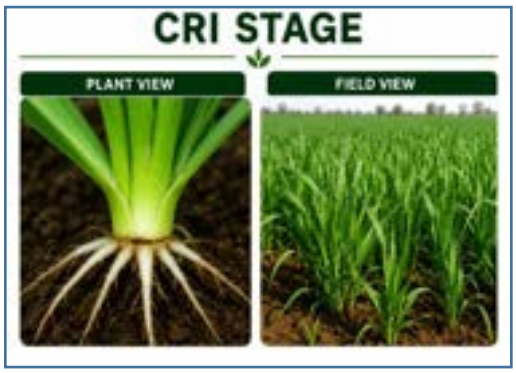
Manures and fertilizers play an important role in wheat cultivation. To get the maximum benefit from fertilisers, these must be properly applied in right quantity and at right time. Adjustment of doses fertilisers for different soil fertility classes should be done on soil test basis *i.e.* location specific. Normally most of the farmers apply fertilizers on blanket recommendations.

Under irrigated conditions for dwarf varieties of wheat, 150 kgN+60 kg P_2O_5+60 Kg K_2O + 25 Kg $ZnSO_4$/ha is recommended. While for tall/desi variety 60 kg N+30 kg P_2O_5+30 Kg K_2O/ha is recommended under irrigated conditions. Half nitrogen and full dose of phosphorus, potash and zinc should be drilled at the time of sowing. Remaining half nitrogen should be applied after first irrigation. If the zinc is not applied at the time of sowing then spray twice 0.5% zinc sulphate + 2.5% urea at 45 and 60 days after sowing. Under

rainfed conditions, 30 kg N+15 Kg P_2O_5/ha is recommended. All the fertilizers must be drilled at the time of sowing (Anuj Kumar *et al*., 2014; Bhullar and Salaria, 2024; Pannu *et al*., 2022).

12. **Irrigation management**

Adequate soil moisture is required for the normal development of wheat plant at all the stages of growth. In general, wheat crop requires 40 cm water and it needs external water supply when available soil moisture percentage falls below 50-60 percent of the field capacity. The crop requires 4-6 irrigations depending upon rainfall and water use of the crop. For maximum water use efficiency, scheduling of irrigation is the most important aspect in water management because scarcity and excess adversely affect the wheat production. Depending on the availability of irrigation water, it should be applied at critical physiological stages of crop i.e. at CRI, Tillering, jointing heading, milking and dough stage. This is the most practical and feasible criterion for irrigation scheduling. Crown Root Initiation (CRI) and heading stages are the most critical to moisture stress (Bhullar and Salaria, 2024).





13. **Weed management**

Weed is one of the major biotic constraints in wheat production as they compete with crop plants for moisture, nutrients, light and space. Wheat is infested with both grasses and broad-leaved weeds. Weeds reduce the grain yield of wheat by 10 to 80% depending upon intensity and type of weed flora under different cropping systems. Weed flora of wheat differ from area to area depending on irrigation, fertiliser use, soil type, weed control practices and cropping sequences. The critical period of weed control in wheat is 30-45 days after sowing (DAS) and crop should be kept weed free during this period (Anuj Kumar *et al*., 2014; Bhullar and Salaria, 2024).

The major weeds of wheat are:

(A) **Grassy weeds:** *Phalaris minor, Avena ludoviciana, Poa annua, Polypogon monspliensis* and *Lolium temulentum*.

(B) **Broadleaf weeds***: Chenopodium album, Rumex dentatus, Melilotus indica, Medicago denticulata, Anagallis arvensis, Vicia sativa, Lathyrus aphaca, Malva parviflora, Chenopodium murale, Convolvulus arvensis, Coronopus didymus, Fumaria parviflora, Cirsium arvense* and others.

To control broadleaf weeds (*R. dentatus,* C. *arvensis,* C. *arvense* and *L. aphaca*) apply Metsulfuron-methyl (Algrip, 20% WP) @ 20g/ha or Carfentrazone-ethyl (Aim 40 % DF) @ 50g/ha or 2,4-D Na salt (80% WP) @625 g/ha by mixing in 500 litre of water per hectare area after 30- 35 days of sowing. To control grassy weeds (*Avena ludoviciana* and *Phalaris minor)* apply Clodinafop-propargyl 15% WP @400 or Pinoxaden @1000 or Fenoxaprop-p-ethyl @1000 + S (Puma activator 0.1%) or Sulfosulfuron 75% WP@ 32.5 + 1250 ml Surfactant (0.25%). To control Complex weed flora (grassy + broad leaf weeds) apply Sulfosulfuron+ metsulfuron (R.M.) (Total) @40 + S (0.25%) orMesosulfuron+ Idosulfuron (R.M.) (Atlantis) @400 + 0.1 activator or Clodinafop-propargyl + Metsulfuron-methyl (R.M.) (Vesta) @400 + 1250 ml surfactant. Apply any one of the above mentioned herbicides by mixing in 500 litre of water per hectare area after 30- 35 days of sowing.

Precautions:

- Sulfosulfuron or its ready-mix formulation (Total) should be avoided in areas where sorghum or maize is grown after wheat harvest; however, no residual effect of these herbicides was observed on cotton.
- Use flat fan or flood jet nozzle for pre-emergence herbicides and flat fan nozzle for post emergence herbicides.
- Change the herbicide group every year to prevent the development of resistance in weeds.
- Some weed plants may escape after the application of herbicides. These plants should be uprooted before they produce seeds. This practice will reduce the weed problem in next crop of wheat.

14. **Harvesting and Threshing**

The most suitable stage for harvesting wheat is when the grains become hard and contain 20-25% moisture. High yielding dwarf varieties of wheat should be harvested when the leaves and stems turn yellow. The maturity time of the crop differs from zones to zones and also depends upon the nature of cultivation *i.e.* whether it is under rainfed or irrigated conditions. Harvesting is generally done manually with serrate-edged sickles. Simple mechanical threshers are widely used for threshing and winnowing of wheat all across the country. Now-a- days in certain areas like Punjab, Haryana, Western U.P., M.P., Rajasthan etc. combine harvesters are mainly used to do harvesting, threshing and winnowing wheat in single operation.

15. **Storage:** Before storage the grains must be thoroughly dried. Successful storage of grains depends on its moisture content. Grains with less than 10% moisture store well. The retention of good viability of grain for sowing of next crop is a problem in eastern India due to high moisture content. The number of species attacks the wheat grain in storage. The most important are khapra beetle, lesser grain borer and floor beetle. The storage bins or godowns must be moisture proof and should be fumigated to control pests. Proper care must be taken to keep grain safe from pest damage and moisture.

16. **Production constraints and challenges for wheat production**

Production constraints are manifold and vary from crop to crop and between regions. Burgeoning population vis-à-vis increasing demand for food; growing competition for cultivable land, irrigation water and energy; intensive cropping especially in the Indo-Gangetic Plains resulting in irrational use of resources; pest-environment interaction; reduction of natural resource base; declining total factor productivity; and yield plateau are the prominent challenges put forth against crop production. Wheat production not only faces the above routine challenges, but the intensity gets magnified in the context of climate change owing to its vulnerability. (Sendhil *et al*., 2018; Sharma *et al*., 2015 and Singh *et al*., 2016).

i. Climatic vulnerability

In India a significant part of wheat area is under heat stress, and Gangetic plains and central and peninsular India are the most heat-stressed regions, whereas it is moderate in northwestern parts of Indo-Gangetic Plains (Joshi *et al*., 2007). Variability in climate is also one of the biggest environmental threats to Indian agriculture, potentially impacting the wheat production and security. In India, it has been predicted that with every rise in 1°C temperature, the wheat production will be decreased by 4-6 million tonnes. Rainfed wheat will experience a reduction in yield with 9–25% profit loss for every 2–3.5°C rise in temperature (Aggarwal, 2009).

ii. Excessive use of inputs and land resources

After the Green Revolution, the productivity of wheat has been significantly increased with the increase in input usage, plant protection chemicals and irrigated areas. The excessive use of fertilizer, chemicals and irrigation has degraded the fertility of the soil and also caused a reduction in groundwater table. The monocropping system led to deterioration in soil quality. If the current trend continues, the country will face a serious problem in utilization of scarce natural resources.

iii. Salt-affected and problematic soils

Salinity is another abiotic stress which has the potential to halt the trajectory of wheat production in India. In India about 4.5 million hectares salt affected area is under wheat cultivation posing a major problem for canal irrigated areas (Singh and Chatrath, 2001). Even though soil amendments and proper drainage are the more constructive solution, pace of reclamation is not substantial. This will significantly reduce the wheat yield.

iv. Pest and disease complex

One of the most important biotic stresses which can disturb the wheat production in India is the disease complex, particularly rusts and blight apart from other diseases and pests. Disease complexes are continuously evolving over time and place which always pose a potential threat to country's wheat production. As year passes, the pests of wheat have developed some resistance even though controlled under contingent situation. If not, a new range of pests and diseases have been emerging putting a serious constraint on the wheat productivity.

v. Availability of improved seed

Adoption system and germplasm dissemination in India have been made in formal (organized) and informal (unorganized) ways. Even though new improved varieties are developed and made available to farmers by agencies around, 80% of all seeds are saved by the farmers. Further, a majority of farmers in India have lack of awareness of improved wheat varieties due to weak linkages (Joshi *et. al*., 2007). The development and diffusion of improved varieties are crucial for achieving target production of wheat.

vi. Declining total factor productivity

A major concern among policy makers is the declining total factor productivity over the years owing to stagnating yield levels with increased use of inputs and resource services. It is a major concern in the intensive cropping areas wherein rice-wheat is widely under cultivation. This can be countered by adoption of improved technologies coupled with the use of optimal resources.

Country's wheat production is vulnerable to various threats (biotic & abiotic stresses, price volatility, yield barriers etc.) which have the potential to affect the wheat production. On a series of production challenges at the forefront and aggravated by climate change, the set production target of 140 million tonnes of wheat by 2050 can be achieved only by improving the crop productivity levels across regions with a limited scope for area expansion. To achieve the region wise targeted productivity, research goals and priorities have to be set for reserach program. Synergy between science and technology, extension, policy governance and institutions should happen for the desired level of output, outcome and impact at all levels. The whole value chain has to be strengthened with potential innovations and interventions for sustainable wheat production in India.

To develop high yielding varieties to meet the ever increasing growing demand. Currently, development of nutrient dense staple food crops is one of the prime research areas for the scientific community across the globe, though yield takes the first place in priority setting during varietal development. Development of biofortified wheat variety (WB 2) with high grain zinc content is the testimony. Therefore, development of high yielding and nutritionally rich (high protein, iron, zinc etc) wheat varieties should be the priority for the wheat researchers. Drought and heat are the two anticipated threats for wheat production, therefore it is pragmatic to focus research to develop high yielding varieties suitable for drought and heat. Furthermore, the national wheat research programs should emphasize in developing suitable wheat varieties for production threats like climate change. Improving the nitrogen-use efficiency by identifying suitable genotypes for better crop productivity and profitability. Develop water use efficient (WUE) genotypes with deeper & vigorous roots, tiller inhibition, alternate dwarfing genes (coleoptile length). Knowledge empowerment of stakeholders on quality parameters. Capitalising the institutional innovations like e-National Agriculture Market for better price discovery and remuneration. Promotion of seed banks for better access of quality seed to the farming community. Fostering climate smart villages: Tracking sensitive growth stages and developing climate-smart adaptation practices and climate-smart actions. Thrust on developing and popularization of bio-fortified wheat varieties to ensure nutritional security especially for women and children.

3.1. B. Rice Production Technologies

In India, total rice production in 2024-25 is estimated to be 1490.74 lakh million tonne as compared to 1378.25 lakh million tonne in 2023-24, showing an increase of 112.49 LMT, from 43.86 million hectares of rice fields, with a productivity of roughly 2390 kg/ha. In comparison to the production levels of many nations worldwide, rice's output is poor despite being cultivated in a variety of soil and climate conditions.

Another barrier to raising the nation's rice yield is the fact that marginal, small, and medium-sized farmers own over 90% of the farmed area. Therefore, there is a lot of room to raise the nation's rice yield. Bangladesh (4375 kg/ha), Indonesia (5152 kg/ha), Vietnam (5573 kg/ha), and China (6710 kg/ha) have the highest productivity. The nation's production could be raised by implementing a variety of initiatives and better technologies. The production of hybrid rice should be encouraged since it has the potential to boost productivity.

1. **Rice Growing Regions**
   - i. North-Eastern Region
   - ii. Eastern Region
   - iii. Northern Region
   - iv. Western Region
   - v. Southern Region

Before going into details of the growth stages, it is important to understand the morphology (external appearance) of the plant. There are two major parts of paddy plant i.e. root system and shoot system. As a rice grain germinates, a sheath or coleorrhiza (embryonic root) can be seen emerging from the soil. This is what happens in upland situation. But in submerged soils, it is the coleoptile (shoot meristem), which emerges ahead of the roots. The radicles (embryonic roots) emerge through the coleorrhiza. Shortly after the radicles appear, secondary roots develop into lateral roots. Later, the embryonic roots disappear and are replaced by adventitious roots, emerging from nodes on the culm. Similarly, plant parts that are visible above the ground, i.e., culm, leaves and inflorescence (panicle), constitute the shoot system. Paddy plant passes through a number of growth stages, starting from germination to maturity. Different rice growth stages are given in Figure 1.

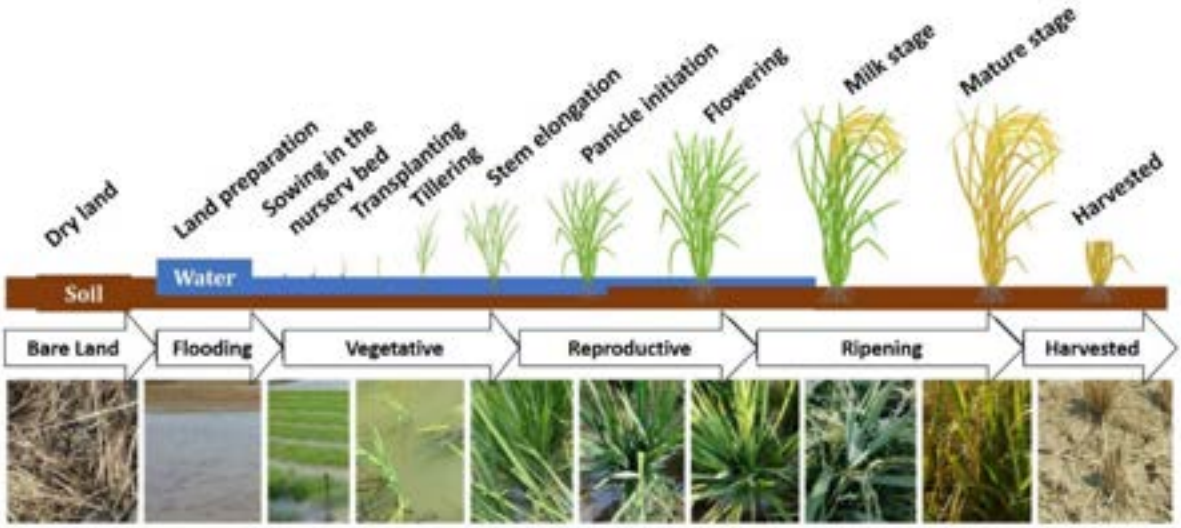


Figure 1. Rice growth stages (Source: Sheng et al 2022)

2. **Production technologies**

i. Rice Varieties

Based on duration rice varieties are divided into short duration (<120 days), medium duration (120-140 days) and long duration (> 140 days).



ii. Agronomic Practices

Systems of rice cultivation in various rice growing areas are largely depending upon the crop growing conditions like soil type, available water and prevailing monsoon.

The principal rice ecosystems followed in India are:

a. Wet system (system of rice intensification, transplanted puddled lowland rice and direct wet seeded puddled lowland rice)
b. Dry system (dry seeded rainfed unpuddled lowland rice and rainfed upland rice)
c. Semidry system (dry seeded rice in unpuddled lowland)

iii. Land Preparation: The field is prepared by ploughing the rice fields with soil turning plough followed by harrowing. The rice field is filled with water and is puddled twice by paddy puddler or once by rotavator. If green manure crop like dhaincha or mung has been taken, it may be mixed with rotavator during puddling followed by planking.

iv. Seed Rate: The seed rate of rice varies based on the methods of sowing/transplanting. In broadcasting method seed rate is about 80kg/ha. In transplanting method, it is about 20-30 kg/ha and under SRI method seed rate is only 5-8 kg/ ha.

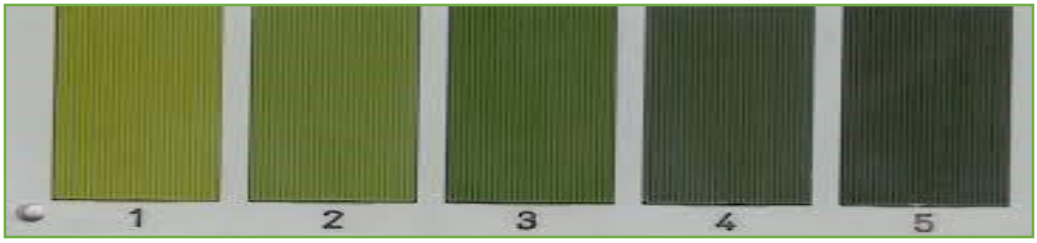
v. Seed Treatment: Seed treatment is done by dissolving 10 g carbendazim (Bavistin) and 1g streptocycline in 10 litres of water sufficient for 10 kg seed. The soaked seed should be for 24 hours before sowing or transplanting. The soaked seeds are covered till it is sprouted.

vi. Sowing Method: Following two methods are commonly practiced: (a) Direct seeding or Broadcasting method: In this method seed is directly sown in unpuddled and puddle field prepared for sowing at appropriate moisture level. (b) Transplanting method: In this method a nursery is prepared for transplanting of rice as required for the methods of transplanting. For manual transplanting the nursery is prepared in 1/20th of transplanting usually on raised beds. For mechanical transplanting the nursery is raised as mat or tray nursery. The 25 days old seedlings (4-5 leaf stage) uprooted from the nursery –bed are the transplanted 3-4 cm deep following 20cm x 10cm spacing with 2-3 seedlings/ hill in the line planting and 10 cm x 15 cm in random planting. However, in case of SRI 10 days old nursery is transplanted at 25 cms x 25 cms spacing of only 1-2 plants per hill.

vii. Sowing Time: The rice is grown almost in all crop seasons i.e. *Kharif*, *Rabi* and summar in the country. However, depending upon the prevailing weather, it is sown in different periods in different regions.

viii. Manures and Fertilizer Management: The fertilizers and organic manures may be applied based on available soil nutrients after the soil tests. The objective should be to reduce the input costs to obtain optimum productivity. In general, about 80-100 kg nitrogen/ha is applied in 3 split doses; half (4050 kg) as basal dose, one forth (20-25 kg) at tillering stage and remaining a week before panicle initiation where top dressing is not possible. Along with basal dose (50% of nitrogen) 40-45 kg P_2O_5 and 30-40 kg K_2O are also applied depending on soil test. Bio fertilizers such as blue green algae or Azolla provide 20-25 kg N/ha, which may be added as partial supplement to inorganic fertilizer. The application of micro-nutrients may also be applied based on soil test.

ix. Nutrient management: Apply FYM 12.5 t/ha or compost or green leaf manure @ 6.25 t/ha. Fertilizers should be applied based on STCR recommendations or N dose based on leaf colour chart reading.



x. **Water Management:** At the time of transplanting, a shallow depth of 2 cm of water is adequate. Two cm of water depth has to be maintained up to seven days of transplanting. After the establishment stage, cycling submergence of water 5 cm has to be continued throughout the crop period. Critical stages of water requirement in rice are a) panicle initiation, b) booting, c) heading and d) flowering. Adequate drainage facilities have to be provided to drain excess water and last irrigation may be given 15 days ahead of harvest.

Alternate Wetting and Drying Irrigation (AWDI): AWDI is used to monitor the depth of ponded water on the field by using Field Water Tube' (FWT) which is made of 40 cm long plastic pipe with a diameter of 15 cm so that water table is easily visible. Tube is perforated with 0.5 cm diameter holes in the bottom and the top 15 cm portion is non-perforated. One field water tube is required for adopting the AWDI in an area of 1 acre. The FWT is installed in the field using mallet and it is inserted upto the perforated portion buried inside the soil. The soil inside the tube is to be removed.



xi. Weed Management:

Any pre emergence herbicide has to be mixed with 50 kg of dry sand on the day of application (3 - 4 DAT) and applied uniformly to the field with thin film water on 3rd DAT. Water should not be drained for next 2 days from the field (or) fresh irrigation should not be given.

- Pre emergence application (PE) of Pretilachlor @ 750 g/ha at 3 DAT followed by early post emergence application of Chlorimuron methyl + Metsulfuron methyl @ 4 g/ha on 25 DAT.
- PE Pyrazosulfuron ethyl @ 20 g ha-1 on 3 DAT + Hand weeding (HW) on 45 DAT.
- PE butachlor 0.75 kg ha-1 + bensulfuron methyl 50 g ha-1 on 3 DAT + HW on 45 DAT
- PE butachlor 0.75 kg ha-1 + bensulfuron methyl 50 g ha-1 on 3 DAT followed by mechanical weeding on 45 DAT.
- PE application of Butachlor @ 1.0 kg /ha on 3 DAT + Finger type single row or double row rotary weeder weeding on 45 DAT.
- Early POE application of Bispyribac sodium 40 g ha-1 (2-3 leaf stage of weeds) + Hand weeding on 45 DAT.
- Post emergence application (POE) of 2, 4-D sodium salt 1.25 kg/ha on three weeks after transplanting.

xii. Plant Protection

Diseases	Control
Khiara	5kg zinc with 2.5 kg lime (in 1000 liters of water) / ha 10 days after transplanting
Blast	Seed treatment with thiram @ 2.5g/kg of seed or tricyclazole 75 wp @ 1.5 g/ kg of seed
Brown spot	Carbendazim 50wp @ 2.0 g/kg seed or Mancozeb 75wp @ 2.5g/kg

Bacterial leaf blight	Seed treatment with streptocycline (1g) + carbendazim 50 W.P. (20g) for 8–10 kg of seed in 10 litres of water for 12 – 15 hours
Insect	**Control**
Stem Borer	Spray Cartap 50 wp @800 g/ha chlorpyriphos 20EC 2,000 ml/ha
Brown plant hopper	Spray Imidacloprid 200Sl@125 ml/ha
Gundhi bug	Spray carbaryl 50 wp @1,500 g/ha during afternoon hours

xiii. Harvesting and threshing

The crop should be harvested when the grains turn yellow moisture content is below 25 %. The harvesting and threshing is done manually and also by combine harvesters and thres

Conclusion

Rice production technologies offer significant potential for enhancing yield, efficiency, and sustainability in rice farming. Implementing a combination of improved rice varieties, precision agriculture techniques, and integrated nutrient management practices can lead to increased productivity and reduced environmental impact. However, ensuring widespread adoption, especially among smallholder farmers, requires addressing challenges related to access to technology, training, and support system

3.2. Cereals: Jowar, Bajra, Maize/ Millets

Millets are a diverse group of small-seeded cereals that are under cultivation for thousands of years and continue to play a vital role in food, nutrition, and livelihood security, particularly in arid and semi-arid regions of Asia and Africa (Kheya *et al.*, 2023). Millets popularly known as "nutri-cereals" due to their superior nutritional profile. They are rich in complex carbohydrates, dietary fiber, essential amino acids, vitamins, and minerals such as iron, calcium, and zinc. They are gluten-free and have a low glycaemic index, making them suitable for addressing health challenges such as diabetes, obesity, and micronutrient deficiencies (Mohanan *et al.*, 2025). Millets are resilient crops, well adapted to harsh climatic conditions, including drought, heat stress, and low soil fertility. They require significantly less water compared to rice and wheat, making them climate-smart crops that can contribute to sustainable agriculture and resource conservation. Moreover, their short growing season, diversified uses and adaptability to marginal lands position them as a strategic crop in the context of climate change and food security (Samtani *et al.*, 2024).

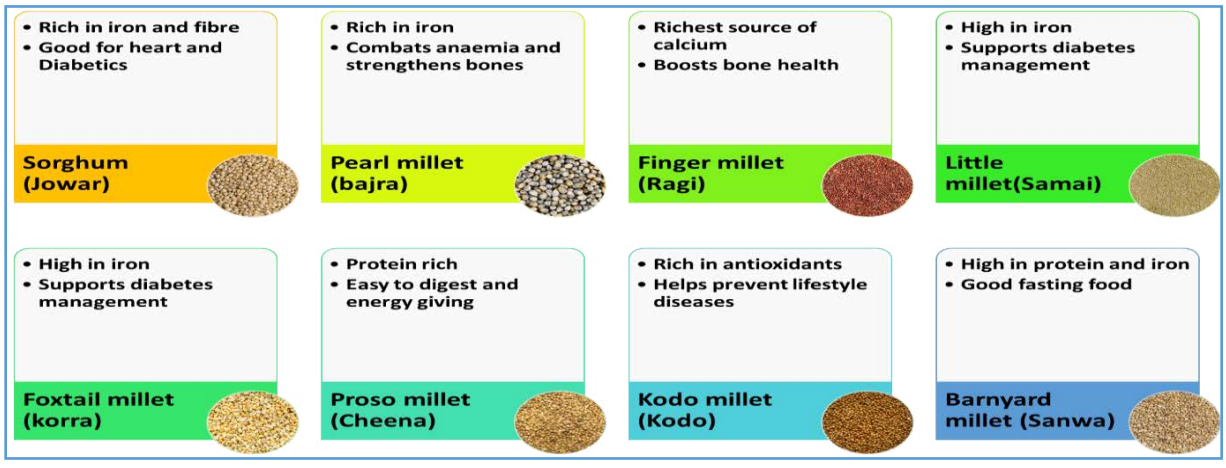
Despite their immense potential, millet cultivation has witnessed a decline in area and production in recent decades due to shifts in dietary patterns, policy priorities, and the expansion of rice and wheat cultivation. However, with renewed attention at both national and global levels including the United Nations declaring 2023 as the *International Year of Millets,* there is a growing momentum to revive and mainstream millets in farming systems and diets (Sreekala *et al.*, 2023). The present chapter focuses on production technologies of millets, encompassing improved varieties, best agronomic practices, soil and nutrient management, pest and disease management, and post-harvest handling. By integrating scientific advancements with traditional knowledge, the chapter aims to provide updated, practical, and sustainable guidelines for enhancing millet productivity and profitability.

1. Importance of Millets

Table 1. Nutritional Composition of Millet grains

Grain	Carbohydrates (g)	Protein (g)	Fat (g)	Energy (kcal)	Dietary (g)	Ca (mg)
Sorghum	67.7	09.97	1.73	334	10.22	28
Pearl millet	61.8	10.96	5.43	348	11.49	27
Finger millet	66.8	07.16	1.92	321	11.18	364
Kodo millet	66.2	08.92	2.55	332	6.39	15
Little millet	65.6	10.13	3.89	346	7.72	16
Proso millet	70.4	12.50	1.10	341	2.20	14
Foxtail millet	60.1	12.30	4.30	331	8.00	31
Barnyard millet	65.6	06.20	2.20	307	9.80	20

(Source: Hariprasanna, 2023)



Millets are rich in dietary fiber, protein, calcium, iron, and essential micronutrients, making them ideal for combating malnutrition and lifestyle diseases such as diabetes and obesity (Babele *et al*., 2022). The nutritional composition of various millets is presented in table 1. Environmentally, millets require significantly less water than major cereals, thrive in poor soils, and are highly tolerant to drought and heat, contributing to soil health, biodiversity, and climate resilience. Economically, they provide livelihood opportunities for small and marginal farmers due to their low input costs and adaptability to rainfed areas, while the growing demand for value-added millet-based products is creating new markets and income opportunities. Socially, millets empower rural communities, particularly women, by promoting traditional food systems and local enterprises (Sharma *et al*., 2025).

2. Classification of Millets

Millets are broadly classified into major and minor (small) millets based on their grain size and area of cultivation. Major millets, such as sorghum, pearl millet, and finger millet, are widely grown and form staple foods in many regions. Minor millets, including foxtail, little, kodo, proso, barnyard, and browntop millets, are smaller in grain size but equally rich in nutrients and more resilient to harsh climatic conditions.

Table 2: Classification of Major and Minor Millets with Their Common, Scientific, and Vernacular Names

Category	Common Name	Scientific Name	Vernacular Names
Major Millets	Sorghum	*Sorghum bicolor*	Jowar
	Pearl Millet	*Pennisetum glaucum*	Bajra, Sajje, Sajjalu
	Finger Millet	*Eleusine coracana*	Ragi, Nachni
Minor (Small) Millets	Foxtail Millet	*Setaria italica*	Kangni, Korra
	Little Millet	*Panicum sumatrense*	Kutki, Samai
	Kodo Millet	*Paspalum scrobiculatum*	Kodra, Arikelu
	Proso Millet	*Panicum miliaceum*	Cheena, Barri
	Barnyard Millet	*Echinochloa frumentacea*	Sanwa, Oodalu
	Browntop Millet	*Brachiaria ramosa*	Korale, Hari Kangni, Andukorralu

(Singh *et al*., 2024)

3. **Improved Varieties and Hybrids** - Adoption of improved varieties and hybrids have significantly enhanced the productivity, resilience, and profitability of millet cultivation.

Table 3: Recommended Varieties/hybrids of Major and Minor Millet Crops in India

S.No	Crop	Varieties
1	Kharif Sorghum	CSH 45, CSH 30, CSH 25, CSH 27, CSH 18, CSV 23, CSV 20, CSV 17, CSH 10, CSH 5, CSV 1, CSV 9, CSH 16
	Rabi Sorghum	CSR-Sor-21, CSR-Sor-17, CSR-Sor-16 for Grain Yield and CRS-Sor-24, CRS-Sor-23 &CRS-Sor-21 for stover yield
2	Pearl millet	Dhanashakti, Chakti*, HHB 299, AHB 1200Fe, ABH 1269Fe, ABV 4, Phule Mahashakti, RHB 223, RHB 234, HHB 311, HHB 67 Improved 2, VR 929
3	Finger millet	VR 929, VL 376, VL 379, CFMV 1, Indravathi, CFMV 2, GPU 28, GPU 66, GPU 67
4	Foxtail millet	SiA 3156, SiA3088, SiA 3085, SiA2644, SiA 2593
5	Barnyard millet	DHBM 93-3, DHBM 23-3, CO 1, CO 2, VL 181, VL 29
6	Little Millet	CLMV 1, Sree Neelima, OLM 203, OLM 217, CO 4, DHLM 36-3, JK 8, LMV518
7	Proso millet	PR 18, TNAU 202, TNAU 145, GPUP 21, Bhawna, TNAU 164, TNAU 151, Sagar, Nagarjuna, CO 4, CO 3, ATL 1(TNPm230), GPUP 25
8	Kodo millet	GPUK 3, TNAU 86, RK 390-25, JK 41, RBK 155, ATL-2, BK-36

(Source: Swarna *et al*. 2023)

These improved genotypes are developed through systematic breeding programs aimed at higher yield potential, drought tolerance, pest and disease resistance, and better grain quality. A list of some promising cultivars for different millets in India is furnished.

4. Crop Production Technologies

i. Land Preparation - Proper land preparation is a crucial step in millet cultivation as it ensures good seedbed conditions for germination, root development, and moisture conservation. Millets can be grown in a wide range of soils, but well-drained loamy or sandy loam soils with good tilth are ideal. The field should be ploughed two to three times using a country plough or tractor to achieve fine tilth and remove weeds. In dryland areas, off-season ploughing helps in moisture conservation and reduces weed infestation. Land levelling facilitates uniform distribution of rainwater and minimizes soil erosion. In regions receiving assured rainfall or irrigation, forming broad-bed and furrows (BBF) or ridges and furrows helps in efficient water management and aeration. Incorporation of organic matter or farmyard manure (5–10 tonnes/ha) during the final ploughing improves soil fertility and microbial activity. Well- prepared land thus supports uniform crop stand, better nutrient uptake, and higher millet productivity.

ii. Sowing Time: The time of sowing is a critical factor influencing the growth, yield, and quality of millets. It largely depends on the type of millet, regional climate, and rainfall pattern. Generally, millets are sown during kharif, rabi and summer season. Kharif crops are sown at the onset of the monsoon, from June to July, under rainfed conditions. Rabi crop is sown during September or October and summer crop is sown during January to February. Timely sowing ensures effective utilization of soil moisture, better seed germination, and reduced pest and disease incidence. Delayed sowing often leads to poor stand establishment and reduced yields due to moisture stress or terminal drought.

iii. Seed Rate & Spacing: The seed rate and spacing in millet cultivation vary depending on the crop species, soil type, and moisture availability, as they influence plant population, resource use efficiency, and yield. For major millets like sorghum and pearl millet, the optimum spacing ranges from 45–60 cm between rows and 10–15 cm between plants to ensure adequate aeration, light interception, and root growth. While for finger millet and other small millets, the recommended spacing is 22.5 – 30 cm × 10 cm. Wider spacing may be adopted in low-rainfall areas to conserve soil moisture, whereas closer spacing suits fertile or irrigated conditions for maximizing yield potential. Maintaining proper seed rate and spacing ensures uniform crop stand, efficient use of nutrients and moisture, and better weed management.

Table 4: Optimum seed rate of millet crops

S.No	Crop	Method of sowing	Seed Rate
1.	Sorghum	Broadcasting	10 kg ha^{-1}
		Line Sowing	7 – 8 kg ha^{-1}
2.	Pearl Millet	Line Sowing	4 – 5 kg ha^{-1}
		Transplanting	2 kg ha^{-1}
3.	Finger millet	Line Sowing	5 – 6 kg ha^{-1}
		Transplanting	4 kg ha^{-1}
4.	Small millets	Broadcasting	8 – 10 kg ha^{-1}
		Line Sowing	5 – 6 kg ha^{-1}

(Source: Bhat *et al.*, 2019)

iv. Seed Treatment - Seed treatment is an essential pre-sowing practice in millet cultivation to ensure healthy crop establishment and protection from seed-borne diseases and pests. Treating seeds with fungicides such as Carbendazim or Thiram at 2–3 g per kg of seed helps prevent fungal infections like smut, downy mildew, and seed rot. In pest-prone areas, treating seeds with a suitable insecticide can protect seedlings from early-stage damage. Additionally, bio-inoculants such as *Azospirillum* and *Phosphobacteria* (25 g per kg of seed) are recommended to enhance root growth, nitrogen fixation, and nutrient uptake. For improving drought tolerance and germination, seed priming with a 1% potassium nitrate (KNO_3) solution for 6–8 hours followed by shade drying can be beneficial. Proper seed treatment not only ensures better germination and seedling vigour but also enhances crop resilience, resulting in improved growth and higher millet productivity.

v. Nutrient Management - Effective nutrient management is vital for achieving good growth and higher yields in millets, especially since they are often cultivated on marginal and low-fertility soils. Incorporating organic manure or farmyard manure (5–10 tonnes/ha) during land preparation improves soil structure,

microbial activity, and nutrient availability. A balanced application of nitrogen (N), phosphorus (P), and potassium (K) is essential. Generally, a dose of 80–40 kg N, 20–30 kg P_2O_5, and 20–30 kg K_2O per hectare is recommended, depending on the crop and soil fertility. A list of recommended dose of fertilizers is given in table 5. Half of the nitrogen and the full dose of phosphorus and potassium should be applied as a basal dose at sowing, and the remaining nitrogen top-dressed at 30–35 days after sowing. In rainfed areas, integrated nutrient management through organic manures, compost, green manuring, and biofertilizers like *Azospirillum* and *Phosphobacteria* enhances nutrient use efficiency and sustains soil health. Micronutrients such as zinc and iron may be supplemented based on soil test results. Balanced and timely nutrient application ensures robust crop growth, better grain filling, and improved quality of millet produce.

Table 5: Recommended dose of fertilizers for major and minor millets.

S.No	Crop	Season	Dose (kg N P K ha^{-1})
1.	Sorghum	*Kharif* Sorghum	80: 40: 40
		Rabi Rainfed	60: 30: 00
		Rabi Irrigated	80: 40: 40
2.	Pearl Millet	Arid Regions	40: 20: 00
		Semi arid regions	60: 20: 00
3.	Finger millet	Irrigated	60: 30: 30
		Rainfed	40: 20: 20
4.	Small millets	Irrigated	40: 20: 00
		Rainfed	20: 20: 00

(Source: Bhat *et al*., 2019)

vi. Water Management

Millets are renowned for their exceptional drought tolerance and ability to thrive under limited water conditions, making them ideal crops for rainfed and dryland ecosystems. However, scientific water management practices can significantly enhance their productivity and water use efficiency. Millets generally require 250–500 mm of rainfall during their growth period, depending on the species and soil type. Proper land levelling and contour bunding help conserve soil moisture, while timely sowing with the onset of monsoon ensures optimal use of available rainfall. In areas with limited irrigation, critical stages such as flowering and grain filling should be prioritized for supplemental irrigation to minimize yield loss. Adoption of micro-irrigation systems like drip and sprinkler irrigation not only saves water but also ensures uniform moisture distribution. Mulching and conservation tillage further aid in reducing evaporation losses and maintaining soil moisture. Thus, efficient water management is crucial for sustaining millet production, particularly under changing climatic conditions and increasing water scarcity.

vii. Weed Management

Weeds compete with the millet crops for moisture, nutrients, light, and space especially during the early growth stages. Millets have a slow initial growth rate, which allows weeds to establish quickly and reduce yield potential. Effective weed control begins with proper land preparation and the use of clean, weed-free seeds. Timely intercultivation and hand weeding, typically at 20–25 days after sowing and again at 40–45 days, help suppress weed growth. Mulching and maintaining optimum crop stand density also minimize weed emergence. In larger areas, pre-emergence herbicides such as atrazine (0.5–0.75 kg a.i./ha) can be applied immediately after sowing to control annual grasses and broadleaf weeds. Integrating mechanical, cultural, and chemical methods ensures sustainable weed management, conserving soil moisture and nutrients for the millet crop while reducing labour requirements and enhancing productivity.

Table 6: Herbicides recommended for weed management in millet crops

Millets	Herbicides/ Integrated weed management practices	Dose of herbicide (kg/ha)	Time of herbicide application
Sorghum	Atrazine	0.75-1.0	PE/early POE
	Pendimethalin	0.75-1.0	PE
	Alachlor	1.5-2.0	PE
	Metolachlor	1.0-1.5	PE
	2,4-D	0.50-0.75	POE
	Atrazine + pendimethalin	0.75+0.75	PE
	Atrazine +alachlor	0.75+0.75	PE
	Atrazine + metolachlor	0.75+0.75	PE
Pearl millet	Atrazine +HW	0.5	PE/early POE
	2,4-D	0.50-0.75	POE
	Pendimethalin	1.0	PE
	Oxadiazone	1.0	PE
Finger millet	Isoproturon (Rainfed areas)	0.5 kg/ha	PE
	Oxyflurofen (Irrigated areas)	0.1 kg/ha	PE
	Oxyflourfen *fb* hand weeding at 20 DAS	0.25 kg/ha	PE
	Oxadiargyl *fb* Intercultivation at 20 DAT	100 g/ha	PE
	Isoproturon	0.50-0.75 kg/ha	PE
	Butachlor	0.75 kg/ha	PE
Foxtail millet	Isoproturon	1.0 kg/ha	PE
Kodo millet	Two hand weeding at 20 and 35 DAS	-	-
	Isoproturon	0.5 kg/ha	PE
	Isoproturon *fb* intercultivation at 20 DAS *fb* hand weeding at 40 DAS	0.5 kg/ha	PE
Little millet	Isoproturon	1.0 kg/ha	PE
Proso millet	Isoproturon	0.5 kg/ha	PE
	Atrazine	0.28-0.56 kg/ha	PE
Barnyard millet	Isoproturon	1.0 kg/ha	PE

Note: DAS: Days after sowing, DAT: Days after transplanting, fb: followed by, PE: Pre-emergence, PoE: Post-emergence

viii. Pest and Disease Management

Effective pest and disease management is essential for achieving stable and high yields in millet crops. Millets are generally hardy and less prone to major pest and disease outbreaks compared to other cereals, yet certain pests and pathogens can cause significant yield losses under favourable conditions. Common insect pests include the shoot fly (*Atherigona spp.*), stem borer (*Chilo partellus*), armyworm (*Spodoptera litura*), and aphids, which damage seedlings, stems, and panicles. Cultural practices such as

timely sowing, crop rotation, and destruction of crop residues help break pest life cycles. Use of resistant varieties and seed treatment with recommended insecticides or bioagents can minimize early pest incidence.

Among diseases, blast (*Pyricularia grisea*), downy mildew (*Sclerospora graminicola*), smut, and ergot are the most prevalent. Seed treatment with fungicides such as thiram or carbendazim (2.5 g/kg seed) prevents seed-borne infections, while crop rotation and removal of infected plant debris reduce disease carryover. Foliar application of suitable fungicides or biocontrol agents at the early stage of infection effectively controls disease spread. Integrated Pest and Disease Management (IPDM) practices like combining resistant varieties, biological control, and need-based chemical applications.

For need-based chemical control of insect pests, application of chlorantraniliprole 18.5 SC (0.3 ml L^{-1} of water) or imidacloprid 17.8 SL (0.3 ml L^{-1}) is effective against shoot fly, stem borer, and aphids. For disease management, mancozeb 75 WP (2.5 g L^{-1}) or carbendazim 50 WP (1 g L^{-1}) can be sprayed at the early onset of disease symptoms to control blast, downy mildew, and other fungal diseases.

ix. Harvesting and Threshing

Harvesting of millet crops should be done at the proper stage of maturity to ensure good grain quality and minimize shattering and post-harvest losses. The crop is ready for harvest when the leaves and stems start drying, and the ear heads or panicles turn hard and attain their characteristic colour. In small-scale cultivation, millets are usually harvested manually by cutting the ear heads or the entire plants with sickles, while in large-scale operations, mechanical harvesters are used for efficiency.

After harvesting, the ear heads are sun-dried for a few days to reduce moisture content before threshing. Threshing can be carried out by beating dried ear heads with sticks, trampling under cattle feet, or using mechanical threshers. The threshed grains are cleaned, further dried to a safe moisture level (around 10–12%), and stored in well-ventilated, pest-proof containers or structures. Proper harvesting and threshing practices not only ensure better grain recovery and quality but also contribute to longer storage life and reduced post-harvest losses in millet production.

x. Yield

The yield of millet crops varies widely depending on the species, variety, soil fertility, rainfall pattern, and management practices adopted. Under rainfed conditions, traditional varieties generally produce 1.0–1.5 tonnes per hectare, whereas improved high-yielding varieties and hybrids grown with good agronomic management can yield 2.5–3.5 tonnes per hectare (Yadav *et al*., 2011). In irrigated and well-managed conditions, crops like pearl millet and finger millet can even yield up to 4–5 tonnes per hectare (Reddy *et al*., 2008). Adoption of improved crop production technologies such as timely sowing, balanced nutrient management, effective weed and pest control, and supplemental irrigation at critical stages—can significantly enhance productivity. Moreover, use of quality seeds and modern practices like precision farming and micro-irrigation further improve yield stability and resource use efficiency (Seetharam *et al*., 2017).

Table 7: Yield Potential of Millet Crops under Different Production Conditions

Crop	Traditional Varieties (t/ha)	Improved Varieties / Hybrids (t/ha)	Potential Yield under Irrigated / Well-managed Conditions (t/ha)
Pearl Millet	1.0 – 1.5	2.5 – 3.5	4.0 – 5.0
Finger Millet	1.2 – 1.8	2.5 – 3.5	4.0 – 5.0
Foxtail Millet	1.0 – 1.5	2.0 – 2.8	3.0 – 3.5
Little Millet	0.8 – 1.2	1.5 – 2.0	2.5 – 3.0
Proso Millet	0.8 – 1.2	1.8 – 2.5	2.5 – 3.0
Barnyard Millet	0.8 – 1.5	1.8 – 2.5	3.0 – 3.5
Kodo Millet	0.7 – 1.2	1.5 – 2.0	2.5 – 3.0
Sorghum	1.5 – 2.0	3.0 – 4.5	5.0 – 6.0

(Source: Seetharam *et al*., 1986; 2017; Rao *et al*., 2010; Yadav *et al*., 2011b and ICAR-IIMR, 2023-24)

Conclusion

Millets play a crucial role in ensuring food and nutritional security, particularly in arid and semi-arid regions. Their resilience to drought, low input requirements, and adaptability to diverse agro-climatic conditions make them ideal crops for sustainable agriculture under changing climate scenarios. Adoption of improved crop production technologies including scientific land preparation, timely sowing, efficient nutrient and water management, and integrated pest, disease, and weed management enhance their productivity and profitability. Post-harvest handling and value addition further increase their economic and nutritional value, creating new avenues for rural livelihoods and agri-based industries. Overall, promoting millet cultivation with modern technologies and market linkages can contribute significantly to resilient farming systems and enhanced farmer income.

3.3. Pulses: Red gram, Green gram, Black gram and Bengal gram

Pulses play an important role in Indian farming and diet. They provide 18–25% plant-based protein and supply essential nutrients like amino acids, vitamins, and minerals, which are especially important for vegetarians. As legume crops, they fix nitrogen in the soil, improve its fertility, and reduce the need for chemical fertilizers. India produces and consumes more pulses than any other country, growing crops like pigeonpea, chickpea, mungbean, and urdbean in different regions, mostly under rainfed conditions. Farmers grow pulses successfully in dry areas and poor soils, and they easily fit them into crop rotations, which helps maintain steady incomes. Pulses grow quickly and often use leftover soil moisture, making them efficient in resource use and resilient to climate changes. In 2023–24, farmers cultivated pulses on about 27.5 million hectares, produced 24.25 million tonnes, and achieved an average yield of 880 kg per hectare. They increased production over the last 10 years, but it still falls short of the country's demand, leading India to import about 2.6 million tonnes each year (DAC&FW, 2024).

1. Pigeonpea (Arhar / Tur)

Pigeonpea (*Cajanus cajan*): Pigeonpea is also called redgram, tur, or arhar and is grown in states like Maharashtra, Karnataka, Uttar Pradesh, Madhya Pradesh, Telangana, Andhra Pradesh, Jharkhand, Gujarat, Odisha, and Tamil Nadu. This crop contains 20–22% protein and grows well even in drought conditions (Singh & Kumar, 2018). People use it mainly as dal in daily diets, while farmers also use its plants as animal fodder and firewood. Farmers cultivate pigeonpea mostly in rainfed tropical and subtropical areas, and it contributes about 15–20% of India's total pulse production (ICAR-IIPR, 2022). As India's demand for pulses is expected to reach 32 million tonnes by 2030, farmers can help reduce imports and improve incomes by increasing pigeonpea yield through better seeds, improved farming practices, and effective pest and disease management (FAO, 2021).

i. **Crop cultivation:** Pigeonpea is grown mainly in the Kharif season from May to July in South India and May to June in North India (DAC&FW, 2024).
ii. **Varieties for cultivation**: In pigeonpea, mainly three types of varieties are grown—early duration (150 days), medium duration (165 days), and long duration (180–210 days). Early and medium duration types cover more than 94% of the total pigeonpea cultivated, while long duration varieties are grown in North Eastern and Plain Zones for vegetable purposes. The list of varieties released for cultivation in different states is attached in Annexure–II (ICAR-IIPR, 2022).
iii. **Land preparation:** Pigeonpea grows best in well-drained black soils, and red soils also suit the crop with good rainfall or timely irrigation. Farmers plough the field in summer with a mould board or disc plough to loosen the soil, then harrow or cultivate to break clods and level the land. Stubbles, weeds, and volunteer plants should be removed. In heavy black soils, deep summer ploughing helps expose pests and diseases to sunlight, reducing their incidence (Singh & Kumar, 2018).
iv. **Seed requirement:** Use certified, healthy seeds for good germination and uniform crop stand. For early varieties (90×20 cm), use 5 kg seed/acre; medium to long varieties (120×30 cm), 4 kg/acre; and long varieties (240×30 cm), 2–3 kg/acre (ICAR-IIPR, 2022).
v. **Seed treatment:** Treat seeds with carbendazim or thiophanate-methyl @ 2 g/kg or Trichoderma @ 5 g/kg to control wilt and collar rot. Then apply Rhizobium (5–10 g/kg) and PSB for better nitrogen fixation and phosphorus uptake. Shade-dry for 30 minutes before sowing (DAC&FW, 2024).
vi. **Fertilizer requirement**: Apply 5–10 t/ha farmyard manure or compost during final tillage to improve soil health. For sole-cropped pigeonpea, apply 20 kg N, 50 kg P_2O_5, and 20 kg K_2O/ha as basal dose at sowing. In phosphorus-deficient soils, use up to 60 kg P_2O_5/ha. Add 20 kg sulphur/ha and zinc sulphate @ 25 kg/ha every 2–3 years in deficient soils. Place fertilizers 5–7 cm below seeds. Adjust doses in intercropping based on the companion crop. Fertilizer recommendations in different states are enclosed in Annexure–I (ICAR-IIPR, 2022).
vii. **Insect pests and their management:**

a. **Pod borer (*Helicoverpa armigera*):** It is the most destructive pest of pigeonpea, feeding on flowers, buds, and developing seeds inside the pods, which causes heavy yield loss. The infestation is highest during flowering and pod formation stages (Sharma et al., 2019). To manage this pest, farmers should sow the crop on time, install pheromone traps (8 per acre) to minimize pest population, and release

the biocontrol agent *Trichogramma chilonis* at 50,000/ha every week. Spraying HaNPV @ 250 LE/ha is effective, while chemical insecticides should be applied only when needed. At the first sign of adults during flowering, spraying Profenofos 50 EC @ 1250 ml/ha in 500 liters of water per hectare is useful as it kills eggs and early larvae. When bigger larvae appear, insecticides like Emamectin benzoate 5 SG @ 220 g/ha, Indoxacarb 14.5 SC @ 500 ml/ha, Spinosad 45 SC @ 73 ml/ha, Chlorantraniliprole 18.5 SC @ 150 ml/ha, or Lambda-cyhalothrin 5 EC @ 300 ml/ha can be sprayed (ICAR-IIPR, 2020).

b. **Maruca pod borer (*Maruca vitrata*):** The larvae bore into flower buds and web flowers and pods together, reducing seed setting. Its management includes timely sowing, removal and destruction of infested flowers and pods, and conservation of natural enemies like *Campoletis chlorideae*. Spraying Spinosad (0.3 ml/litre) or Emamectin benzoate (0.4 g/litre) at early flowering stage controls the pest (Kumar et al., 2018)

c. **Plume moth (*Exelastis atomosa*):** The pest damages flowers and developing pods by internal feeding, which leads to seed shriveling. This pest can be controlled by spraying Quinalphos 25 EC @ 2.0 ml/litre or neem seed kernel extract (NSKE) 5% during the flowering stage for eco-friendly management (Reddy *et al.*, 2017).



d. **Pod fly (*Melanagromyza obtusa*):** The maggots feed inside developing seeds, resulting in shriveled grains and poor germination. Management includes early sowing, growing tolerant varieties, collection and destruction of infested pods after harvest, and spraying dimethoate 30 EC @ 2.0 ml/litre at 50% pod formation stage (ICRISAT, 2019).



e. **Aphids (*Aphis craccivora*):** This insect infest tender shoots, the undersides of leaves, and flower buds, causing curling and stunting of shoots. Their management involves release of natural predators such as ladybird beetles and lacewings, spraying neem oil 2% or NSKE 5%, and using imidacloprid 17.8 SL @ 0.5 ml/litre at early infestation if needed (Singh & Singh, 2021)



viii. Diseases and their management:

a. **Fusarium Wilt** (*Fusarium udum*): It is a soil-borne fungal disease that causes yellowing, wilting, and plant death at any growth stage. Splitting wilted plants shows red discoloration in the middle portion of roots and stem. Management includes using wilt-resistant varieties, crop rotation with non-host crops for 3–4 years, deep summer ploughing, seed treatment with *Trichoderma* @ 5 g/kg or carbendazim 50 WP @ 2 g/kg, and soil application of *Trichoderma* @ 1 kg/acre mixed with 100 kg FYM (Nene *et al.*, 1996)

b. **Sterility Mosaic Disease** (SMD): The disease is caused by *Pigeonpea sterility mosaic virus* (PPSMV) transmitted by the eriophyid mite (*Aceria cajani*), and it results in bushy, pale-green plants with no flowering. Management includes using resistant varieties such as BDN-2013, ICPL-15036, and Maruti, rouging of infected plants, and controlling mite vectors with dicofol 18.5 EC @ 2.5 ml/l or propargite 57 EC @ 2 ml/l (Reddy *et al.*, 2012).




c. **Phytophthora Blight** (*Phytophthora drechsleri* f.sp. *cajani*): It causes water-soaked lesions on leaves and purple blight on stems, followed by gall formation and premature wilting. Management practices include improving field drainage, avoiding high plant density, and spraying metalaxyl + mancozeb (0.3%) or cymoxanil + mancozeb (0.25%) at disease onset (Pande *et al.*, 2011).




d. **Alternaria Leaf Spot** (*Alternaria alternata*): It appears as small, irregular brown spots on leaves with concentric rings, causing defoliation under humid conditions. Management includes spraying carbendazim 50 WP @ 1 g/l, mancozeb 75 WP @ 3 g/l, chlorothalonil 75 WP @ 2 g/l, or hexaconazole 5 EC @ 1 ml/l at the first symptom appearance, followed by a second spray at 10–15 day intervals (ICRISAT, 2013)




e. **Cercospora Leaf Spot** (*Cercospora* spp.): It produces small, circular to irregular brown spots with grey centers on leaves, leading to premature leaf drop. Management includes crop rotation, removing infected debris, and using tolerant varieties. Fungicidal sprays with carbendazim, mancozeb, or chlorothalonil are recommended (Reddy & Sharma, 2015).




f. **Dry Root Rot** (*Macrophomina phaseolina*): This disease is a major problem in recent years, especially under high temperature and moisture stress. It causes root decay, hollow stems, and plant mortality. Management involves crop rotation with cereals, deep summer ploughing, application of *Trichoderma* @ 2.5 kg/ha mixed in FYM, and avoiding drought stress during crop maturation (Sharma *et al.*, 2010).

g. **Macrophomina Stem Blight**: It is also caused by *M. phaseolina*, produces yellowing and drooping of leaves, spindle-shaped lesions on stems, girdling at the plant base, and premature death. Management includes irrigation to reduce stress, crop rotation, conservation tillage, resistant varieties, and fungicidal sprays such as Carbendazim 12% + Mancozeb 63% WP @ 3 g/l (Pande *et al.*, 2011)

h. **Sclerotial Collar Rot (***Sclerotium rolfsii*): Disease affects seedlings to flowering plants, attacking the collar region above the soil. Infected tissue becomes soft and rotten, leading to plant collapse. White cottony mycelium and mustard seed–like sclerotia develop under humid conditions. Management includes seed treatment with *Trichoderma* or carbendazim, soil application of *Trichoderma* with FYM, and drenching with carbendazim or tebuconazole (0.1%) at early infection stages (Reddy *et al.*, 2012)




i. **Harvesting and yield**: Pigeonpea is harvested when 75–80% of pods turn brown and leaves shed to avoid shattering losses and ensure quality. Combine harvesters can be used for mechanical harvesting. Average yields range from 8–12 q/ha in rainfed areas and up to 15–20 q/ha under irrigated and improved management practices. Timely harvest ensures better grain quality and market value (FAO, 2022).

2. Mungbean (Greengram)

Greengram (Vigna radiata) is a short-duration pulse crop grows well in different climates. It contains 20–25% protein, vitamins, minerals, and amino acids, making it healthy and nutritious. Farmers grow it as both sole and intercrop. It fixes nitrogen and improves soil fertility.

India is the largest producer of greengram. Major states are Rajasthan, Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Telangana, Madhya Pradesh, and Uttar Pradesh. In 2022–23, it was cultivated on about 5.5 million hectares, producing 3.06 million tonnes with an average yield of 557 kg/ha.

The greengram and blackgram share common cultivation practices and varieties

3. Urdbean (Blackgram)

Blackgram (Vigna mungo), also called urad, is a major pulse crop in India. It has about 24% protein, minerals, and amino acids, making it healthy for a vegetarian diet. The crop fixes nitrogen, improves soil fertility, and helps the next crop.

Farmers mainly grow blackgram as a kharif crop under rainfed conditions, and as a rabi crop in southern and coastal regions. It is grown on about 3.13 million hectares, producing 1.83 million tonnes with an average yield of 585 kg/ha. Uttar Pradesh and Andhra Pradesh are the top producers, followed by Madhya Pradesh, Tamil Nadu, Maharashtra, and Rajasthan. Its short duration of 60–90 days, has ability to grow in poor soils and good demand make blackgram an important crop for small farmers, supporting food, nutrition, and income.

4. The greengram and blackgram share common cultivation practices and varieties are listed in Annexure – IV.

i. **Crop cultivation**: Greegram and blackgram cultivation is mainly done in kharif and rabi seasons in different states. In some states they are now being grown during spring/summer and paddy fallow areas. Sowing is mainly done during May to June in kharif, October in Rabi season and February to March in Spring/summer and paddy fallow areas (IIPR, 2020).

ii. **Land preparation**: Both the crops can be grown in all kinds of soils. They requires weed-free finely tilled field for good germination and healthy crop growth (Singh et al., 2016).

iii. **Seeds requirement**: Generally 5 kg of seed per acre is sufficient for line sowing, while broadcasting may require slightly more. Seeds should be bold, healthy, and certified. **Seed treatment:** Before sowing, seeds are treated with Carbendazim 50WP @ 2 g per kg of seed, followed by with Rhizobium culture 5g/kg seed and PSB (Phosphorus Solubalising Bacteria) culture 5g/kg to enhance nitrogen fixation and P uptake (Reddy, 2015).

iv. **Sowing:** Sowing is done using seed cum-fertilizer drills with spacing of 30cm x 10cm. In some cases sown as intercrop with pigeonpea.

v. **Fertilizer requirement**: Farmers should add 5–10 tonnes of farmyard manure or compost per hectare during the last tillage. Apply 8–10 kg nitrogen, 16–20 kg phosphorus (P_2O_5), and 8–10 kg potash (K_2O) per acre (equal to 20–25 kg N, 40–50 kg P_2O_5, and 20–25 kg K_2O per hectare) as a basal dose at sowing. In zinc-deficient soils, apply zinc sulphate ($ZnSO_4$) at 10 kg per hectare once every 2–3 years (Ali & Gupta, 2012).

vi. **Insect pests and their management:**

a. **Whitefly (*Bemisia tabaci*):** This insect transmits yellow mosaic virus and sucks sap from leaves, causing yellowing and stunted growth. Management includes use of resistant varieties, treating

seeds with imidacloprid 600FS (48%W/w) @ 5ml/kg seed and spraying insecticides like imidacloprid 17.8 SL (0.3 ml/l) or thiamethoxam 25 WG (0.25 g/l) (Nene et al., 1996).



b. Aphids (*Aphis craccivora*): The insects suck sap and transmit viral diseases. Control measures include removal of infested shoots, use of yellow sticky traps, and spraying systemic insecticides such as dimethoate 30 EC (1 ml/l) or acetamiprid 20 SP (0.25 g/l).



c. Thrips (*Thrips tabaci*): They feed on tender leaves and flowers, causing curling and distortion of the foliage. Management involves maintaining proper plant spacing, removing weeds, and spraying fipronil 5 SC (1 ml/l) or spinosad 45 SC (0.3 ml/l) if infestation is severe (ICAR-IIPR, 2021).

d. Pod borers (*Helicoverpa armigera* and *Maruca vitrata*): Damage flowers and developing pods, leading to direct yield loss. Management includes timely sowing, installation of pheromone traps (5/acre), release of Trichogramma chilonis (50,000/acre), and spraying indoxacarb 14.5 SC (0.5 ml/l), chlorantraniliprole 18.5 SC (0.3 ml/l), or spinetoram 11.7 SC (0.5 ml/l) starting from flowering stage (ICAR-IIPR, 2021).



vii. Diseases and their management:

a. Yellow Mosaic Disease (YMD): It is caused by Mungbean yellow mosaic virus and spread mainly by whitefly (Bemisia tabaci). It shows bright yellow patches on leaves, which later spread over the whole leaf. Infected leaves may curl, plants remain stunted, and pod setting reduces, causing heavy yield loss. Management includes, growing resistant varieties like IPM 02-3 and PM 5 and adjusting sowing time to avoid peak whitefly activity. Remove and destroy diseased plants. For whitefly control, spray imidacloprid 17.8 SL @ 0.3 ml/l or thiamethoxam 25 WG @ 0.25 g/l of water, and use yellow sticky traps (8 per acre) (Nene *et al.*, 1996; Varma & Malathi, 2003).

b. Leaf crinkling: The disease is caused by Mungbean yellow mosaic India virus and spread by whiteflies and thrips. Infected plants show small, distorted, and crinkled leaves with a rough, leathery surface. The leaves become dark green, plants remains stunted, flowering and pod setting are reduced. Management includes growing resistant varieties, removing infected plants and seed treatment with imidacloprid 600FS @ 5 ml/kg is useful. To control whiteflies and thrips, spray imidacloprid 17.8 SL @ 0.3 ml/litre or thiamethoxam 25 WG @ 0.25 g/litre of water and install yellow sticky traps (8–10 per acre) (Rao *et al.*, 2017).





c. Powdery mildew: It is, caused by Erysiphe polygoni, is common in dry and cool weather. It shows as white, powdery growth on both sides of leaves, stems, and pods. Infected leaves turn yellow, dry early, and reduce pod development. To control it, spray wettable sulphur 80 WP @ 2 g/litre of water or hexaconazole 5 EC @ 1 ml/litre at the first sign of the disease and repeat every 10–15 days if needed (Singh *et al.*, 2014).

d. Cercospora Leaf Spot (*Cercospora canescens and C. cruenta*): Diseased plants shows small brown spots on leaves, often with a yellow halo. Severe attack causes early leaf fall, reduces photosynthesis, and weakens the plants. Management involves, spraying of mancozeb 75 WP @ 2 g/litre or carbendazim 50 WP @ 1 g/litre, give 2–3 sprays at 10–15 day intervals from the first sign of the disease (Iqbal *et al.*, 2018)

e. Anthracnose *(Colletotrichum lindemuthianum*): Anthracnose attacks stems, petioles, and pods, causing dark, sunken spots that may girdle plant parts. Pods show black spots, and seeds become shriveled and discolored. The disease spreads mainly through infected seed. To manage it, treat seed with carbendazim or thiophanate methyl @ 2 g/kg before sowing. Spray mancozeb 75 WP @ 2 g/litre or carbendazim @ 1 g/litre at the early stage of infection to reduce disease severity (Kaur *et al.*, 2011).

f. Root Rot (*Macrophomina phaseolina*): This is a soil-borne disease that kills seedlings and causes root decay and stem shriveling, often leading to patches of dead plants. Leaves dry, roots become hollow and discolored, and nodulation is poor. The disease spreads more in high soil temperature and moisture stress. To manage it, rotate crops with non-hosts, treat seeds with Trichoderma harzianum @ 5 g/kg and soil application fortified with FYM @ 1kg in 100kg of FYM for one acre will reduce the disease (Bashyal *et al.*, 2020).

g. Bud necrosis: It is caused by Groundnut bud necrosis virus (GBNV) and spread mainly by thrips. Infected plants remain stunted, and young leaves show dark brown necrotic spots with curling. The growing buds dry up, and in severe cases, plants fail to flower and set pods, causing heavy yield loss. Management includes growing tolerant varieties, removing diseased plants. Seed treatment with imidacloprid 600FS @ 5 ml/kg before sowing is useful. Spraying imidacloprid 17.8 SL @ 0.3 ml/litre or thiamethoxam 25 WG @ 0.25 g/litre helps control thrips. Installing blue sticky traps (8–10 per acre) also reduces vector population (Reddy *et al.*, 2015).

vii. Harvesting and yield: Both greengram and blackgram are harvested when 80–85% of the pods turn black and dry. The dried plants are then threshed manually or using mechanical threshers, followed by cleaning and proper storage of seeds. Under good management practices, yields range from 8–10 quintals per hectare in rainfed conditions and 10–12 quintals per hectare in irrigated conditions (Ali & Gupta, 2012).

6. Chickpea (Bengalgram)

Bengalgram: It is one of the most important rabi season pulse crops in India rich in protein, carbohydrates, vitamins, and minerals, making it a key food in vegetarian diets (Ali & Kumar, 2005). The crop fixes nitrogen from the air, improves soil fertility, and reduces the need for chemical fertilizers, which supports sustainable farming (FAO, 2019). It grows well in well-drained loamy soils with moderate rainfall and cool, dry weather. Because of its wide adaptability, low input needs, and use in crop rotation, Bengalgram is ideal for rainfed areas (Singh et al., 2014). Farmers grow it both alone and as an intercrop, which provides income and improves soil health for the next crop. In India, farmers grow Bengalgram (chickpea) on about 10.91 million hectares, producing nearly 13.75 million tonnes in 2021–22 with an average yield of 1,260 kg/ha (DAC&FW, 2022). The main producing states are Madhya Pradesh, Rajasthan, Maharashtra, Gujarat, and Uttar Pradesh, which together contribute most of the country's output.

i. Crop cultivation: Cultivation of Bengal gram is done after the onset of the rabi season, preferably from first week of October to mid-November, depending on the region and soil moisture conditions (ICAR-IIPR, 2020).

ii. Land preparation: The field is ploughed once with a mouldboard plough or tractor plough, followed by 2–3 harrowings to break clods and achieve a fine tilth. In areas of heavy rains, providing good drainage is essential.

iii. Seeds requirement: Generally 25 kg of seed per acre for desi type and 40kg per acre for kabuli type is sufficient for line sowing in one acre. Varieties recommended are listed in Annexure – V.

iv. Seed treatment: Treat Bengalgram seeds with carbendazim @ 2 g/kg or Carboxin 37.5% + Thiram 37.5% DS @ 3g/kg or Prochloraz 5.7% + Tebuconazole 1.4% @ 0.3ml/kg seed or Carbendazim 25% + Mancozeb 50% @ 3g/kg seed or Trichoderma spp @ 5g/kg seed to control collar rot, wilt, and seedling blight. After fungicide treatment, coat seeds with Rhizobium culture 5 g/kg and PSB culture 5 g/kg using a jaggery solution, then dry them in shade for 30 minutes before sowing (ICRISAT, 2012). In pest-prone areas, treat seeds with imidacloprid 48% FS @ 5 ml/kg to protect seedlings from early pests like aphids and thrips.

v. **Sowing:** Seeds should be sown at a depth of 5–8 cm using a seed drill at a spacing of 30–45 cm between rows and 10–15 cm between plants.

vi. **Fertilizer requirement:** Bengalgram needs less fertilizer because it fixes nitrogen from the air. At sowing, apply 20–25 kg nitrogen, 40–60 kg phosphorus (P_2O_5), and 20 kg potash (K_2O) per hectare as a basal dose (Singh & Saxena, 2016). In sulphur & zinc deficient soils, apply 20 kg sulphur and 5–10 kg zinc sulphate per hectare. Place all fertilizers 5–7 cm deep and away from the seed to avoid seed injury.

vii. **Insect pests and their management:**

a. **Pod Borer** (*Helicoverpa armigera*): Caterpillars bore into buds, flowers and pods of Bengalgram, feed on seeds, and cause heavy yield loss. To manage this insect, do deep summer ploughing to kill pupae. Use pheromone traps @ 8 per acre for mass trapping. Spray HaNPV @ 250 LE/ha or Bacillus thuringiensis at early larval stage. As first spray, use Profenofos 50% EC @ 3 ml/litre to kill eggs and young larvae. When pest reaches ETL, spray chlorantraniliprole 0.3 ml/litre or emamectin benzoate 0.4 g/litre for best control (ICAR-IIPR, 2022).

b. **Cutworms** (*Agrotis ipsilon*): Larvae cut young seedlings at ground level, causing patchy gaps in the field. Deep ploughing in summer helps destroying resting stages of the insect. Destroying crop residues, application of neem cake @ 250 kg/ha, spraying chlorpyriphos 2.5 ml/litre or lambda-cyhalothrin 0.5 ml/litre are best to control the insect (Ali et al., 2019).

c. **Leaf Miner** (*Aproaerema modicella*): Larvae mine into leaves, creating irregular whitish patches, reducing photosynthesis and plant vigor. Timely sowing; destruction of infested leaves; spraying neem oil 3% or chemical insecticides like quinalphos 2 ml/liter when infestation crosses ETL (Sharma et al., 2020).

viii. Diseases and their management:

a. **Fusarium Wilt** (*Fusarium oxysporum* f. sp. *ciceri*): Fusarium wilt is one of the most destructive soil-borne diseases of Bengalgram, causing yellowing, drooping of leaves, and eventual death of plants, often in patches. When roots of infested plants are split opened, red discoloration can be seen in the center. Management includes using wilt-resistant varieties such as JG 315, JG 74, and WR 315, treating seed with carbendazim @ 2 g/kg seed or Trichoderma 5g/kg and soil application @ 1kg fortified with 100kg FYM per acre, following a 3–4 year crop rotation with non-host crops and avoiding continuous chickpea cultivation in the same field (Nene et al., 2012).

b. **Ascochyta Blight** (*Ascochyta rabiei*): This fungal disease is favored by cool and humid weather. Symptoms include small circular brown spots with dark margins on leaves, stems, and pods, which later enlarge and cause blighting. Management involves using resistant varieties like ICCV 10 and ICCV 96029, treating seed with thiram or carbendazim @ 2 g/kg seed, avoiding early sowing in high-risk areas and spraying fungicides like chlorothalonil (0.2%) or mancozeb (0.25%) at 10–15 day intervals after the first symptoms appear (Pande *et a*l., 2005).

c. **Botrytis Gray Mold** (*Botrytis cinerea*): Botrytis gray mold mainly occurs in late-sown crops during prolonged cool and wet weather. Symptoms include water-soaked lesions on leaves, stems, and flowers, followed by gray fungal growth, leading to rotting of flowers and pods. It causes severe yield reduction, especially in dense crops. Management includes avoiding late sowing, ensuring wider spacing for good aeration. Spraying Iprodione 50WP @ 2.0g/l or Carbendazim 50WP @ 1g/l or Tebuconazole 50%+Trifloxystrobin 25% @ 0.5g/l of water at flowering stage control the disease (Singh & Rathi, 2018).

d. **Collar Rot** (*Sclerotium rolfsii*): Collar rot in Bengalgram causes wilting and death of seedlings soon after germination. The collar and surround roots shows white fungal growth with small mustard-like sclerotia. The disease spreads fast in warm, moist soils. To manage it, do deep summer ploughing to expose sclerotia, treat seed with thiram @ 3 g/kg or Trichoderma @ 5 g/kg along with soil application @ 1kg/acre fortified with 100kg FYM. Avoid excess irrigation in early crop stages (Ghosh *et al*., 2013).

e. **Dry Root Rot** (*Rhizoctonia bataticola*): Dry root rot appears as sudden drying of plants, with dark lesions on roots and lower stems. The pith becomes shredded, and plants can be easily pulled out due to root decay. The pathogen survives in soil and crop residues. Management involves crop rotation, using healthy seed, seed treatment with carbendazim @ 2 g/kg, or thiram @ 3 g/kg or Trichoderma @ 5 g/kg along with soil application @ 1kg/acre fortified with 100kg FYM (Pande *et al*., 2010)

f. **Powdery Mildew** (*Erysiphe polygoni*): Powdery mildew occurs mainly in late crop stages, producing white powdery growth on leaves, stems, and pods, which later turn brown and necrotic. It is more severe under dry and warm conditions. Management includes growing resistant varieties and spraying sulfur dust @ 25 kg/ha or wettable sulfur 0.2% at the first sign of infection (ICAR-IIPR, 2022).

g. **Rust:** Chickpea rust is caused by the fungus *Uromyces ciceris-arietini*, is a serious foliar disease that affects leaves, stems, and pods, producing small orange to reddish-brown pustules. Management involves growing resistant varieties and spraying fungicides like hexaconazole 5% EC or propiconazole 25% EC at 1 ml/liter at the onset of symptoms, with two subsequent sprays at 15–20 day intervals (Nene & Reddy, 1987).

ix. **Harvesting and yield**: Chickpea is ready to harvest 90–120 days after sowing when most pods turn brown and plants start drying, when about 90% of pods are mature to avoid seed loss. Harvested plants are dried in the field or under shade before threshing to separate seeds. In rainfed conditions, chickpea yields 1,200–1,500 kg/ha, and higher yields are possible with irrigation and good management (FAO, 2021).

Annexure I: Fertilizer recommended for pigeonpea across different states

State	Nitrogen (N) kg/ha	Phosphorus (P_2O_5) kg/ha	Potassium (K_2O) kg/ha	Sulphur (S) kg/ha	Zinc Sulphate ($ZnSO_4 \cdot 7H_2O$) kg/ha
Andhra Pradesh	20	50	20	20	25
Telangana	20	50	20	20	25
Karnataka	20	50	20	20	25
Maharashtra	20	50	20	20	25
Madhya Pradesh	20	50	20	20	25
Uttar Pradesh	20	40	20	20	25
Gujarat	20	40	20	20	25
Bihar	20	40	20	20	25
Jharkhand	20	40	20	20	25
Odisha	20	40	20	20	25

Annexure II: Pigeonpea varieties released for cultivation in different states

State	Varieties
Karnataka	TS-3R, BRG-4, BRG-5. GRG 811, BRG-3, GRG 152, RVSA-16-1, BRG 3, GRG 152
Madhya Pradesh	ICPH 2671, Pusa Jawahar 21-29, Pusa Jawahar 21-01, Pusa Jawahar 21-02
Maharashtra	PKV, Tara, BDN 711, Phule Rajeshwari, BDN 716
Gujarat	AGT2, GJP-1, GNP-2, GT 103, GT 104, Gujarat Tur 105, GT 104, GNP-2 (BP-06-33), Gujarat Tur 105, Gujarat Tur 106, GT 109 (Shweta), Gujarat Tur 111, Gujarat Tur 110
Chattisgharh	Rajeev Lochan, Chattisghar Arhar-1, ChattisgarhArhar 1, C G Arhar 2,
Andhra Pradesh	WRG 65. LRG 52, WRGE 93, RVSA-16-1, Krishna, Tirupati Kandi, Krishna (LRG 105), Tirupati Kandi 59 (TRG 59)
Telangana	RGT-1, PRG 176, ICPH 2740, TDRG-4, WRGE 9, RVSA-16-1, Warangal Kandi-1, LRG 133-33, Warangal Kandi 1 (WRGE 97), WRG 255
Utter Pradesh	IPA 203, IPH 15-03, IPA 206, IPH 09-5, IPA 206
Punjab	PAU 881, AL 882, AL 882
Bihar	Rajendra Arhar-1, Pusa Arhar 151,
Tamil Nadau	CORG 8, CRG 2012-25, RVSA-16-1, CORG 8 (CO-8)
Delhi	Pusa Arhar 16, Pusa Arhar 16, Pusa 2018-2, Pusa Arhar Yamuna (PAHY 5)
Uttarakhand	Pant Arhar-6,

Annexure III: Centrally released Mungbean varieties for cultivation in different states

Sl.No	Zones	Varieties
1	SZ	IPM 02-14, DGGV-2, LGG 600, LGG 610
2	NEHZ	SML 1115, GM 6
3	NWPZ	MH 421, IPM 410-3 (Shikha), MH 1762
4	NEPZ	IPM 512-1 (Soorya), MH 1142, SML 2015, ML 1839, MH 1772
5	All zones	IPM 205-7
6	NHZ	Pusa 1371

Annexure IV: Mungbean varieties released by different states for cultivation

Sl.No	States	Varieties
1	Haryana	Basanti, MH 318
2	Chattisharh	Pairymung, TM 2000-2,
3	UP	KM 2195, KM 2328, Varsha (IPM 2K 14-9), Kanika (IPM 302-2), KM 2342, IPM 312-20, IPM 409-4 (Heera), HUM 27, PMS-12
4	Punjab	SML 832, ML 2056, SML 1827, ML1808
5	Karnataka	DGGV-2, Somnath, TRCRM-147
6	Kashmir	Shalimar Moong-2
7	Tamil Nadu	CO 8, VBN 4 (VGG 10-008), VBN 5, VBN 6,CO 9, VBN 7
8	Assam	SGC 16, sgc 16 (Rupohi), SGC 16 (Rupohi), SGC 20
9	MH	Utkarsh (KM 11-584), PM 707-5, Phule Suvarn
10	Telangana	Yadadri (WGG 42), Sri Rama (MGG 351), MGG 385,
11	Rajasthan	RMG 975,MSJ 118
12	Gujarat	GBM-1, GAM 5, Gujarat Mung-7, GAM 8 (Hara moti), GM 9, GJM 1701
13	Uttarkhand	Pant-Mung 8 (PM 09-6), Pant M 9
14	Delhi	Pusa 1431, Pusa 1641, PMS 8, PMD 9, PMD 10
15	Tripura	Tripura Mung 1 (TRCM 131)
16	J&K	Shalimar Moong-3
17	Andhra Pradesh	Lam Pesara 574, Lam Pesara 607, LGG 630
18	Odisha	OUAT Kalinga Greengram 1 (Shreejan)
19	West Bengal	Ankush

Annexure V: Urdbean varieties released by different states for cultivation

Sl.No	States	Varieties
1	Haryana	UH-1
2	Chattisharh	Indira Urd Pratham
3	UP	Vallabh Urd 1,
4	Punjab	Mash 1137, Mash 883,
5	Karnataka	DBGV-5, BDU-12, DBG -16, TRCRU-22
6	Tamil Nadu	VBN 6, MDU1, KKM-1, ADT 6, VBN 11 (VBG 12-062), CO 7, LBG 791, Black gram ADT 7 (AD) (TR) BG 14003, VBN 12
7	Assam	SBC 40 (Shyamal), SBC 47, SB 42-8,
8	MH	PDKV Blackgold(AKU 10-1), Phule Vasu (PU-0609-43), Phule Rajan (PU 0819-18)
9	Telangana	Mahira Miniumu-01 (MBG-1070)
10	Rajasthan	PratapUrd-1, KPU 524-65(Kota Urd 3)
11	Gujarat	JAU 4
12	Uttarkhand	Pant Urd 7,Pant U 8, Pant U 9, Pant Urd 11
13	Tripura	Tripura Maskalai (TRC Urd 99-2)
14	Andhra Pradesh	TBG 104 (Tirupati Minumu-1, GBG 1, Lam Minumu 884, LBG 904, TBG 129
15	Odisha	OBG 33,
16	Madhya Pradesh	IPU 11-02, IPU 13-1, IPU 10-26, IPU 17-1, TJU 339, TJU 130, Dristi (IPU 17-2), Narmada (IPU 19-10), IPU 13-6

17	Jharkand	Birsa Urd 2

Annexure VI: Centrally released Kabuli Chickpea variety

Sl. No	States	Varieties
1	Karanataka, Telangana, Andhra Pradesh, Tamil Nadu Orissa	MNK 1, NBeG 119, RLBGK 1, CSJK 174, Kota kabuli Chana 4, Raj Vijay Kabuli Gram
2	Hariyana, Punjab, Delhi. Rajsthan and Madhyapradesh	GLK 26155, GNG 1969, GLK 28127,Pusa 3022, Vallabh Kabuli Channa-1, JGK 6, RVKG 2020, Kota Kabuli Chana 2, Nandyal Gram 810, IPCK 13-163, GJGK 1617, L 558
3	Bihar, Uttara Pradesh	HK 05-169,
4	Uttarakhand, Assam	CSJK 6, Phule G 0027,

Annexure VII: Centrally released Desi Chickpea variety

Sl.No	Zones	Varieties
1	Karanataka, Telangana, Andhra Pradesh, Tamil Nadu Orissa	SA-1, NBeG 857, RG 2016-134, Kota Desi Chana 2, Nandyal Gram 1267
2	Hariyana, Punjab, Delhi. Rajsthan and Madhyapradesh	GNG 1958, GNG 2144,CSJ 515, GNG 2171, Pant Gram 5, BG 3043, Haryana Chana No 7, IPC MAS-1, , Pusa Chickpea 4005, GNG 2461, Pusa Chickpea Aswini
3	Bihar, Uttara Pradesh	GNG 2207, GNG 2299, PBG 9, Kundan, Swarna Lakshmi, Kota Desi Chana 3, Gujarat Gram 8, Pant Gram 10, Karan Chana 20, Raj Vijay Gram 2023
4	Madhya Pradesh, Maharashtra, Gujarat, Chattishgarh, Jharkhand,	JSC 55, JSC 56, Phule G 0405, IPC 2006-77, Pusa Parvati, Phule Vikram, Jawahar Gram 24, RVG 204,PDKV Kanak, Pusa Chickpea 20211, RG 2015-08, IPCMB 19-3, Pusa JG 16ADVIKA, Saatvik, Nandyal Gram 924
5	Uttarakhand, Assam, Nagaland	GJG 0809

3.4. Oilseeds: Groundnut, Sesamum, Safflower, Sunflower, Soybean and Castor

Groundnut

Groundnut **(*Arachis hypogaea* L.)** is one of the most important **oilseed crops** of tropical and subtropical regions. It is valued as a **source of edible oil (48–50%)**, **protein (25–30%)**, and **carbohydrates (20%)**.

It is a **leguminous crop**, capable of fixing atmospheric nitrogen through root nodules, improving soil fertility. Groundnut is consumed as grain, roasted nut, peanut butter, oil, and in confectionery products. **India** is the **second largest producer** of groundnut in the world (after China), contributing about **20–25% of global production**.

i. Importance of groundnut

- **Edible oil:** High-quality oil used for cooking and in food industries.
- **Food uses:** Roasted nuts, peanut butter, sweets, confectionery, and bakery products.
- **By-products: Oil cake:** Rich in protein and used as **cattle feed and organic manure**.
  Haulms: Nutritious fodder for livestock.
- **Soil health:** Improves soil fertility by **fixing 50–60 kg N/ha** through symbiosis.
- **Economic importance:** High export potential of kernels and value-added products.
- **Sustainability:** Suited to **rainfed dryland agriculture** and crop rotation systems.

ii. Recent trends in area, production & productivity in India:

- **Area:** 47.8 lakh ha
- **Production:** 10.30 million tonnes
- **Average productivity:** 1935 kg/ha
  (Source: DAC, Govt. of India, 2nd Advance Estimates, 2024–25)
- **Major states:** Gujarat, Andhra Pradesh, Tamil Nadu, Rajasthan, Karnataka, Telangana, Maharashtra.
- **Leading state:** Gujarat (40–45% of national production).

Management Practices:

Land preparation: 1 deep ploughing followed by 2-3 harrowings; fine tilth is needed.

iii. Sowing time and sowing method: In India, groundnut is mainly grown in during *Kharif* (June–July), *Rabi (*November–December) and summer: 15 thJanuary to 15 thFebruary

The groundnut is generally sown in flat beds. Some of the improved methods to get higher yield over the conventional method are given below: (See Figure 1 and Figure 2)

BBF method is useful in areas having deep vertisol with high rainfall. This system consists of raised beds of 1.2 m width and 15 cm height with two furrows of 30 cm width on either side. Each raised bed would accommodate four rows with 30 cm spacing between rows. On an average, 15% higher yield of groundnut has been reported from the medium black soil over the flat bed.	

Fig. 1: Broad-bed and furrow method (BBF)

Groundnut is generally sown on flat beds using a seed drill but sowing on either side of the ridge helps the plants to prevent from come in direct contact with the excess water. Furrows are more advantageous as they increase moisture recharge in the soil by collecting water and simultaneously help in draining away excess water.	

Source: ICAR-IIGR (2025)

Fig. 2: Ridge and furrow method

iv. Seed treatment

The seed must be tested for their germination and should be treated with tebuconazole 2 DS @ 1.5 g/kg or carbendazim @ 2 g/kg seeds to control seed borne diseases. The seed can also be treated with *Trichoderma harzianum* or *Trichoderma viride* @ 10 g/kg seed or it can be applied @ 10 kg/ha as soil application. To prevent the seed damage from soil insects at initial stages, depending upon per cent infestation spray Imidacloprid 17.8 SL @ 2 ml/kg seed or Imidacloprid 600 FS @ 1 ml/kg seed or chlorpyriphos 20EC @ 12.5 ml/kg. *Rhizobium* culture @ 6 g/kg (Treat the seeds in the order of fungicide, insecticide and rhizobium) chloropyriphos @ 12.5-25 ml/kg seed can be used. Spreading and semi-spreading types groundnut varieties have dormant seeds just after harvest which usually require a resting period of 60-70 days. Dormancy can be broken by exposing seeds to ethrel solution of 250 ppm. Bunch type varieties can be used immediately after harvesting for sowing. Thereafter, the kernels should also be treated with suitable Rhizobium and PSB cultures (6 g/kg).

v. Recommended varieties

Table 1: Recently released varieties for different states

State	Recommended groundnut varieties
Andhra Pradesh	Spanish: Kadiri-6, Narayani, Girnar-4, Vashishta, ICGV-91114, Kadiri-9, Harithandhra, Kadiri lepakshi, Dharani, Hima. Anantha, Dharani, TAG-24, Greeshma, Tirupati-4, Kadiri Amaravathi and Kadiri Chitrvathi. Virginia: Kadiri 7 bold
Gujarat	GJG-22, GJG-17, KDG-128, KDG-123, GG-34, GG HPS-2, GJG-32, GG-6, GG-7, GG-16, GG-20, TG-26, GJG-HPS-1, Prutha, JL-501, TG 37 A
Maharashtra	GJG-32, GJG-33, Groundnut Co7, Konkan Bhuratna, AK 335, Phule Unnati, KDG-128, KDG-123, Phule Bharti, TKG-19A, TLG-45, PhuleUnap, Ratneshswar, AK-265, AK-303, TAG-24
Tamil Nadu	GJG-32, GJG-33, VRI 8, Phule Chaitanya, Phule Dhani, BSR 2, KDG-128, KDG-123, ALG-06-320, TMV-13, VRI-6, VRI-7, AK-265, Ajeya, ICGV- 00348, ICGV-00350, Vijetha, GG-16
Telangana	Kadiri Lepakshi, Girnar-4, Vashishta, GJG-32, GJG-33, Phule Chaitanya, GJG-33, Kadiri Amaravati, Kadiri-5, Kadiri-6, KDG-128, KDG-123, Kadiri-8, Kadiri-9, Dharani, Kalahasti, Narayani, Prasuna, Abhaya, Greeshma, Vijetha, ICGV-00350
Karnataka	Dh-232, Dh-245, GJG-32, Phule Dhani, KDG-128, KDG-123, GKVK-5, G2- 52, AK-265, Ajeya, ICGV-00348, ICGV- 91114, VRI-6, VRI-7, GG-16, TGLPS-3, Vikas, Kadiri Haritandhra
Rajasthan	Raj Mungfali-3, KDG-128, KDG-123, HNG-10, HNG-69, HNG-123, GG-7, GG- 20, TBG-39, TG 37 A, TAG-24, Girnar-2, PM-1, PM-2, Pratap Rajmoongphali, Durga

vi. Seed rate

Kharif: 125-150 kg kernel/ha depending on kernel size.
Rabi: 150-180 kg kernel/ha depending on kernel size.

vii. Spacing

Spanish bunch, *Kharif*: 30 x 10cm. *Rabi:* 22.5 x 10cm
Virginia bunch, *Kharif* : 30 x 15cm., *Rabi:* 22.5 x 15cm

viii. Manure and fertilizers

Fertilizers are to be applied as per soil test based recommendations
RDF: In Andhra Pradesh Apply 20 kg N + 40 kg P_2O_5 + 50 kg K_2O/ha as basal for *kharif* and 20kg N+ 40kg P_2O_5+ 50 kg K_2O/ha as basal and 10kg N/ha at flowering for *rabi* crop.
Phosphorus should be applied through SSP.
Organics: FYM/Compost @ 10 t/ha once in 2 - 3 seasons.
For calcium: Apply gypsum @ 500 kg /ha at flowering stage by placement.
For zinc deficiency: Apply Zinc sulphate @ 50 kg/ha once in 3 seasons.
For iron deficiency: Spray 0.5% $FeSO_4$ with 0.1% citric acid at one-week interval.
For bio-fertilizers: Seed treatment @ 5-10g/kg and soil application of @ 600g/ha of *Rhizobium* and PSB each.

For intercropping: Use 100% N to groundnut and 50% N to any intercropped cereals
Recommended fertilizer dose for groundnut in major states (See Table 2)

Table 2: Recommended fertilizer dose for groundnut (RDF in major states)

State	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Gujarat	12	25	0
Andhra Pradesh	20	40	50
Tamil Nadu	17	34	54
Karnataka	25	50	25
Rajasthan	20	40	0

ix. Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) combines the use of chemical fertilizers, organic manures and biofertilizers to ensure soil fertility, crop productivity and sustainability. For Groundnut, application of 4t/ha FYM or 2t/ha of vermicompost or compost along with recommended NPK doses enhances soil health and nutrient use efficiency. Biofertilizers such as **Rhizobium + PSB** may be applied to improve nutrient availability. Incorporate crop residues or green manure for long-term soil health.

x. Weed management

Crop must be weed free up to 45 days after sowing.
Pre-emergence: Application of Pendimethalin @ 2.5 to 3L/ha or Oxyflourfen @ 1.5 to 2.0L/ha followed by one inter-cultivation and one hand weeding.
Post-emergence: Imazethaphyr @ 750 ml/ha or Quizalofop ethyl @ 1.0 L/ha at 20 DAS.

For intercropping system: Use Pendimethalin 30 EC@ 1.0 kg a.i./ha or Oxyfluorfen 23.5 EC@ 0.12 kg a.i./ha.as pre-emergence in groundnut + pigeonpea.

xi. Irrigation management

- Flowering, peg penetration and pod development are critical stages.
- Eight to nine irrigations at 10-day interval with last irrigation at 90-95 DAS are sufficient to supply about 400 to 450 mm water depth. Withheld irrigation for 25 days after crop establishment to boost synchronized flowering.
- About 24-30 % irrigation water can be saved due to use of sprinklers.

xii. Soil moisture conservation practices for rain fed crop:

Mulching of groundnut shells using 12.5 t/ha at 15-20 DAS to reduce evaporation losses of soil moisture. Spray $CaSO_4$ solution (50 g/l) to reduce transpiration losses. Spray urea solution (20 g/l) during dry spell period to recover the crop stress.

xiii. **Intercropping**

Groundnut + Redgram at 7:1 or 11:1 row ratio Groundnut Castor at 7:1 or 11:1 row ratio Groundnut + Bajra/Jowar in 6:2 ratio Groundnut mixed crop with cowpea, field bean, castor and red gram.

xiv. Diseases and insect pest management

Soil borne pathogens and pests

- Incorporate neem, castor or mustard cake @ 500 kg/ha, 15 days before sowing or in seed furrow at the time of sowing
- Incorporate carbofuran 3G @ 33 kg/ha or phorate 10G @ 10kg/ha at the time of land preparation (for nematodes)
- Soil application *T. viride or T. harzianum* @ 4 kg enriched in 250 kg FYM or 200kg castor cake
- Foliar diseases – leaf spots, rust and viral diseases
- Spray Tebuconazole @500 ml/ha or Hexaconazole @ 1000 ml/ha against foliar diseases Inter-crop with pearl millet (7:1), pigeon pea (7:1), sorghum/maize (7:1), castor (4:1) and cowpea/ soybean (4:1)
- Grow 4 rows of pearl millet or jowar as border crop and castor or soybean as trap crop (250 g seeds/ha)
- Remove *Parthenium hysterophorus* weed before flowering
- Destroy PBND infected plants

Defoliators

- Dig (1 feet) trench around field and dust with carbaryl 50 WP
- Spray of quinalphos 25EC @ 1000 ml/ha or chlorpyriphos 20EC @ 1250 ml/ha or profenofos 50EC @ 500 ml/ha, thiodicarb 75 WP @ 500 g/ha for Spodoptera or novaluron 10EC @ 500 ml/ha at 15 days interval
- Spray NPV-Spodoptera and NPV-Helicoverpa @ 500 LE/ha or *Bacillus thuringiensis* @ 1 kg/ha or Nomuraea rileyi @ 1 kg/ha or *Beauveria bassiana* @ 1 kg/ha along with surfactant during evening hours at 60-75 DAS
- Use poison bait (rice bran 12.5 kg + molasses/jaggery 2.5 kg +Chlorpyriphos 25 EC @ 1.25 l) to manage Spodoptera and hairy caterpillars

Sucking pests

- Release *Chilomenus exmaculata* @ 1250/ha twice against sucking pests
- Spray dimethoate 30 EC @ 1000 ml/ha or imidacloprid 17.8SL @ 150 ml/ha or acetamiprid 20SP @ 300 g/ha or monocrotophos 36 SL @ 800ml/ha at 25-35 days after sowing

xv. Crop duration

100-110 days for *kharif* and 110-120 days for *rabi* season groundnut.

xvi. Harvesting, drying and storage

As groundnut is an indeterminate crop, hence synchronous maturity of its pods cannot be obtained. Therefore, harvesting should be done when 75-80% of pods are fully mature. The important indications of maturity are yellowing of foliage, necrotic spotting of leaves, dropping of old leaves, pods become very hard and tough, they give cracking sound when split open with fingers, the inside of the shell turning dark, with netted venation, seed coat develops pink or red color (normal color of the varieties) and raising of the soil to the base of the stem is observed. Generally harvesting is done by pulling or lifting the plants from the soil with pods intact. If soil moisture is adequate, then hand pulling. If soil is dry, tractor or bullock drawn blades are used for lifting the vines with pods. Harvesting before maturity reduces yield and oil percentage and seeds

are highly susceptible to aflatoxin. If delayed, results in increased incidence of stem rot, weakening of gynophore/peduncle and some of the pods may remain in soil itself at the time of harvesting. Different maturity stages of groundnut.



Source: ICAR – IIGR (2025)

Fig: Differently maturity stages of groundnut

Storage at farmer level is invariably in the form of pods. Farmers usually dispose of groundnut pods within a month from drying yard itself. A few store it for 6 months (till *kharif* seeding) in anticipation of high price. Pods for seed purpose are stored for 7–8 months. Pods for seed purpose are stored in earthen pots, mud bins or bamboo baskets or Gunny bags having polythene lining.If the seed moisture content is above the critical level of 9-10%, then aflatoxin production due to *Aspergillus flavus* just before the post–harvest drying and mold growth at later stage takes place.

Yield: *Kharif*: 22-25 q/ha;

Rabi: 20-25 q/ha;

Processing to Consumer:

Harvested pods dried and threshed to extract kernels/seeds

↓

Cleaning & drying of seeds to 8–9% moisture

↓

Oil extraction in expellers/solvent plants

↓

Oil refining and packaging

↓

Transport & marketing to industries/export houses.

Sesamum

Sesamum (*Sesamum indicum* L.), is commonly known as gingelly, til and simsim. India stands first place in terms of area and production in the world with an area of 1.71 mha and production of 0.80 mt. It is mainly grown in Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, West Bengal, Andhra Pradesh, Telanagana, Karnataka, Maharashtra and Tamil Nadu. It is the most ancient oilseed known and used for multiple purposes. It is called as "Queen of oilseeds" because of its excellent qualities of the seed, oil and meal. Sesame seed is highly nutritive (oil 50%, protein 25%) and

Its oil contains an antioxidant called 'sesamol' which imparts a high degree of resistance against oxidative rancidity. Sesame cake is nutritious feed for dairy cattle and it can also be used as fertilizer. Sesame

seeds are digestive, rejuvenative, antiaging, and rich in vitamins E, A and B complex and minerals like calcium, phosphorus, iron, copper, magnesium, zinc, and potassium. This unique composition coupled with high-unsaturated fatty acid make the sesame nearly perfect food. Sesame is the most neglected oilseed crop grown on marginal lands under poor management resulting in low yield levels. Further, the low yield is due to the non-availability of cultivars to suit the diverse agro-climatic conditions.

i. Growing seasons:

Higher sesame yields can be realized by planting at appropriate time. Sesame is grown in all crop growing seasons viz., early *kharif, kharif*, late *kharif, rabi* and summer. For maximum yield realization, it requires fairly high temperatures of 25-35°C and evenly distributed rainfall during its growth period. Appropriate sowing times for different seasons are given in (table.3).

Table 3: Appropriate sowing time of sesame in India

Season	Sowing time	Harvesting time	Situation	Area (%)	States
Kharif (Rainy)	June-July	Sept-Oct	Rainfed	65-70	Rajasthan, UP, M.P., Gujarat
Late Kharif	Aug-Sep	Nov-Dec	Rainfed	7-8	A.P., Gujarat, M.P., M.H., T.G., Karnataka
Rabi (Winter)	Oct-Nov	Feb-Mar	Irrigated	3-5	Odisha, T.N., W.B., A.P.
Summer	Jan-Mar	April-June	Irrigated	15-20	W.B., A.P., Gujarat, T.N., Odisha, T.G.

Source: ICAR-IIOR (2017).

ii. **Recommended Varieties:** ***Kharif:*** GT-11, RT-351, RT-352

Summer: Tilhan Tec Til-1, YLM-11, Unnat Rama, VRI-4, Pragathi, Jagityal Til-1, Telangana Til-1, Suprava,

iii. **Soils:** Sesame can be grown on a wide variety of soils but well drained fertile light to medium textured soils with good depth are preferred. The optimum pH range is 5.5-8.0. Heavy water logged, acidic or alkaline, as well as soils with high salt contents are not suitable for sesame cultivation.

iv. **Land preparation:** Sesame requires well pulverized seedbed with fine tilth for good germination and establishment of desired plant stand. The soil gets fine tilth by ploughing the field 2-3 times followed by harrowing and planking. Keep the field weed free and well levelled to avoid water logging to which sesame is highly sensitive.

v. **Seed rate and sowing method:** For easy interculture and to realize higher seed yield, adopt line sowing. A seed rate of 4-5 kg/ha is adequate to achieve the required plant stand. Wherever seed drills are used, the seed rate may be reduced to 2.5 to 3 kg/ha. For even distribution of seed for sowing mix the seed with sand or dry soil or fine powdered FYM in 1:20 ratio. Use Desi plough or seed drill for line sowing. Optimum depth for seed placements is 2.5 cm with spacing of 30 x 10-15 cm. Avoid deep sowing as it adversely affects germination and plant stand.

vi. **Seed treatment:** For the prevention of seed borne diseases, treat the seed with Thiram 3 g/kg or Thiram (1.5 g) + Bavistin (1.5 g). Wherever bacterial leaf spot disease is a problem, soak the seed for 30 minutes in 0.025% solution of Agrimycin-100 prior to sowing.

vii. **Manures and fertilizers:** Apply well decomposed FYM 5-10 t/ha. Sesame responds well to inorganic fertilizers. T. Apply half the recommended dose of nitrogen and full dose of phosphorus and potash at the time of sowing. The remaining half nitrogen may be top dressed at flower initiation (30-35 days after sowing). The state wise fertilizer recommendations are given in (Table 4). However, application of fertilizers may be taken up as per the soil test based recommendations. In case of micronutrient deficiency, they may also apply as basal in soil or as foliar spray.

Table 4: Fertilizer recommendations in different sesame growing states

State/Situation	Recommended dose of N:P:K (kg/ha)	State/Situation	Recommended dose of N:P:K (kg/ha)
Rajasthan		West Bengal	
Heavy soils	40:20:0	Irrigated	50:25:25
Light soils	40:25:0	Rainfed	25:13:13

Gujarat Kharif Semi-rabi	 50:25:40 25:12.5:0	Tamil Nadu Irrigated Rainfed	 35:23:23 23:13:13
Madhya Pradesh Rainfed Summer	 40:30:20 60:40:20	Uttar Pradesh	20:10:00
Andhra Pradesh Telangana	40:40:20 30:30:20	Odisha Irrigated Rainfed	 40:20:20 30:15:15

ICAR-IIOR (2017).

viii. **Weeding and interculture:** Sesame is very sensitive to weed competition up to 40 days. Two weedings are required, one around 15-20 days and another at 30-35 days after sowing followed by bullock drawn blade harrow to keep the field weed free. Pre plant incorporation of fluchloralin @1.5 kg a.i./ha or pre emergence application of alachlor @ 1.5 kg a.i./ha is effective.

ix. **Irrigation:** The *kharif* crop may need protective irrigation(s) if there is moisture stress. Winter crop should be irrigated 2-3 times. The summer crop has to be irrigated 4-5 times depending on the type of soil. Water stress at critical stages like flowering or capsule formation lead to yield loss. Seed priming (soaking seed in water before sowing) during summer season or in places with moisture stress resulted in good crop establishment.

x. **Management of insect pests:** The major insect pests of sesame are leaf roller and capsule borer (*Antigastra*), gall/bud fly, leaf hopper and sphinx caterpillar.

- Collect and destroy leaf rolls, shoots, capsules infested by *Antigastra* and buds infested by gall/bud fly in the initial stages of pest attack.
- Erect bird perches (40-50 no/ha) to facilitate predation of larvae.
- Treat the seed with imidacloprid 70WS @ 7.5 g/kg or thiamethoxam 25WG @ 5 g/kg for management of sucking pests.
- Spray NSKE 5% or quinalphos 25 EC @2 ml/l or profenophos 50 EC @ 2 ml/l or spinosad 45 SC @ 0.2 ml/l against leaf roller and capsule borer and sphinx caterpillar.
- Spray dimethoate 30 EC @ 1.7 ml/l or imidacloprid 17.8 SL @0.3 ml/l or dichlorvos 76 EC @ 0.7 ml/l against gall/bud fly at bud initiation stage.
- Spray acetamiprid 20 SP @ 0.3 g/l or imidacloprid 17.8 SL @0.3 ml/l or dimethoate 30 EC @ 1.7 ml/l or oxydemeton-methyl @ 1.5 ml/l for management of leafhopper.

xi. **Management of diseases:** The major diseases of sesame are powdery mildew, phyllody, macrophomina root rot and bacterial blight.

- Summer deep ploughing, intercropping with beans 1:1 or 2:1 ratio
- Uproot and destroy the infected plants
- Seed treatment with *Trichoderma viride* or *T.harzianum* @4g/kg or thiram 75 SD (0.2%) + carbendazim (0.1%) @ 3 g/kg seed or thiram 75 SD @2g/kg seed.
- Apply farm yard manure at 10 t/ha. Drench the soil with carbendazim 1 g/l for macrophomina root rot at 7 days interval.
- Foliar spray of wettable sulphur 2 g/l or propiconazole 1 ml/l or karathane 1ml/l for powdery mildew disease alternatively at 10 days interval.
- Three sprays of neem oil 1 ml or dimethoate 30 EC 1.7 ml/l alternately at 30, 40 & 60 days after sowing for control the phyllody disease.

- Foliar spray of streptocyclin (500 ppm) + copper oxy chloride 2.5 ml/l against bacterial blight.

xii. **Harvesting and threshing:** The best time of harvesting is when leaves turn yellow and start dropping while the bottom capsules are lemon yellow. Do not allow the crop to dry completely in the field to avoid shattering of capsules.

xiii. **Yield potential:** Rainfed: 6-8q/ha, Irrigated: 10-12 q/ha

xiv. Tips to get higher Sesamum yields

1. Use good quality seed of recommended variety
2. Seed treatment with fungicide and bactericide

3. Select well levelled field with good drainage facility
4. Line sowing at appropriate time with proper spacing
5. Thinning at 15-20 DAS
6. Maintain weed free crop up to 40 days
7. Apply recommended dose of fertilizers at appropriate time based on soil test
8. Adopt need based plant protection measures
9. Irrigation at critical stages for rabi-summer crop
10. Harvest at physiological maturity stage to avoid shattering
11. Dry the seed before storage (moisture content 8-9%)

Safflower

Safflower (*Carthamus tinctorius* L.) commonly known as Kardi (Marathi), Kusube (Kannada), Kusum (Hindi) and Kusuma (Telugu) is one of the important rabi oilseed crops of the country. In 2024-25, safflower was grown on about 0.52 lakh hectares with a production of 0.43 lakh tonnes and average productivity around 843 kg/ha. It is mainly grown in Maharashtra, Karnataka, Gujarat, Andhra Pradesh, Madhya Pradesh and Telangana. The present productivity of 843 kg/ha is very low as compared to the demonstrated productivity of 1109 kg/ha (DAC & FW, 2025). Poor crop management under input starved conditions is the most important reason for such low productivity. However, concerted research efforts made under the All India Coordinated Research program AICRP on Safflower and ICAR-Indian Institute of Oilseeds Research (IIOR), Hyderabad have resulted in development of hybrids, improved varieties, production and protection techniques capable of boosting the productivity levels of safflower. The following are the improved production practices recommended for different safflower growing areas of the country.

i. Recommended cultivars: ISF-300, ISF-123, ISF-764, ISF-1, RVSAF-18-1, PBNS-184, Parbhani Suvarna (PBNS-154).

ii. Soils: Safflower requires moderate to high fertile, fairly deep, moisture retentive and well drained soils with neutral pH reaction. Heavy soils with poor drainage must be avoided for growing safflower especially under irrigated conditions. The crop is fairly tolerant to saline conditions.

iii. Seed bed preparation: In monocropped black soils of *rabi* areas, harrowing 3 to 4 times during the *kharif* season as effective as deep ploughing or sub soiling to keep weed free.

iv. Sowing time: The optimum time of sowing is second fortnight of September to second fortnight of October.

v. Seed rate and spacing: 3 to 4 kg/acre with a spacing of 45x20 cm

vi. Seed treatment: Before sowing, the seed should be treated with Thiram 3 g or Captan 2 g or Carbendazim 2 g/kg seed to protect from soil borne diseases.

viii. Thinning and Inter cultivation: Thin the excess seedlings within 15-20 days after emergence and maintain the desired plant to plant spacing. Give one or two hand weedings and hoeing/harrowing at 25 to 30 and 45 to 50 days after sowing depending on the length of rosette period and the severity of weed infestation

ix. Fertilizers: For adequate and balanced fertilization, incorporate 2 t/acre of well decomposed FYM/compost 2-3 weeks prior to sowing. It is desirable to apply fertilizer based on soil test values. The recommendation of inorganic fertilizer (kg/acre) for different states is given in Table 5

Table 5: Recommended inorganic fertilizer in Safflower

State	N (Nitrogen)		P_2O_5(Phosphorus)		K_2O (Potash)	
	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
Telangana/ Andhra Pradesh	16	-	10	-	0	-
Karnataka	14	30	20	30	10	14
W.Maharastra	20	-	10	-	0	-
Marthwada	16	24	08	16	0	0
Vidarbha	10	20	10	20	0	0
Source: ICAR-IIOR (2017)						

Dual inoculation of Azospirillum or Azatobactor (25g/kg seed) along with 50% of recommended N provide higher profits under rainfed conditions. 6-12 kg S/acre gives higher seed and oil yield in Sulphur deficient soils.

x. Water management: Give a light pre-sowing irrigation if the soil moisture in the seed zone is not adequate for germination. In soils that crack, apply irrigation well before cracks develop for better control of water. If there is provision for only one irrigation, provide it before soil moisture becomes very critical for crop growth.

xi. Intercropping systems: Some of the remunerative intercropping systems for rainfed situations are coriander +safflower (3:1) and chickpea + safflower (6:3) in Karnataka, Telangana, Andhra Pradesh and Maharashtra; linseed + safflower (3:1) in Maharashtra, Madhya Pradesh, Chattisgadh and eastern Uttar Pradesh.

xii. Management of Insect pests: The major insect pests of economic importance are aphids, leaf eating caterpillars in Karnataka and gujhia weevil in Akola region of Maharashtra.

Avoid late sowing and sow moderately aphid resistant varieties like A-1 or Bhima.

Spray NSKE 5% on border 2m as soon as incidence is noticed to reduce aphid spread. Spray insecticide like dimethoate 30EC @ 1000 ml/ha or acephate 75SP @ 750 g/ha or thiamethoxam 25WDG @ 100 g/ha or chlothianidin 50WDG @ 100 g/ha or acetamiprid 20SP @100g/ha two times.

For controlling safflower caterpillar, spray Indoxacarb 15 EC @ 150 ml/ha or Spinosad 45 SC @ 100 ml/ha as soon as larvae are noticed.

To reduce gujhia weevil damage, apply Phorate 10G to soil @ 10 kg/ha and foliar spray with chlorpyriphos 20EC @ 1000 ml/ha two to three times depending on level of infestation.

Management of diseases:

The major diseases of safflower are wilt, root rot and leaf spot.

Grow resistant/tolerant varieties like A-1, Phule Kusuma, SSF 708 in wilt endemic areas.

Treat the seed with carbendazim 50WP@ 1 to 2 g/kg or carboxin + thiram 75 WP @ 2 g/kg seed or Trichoderma harzianum @ 10g/kg seed.

Treat seeds with thiram or captan or cymoxanil + mancozeb 72.5 WP or carboxin + thiram 75 WP@2-3g/kg seed.

Spray mancozeb 75WP @ 2.5g/l or propiconazole 25EC 1ml/l or carbendazim + mancozeb 75WP @ 2-3g/l immediately after disease is noticed and repeat the spray 15 days later depending on the intensity of disease.

Treat seeds with carboxin + thiram 75WP@ 2 g/kg seed or cymoxanil + mancozeb 72WP @ 2-3g/kg seed, captan 75 WP 2g/kg seed or Trichoderma harzianum @ 10g/kg seed.

Bird damage: Safeguard the crop from bird damage during the period from seed filling to physiological maturity.

Harvesting and threshing: Harvest the crop preferably in the early hours. Cut plants with the help of sickles at the base or uproot (black soils) by pulling and stack them in the field in the form of small and well pressed heaps until they are fully dried. Thresh either by beating with sticks or with the help of bullock drawn stone rollers or tractor and the resulting material is winnowed to clean seeds. The threshing and

cleaning operation can also be done with power operated thresher used for other crops such as wheat. Combine harvesters used in wheat could also be used for harvesting and threshing of safflower.

Yield potential: The seed yield potential ranges from about 320 to 480 kg/acre under scanty moisture conditions and about 600 to 800 kg/acre under favourable moisture conditions. Under minimal irrigation, yield levels of 800 to 1120 kg/acre could be achieved. In addition to seed yield, (800-1000 kg/acre) under well managed conditions the non-spiny safflower cultivars are expected to yield 30-40 kg/acre petals. Presently, the petals are being sold at Pune, Phaltan and Tandur @ Rs. 800-1000/kg. Manual petal collection costs around Rs. 500-600/kg petals.

Sunflower

Sunflower (*Helianthus annuus L.*) is an important oilseed crop valued for its attractive bright yellow flowers and nutrient-rich seeds. It is a hardy, short-duration crop that adapts well to a wide range of agro-climatic conditions, especially warm and semi-arid regions. Sunflower seeds are a major source of high-quality edible oil, rich in unsaturated fatty acids, vitamins, and antioxidants, making it highly suitable for human consumption and health benefits. In addition to oil extraction, the crop also provides valuable by-products such as oilcake for livestock feed and hulls for industrial use. With its high yield potential, tolerance to drought, and wide adaptability, sunflower has become one of the most important oilseed crops cultivated across the world, contributing significantly to edible oil production and farmers' income.

i. Importance of Sunflower:

- Produces **high-quality edible oil** rich in unsaturated fats, especially linoleic acid, which is good for heart health.
- Widely used in **cooking, cosmetics, pharmaceuticals, and industrial applications.**
- Sunflower oilcake, the by-product after oil extraction, is a **nutritious protein-rich cattle feed.**
- Grows quickly and can be cultivated in different seasons (kharif, rabi and summer) due to its wide adaptability.
- Provides **pollination benefits**, as sunflowers attract bees and enhance honey production.

ii. Area of production & productivity (India – Recent trends):

In 2024-25, sunflower was grown on 1.80 lakh hectares in India, producing 1.13 lakh tonnes with an average yield of 1061 kg per hectare. Karnataka had the largest area and production, while Telangana recorded the highest yield (1691 kg/ha). Tamil Nadu and Odisha also showed good yields. States like Andhra Pradesh, Jharkhand, and Maharashtra contributed very little. Overall, Karnataka, Telangana and Tamil Nadu are the main sunflower-growing states in India (DAC & FW 2024-25).

iii. Management Practices:

a. Tillage and seed bed preparation: For better germination establishment and growth, prepared seed bed is required. In light soils, 1 or 2 ploughings followed by planking and harrowing are necessary. In medium to heavy soils, 1 or 2 harrowings should be done immediately after rains or when soil moisture is favourable. Final seed bed should have fine tilth.

b. Sowing time: Though sunflower can be grown in all seasons, sowing time should be decided to avoid continuous drizzle, cloudy period or temperature more than 38^0c during flowering period. In traditional areas during *kharif,* sunflower can be sown 2nd fortnight of June to middle of July in light soils and up to 2nd fortnight of August in heavy soils. During rabi, sunflower can be sown from September to end of November. In non-traditional areas, it can be sown from January to February end in spring season.

c. Seed rate and spacing: Use 5-6 kg/ha seed for rainfed crop and 4-6 kg/ha for irrigated crop. Sow by dibbling the seed with a spacing of 60 x30 cm in heavy soils and 45x30 cm in light soils. Follow ridge and furrow system.

d. Cultivars: The recommended hybrids for different states are as given in (Table.6)

Table 6: The recommended hybrids for different states

State	Hybrid
All Sunflower growing regions in India	SUNH-1, SUNH-2 and SUNH-3
Andhra Pradesh	NDSH-1012, SUNH-1, SUNH-2 and SUNH-3
Karnataka	KBSH-90, KBSH-78, KBSH-85, KBSH-88, RSFH-187 and RSFH-700
Maharashtra	PDKVSH-964, LSFH-171,LSFH-35
Tamil Nadu	COH-3, CO H-4
Punjab	PSH-2080,PSH -118, PSH-1962

e. **Seed treatment:** Treat seed with thiram or captan @3 g/kg of seed to protect from seed borne diseases. In areas of known downy mildew incidence, treat the seeds with metalaxyl @ 6g/kg of seed.

f. **Thinning:** Thinning of excess seedlings to retain one seedling per hill is essential and can be done at 10 to 15 days after germination for realizing higher yield, easy intercultural operations and management of insect pests and disesases.

g. **Fertilizer management:** For adequate and balanced fertilization, incorporate 7 t/ha of well decomposed FYM/compost 2-3, weeks prior to sowing. It is desirable to apply the fertilizer based on the soil test values. In general, 60:60:30 NPK is recommended for rainfed crop and 60:90:30 NPK for irrigated crop. Apply 50% N+100% PK as basal and remaining N in two equal splits at 30 and 55 days after sowing for irrigated crop. Single super phosphate (SSP) is preferred as a source of P as it supplies sulphur, which is important to increase the oil yield. Apply sulphur @25 kg/ha in the form of gypsum in deficit soils. Boron is an essential micronutrient for sunflower, which increases seed filling and yield. Apply borax@2g/l as directed spray to capitulum at star bud stage. The use of biofertilizers integrated to supplement part of nutrition helps in cost reduction and maintaining soil health. Seed treatment with dual inoculation of *Azospirillum* and *Azotobacter* resulted in 50% reduction in recommended N for sunflower. The fertiliser recommendations of sunflower specific for each state given in (Table.7)

Table 7: The fertiliser recommendations of sunflower for specific state

State		Fertilizer (kg/ha)		
		N	P_2O_5	K_20
Andhra Pradesh	Rainfed	60	60	30
	Irrigated	60	90	30
Karnataka	Rainfed	50	25	25
	Irrigated	60	75	60
Maharashtra	Rainfed	40	60	0
	Irrigated	60	95	60

Source: ICAR-IIOR (2020).

h. **Weeding management:** First 4-6 weeks after emergence are the most critical for weed competition. Perform two hoeings and one hand weeding at an interval of 15 days starting from 15-20 DAS. In areas of labour shortage, pre-emergence application of herbicides *viz.*, Alachlor or Pendimethalin or Fluchloralin @ 3-5 ml/l followed by one hand weeding and hoeing at 35 days is recommended for effective weed control

i. **Irrigation management:** Provide irrigation at 8-10 days interval in light soils and 15-25 days in heavy soils. Do not miss irrigation at critical crop growth stages i.e., bud initiation (35-40 DAS), flower opening (55-65 DAS) and seed filling (65-80 DAS) for realizing higher seed yield. Moisture stress at these stages causes significant yield reduction.

j. **Intercropping systems:** Redgram + Sunflower (2:1/1:1/1:2), groundnut + sunflower (5:1/3:1) and soybean + sunflower (2:1) are remunerative inter cropping systems.

iv. Major pest & diseases and their management:

Major pest and diseases, their symptom and management in sunflower are given in (table.8)

Table 8: Major pest & diseases and their management:

	Symptoms	Management
Pest		
Pod/Head borer (*Helicoverpa*)	Bores into flower heads and feeds on seeds	Handpick larvae; use pheromone traps; spray **Spinosad 0.5 ml/lit** or **Emamectin benzoate 0.4 gm/lit**
Aphids	Clusters on young shoots, sucking sap, leaf curling	Spray Imidacloprid 0.3 ml/lit or Thiamethoxam 0.3 gm/lit
Jassids / Green leaf hopper	Leaf yellowing & curling	Spray Dimethoate 2 ml/lit or Acetamiprid 0.2 gm/lit
Whiteflies	Sticky honeydew, yellowing leaves	Use yellow sticky traps, spray malathion 50 EC@ 2ml/lit
Diseases		
Downy mildew	Yellow patches on leaves	Use resistant varieties, fungicide spray
Rust	Orange spots on leaves	Spray Mancozeb 1g/lit
Alternaria leaf spot/ blight	Brown leaf spots	Timely fungicide spray

Crop Duration: Sunflower is a short-duration crop (90–100 days) and ideal for crop rotation.
Harvesting: (Cutting and collecting the mature crop yield)

It will be done when back of the flower head turns brown and seeds become hard.
Avoid delay to reduce seed loss.

Yield: Rainfed: 8-10 q/ha

Irrigated: 20-25 q/ha

Threshing: Heads are dried and manually beaten or machine threshed to separate seeds.

Soybean

Soybean (*Glycine max L.*), often called the "**Wonder Legume"** or **"Golden Bean**," is one of the most important oilseed and pulse crops of India. It is a major source of both **edible oil (18–20%)** and **protein (40–42%),** making it a dual-purpose crop. The crop belongs to the family *Leguminosae* and is capable of fixing atmospheric nitrogen through *Rhizobium japonicum* bacteria in its root nodules, thus enriching soil fertility.

Soybean oil is rich in polyunsaturated fatty acids and free from cholesterol, while the seed meal is an excellent source of high-quality protein used in livestock and poultry feed. It is also used for manufacturing various industrial products such as paints, soaps, and biodiesel.

India ranks among the top five soybean producers in the world, contributing about **4-5% of global production**. Major soybean-growing states are Madhya Pradesh, Maharashtra, Rajasthan, Telangana and Karnataka. In 2024-25, soybean was grown on about 13.62 lakh hectares with a production of 151.8 lakh tonnes and average productivity around 1162 kg/ha (DAC & FW 2024)..

i. Growing season

Soybean is primarily a ***Kharif* crop**, sown with the onset of monsoon and harvested in late *Kharif*. It requires **warm temperatures (25–30°C)** and **well-distributed rainfall (600–800 mm)** during the growing period. The crop is sensitive to waterlogging; hence, good drainage is essential. Sowing seasons and major growing states are given given in (Table.9).

Table 9: Sowing seasons and major growing states

Season	Sowing time	Harvesting time	Situation	Area (%)	States
Kharif (Rainy)	June–July	Oct-Nov	Rainfed/ Irrigated	95	M.P., Maharashtra, Rajasthan, Gujarat, Telangana

The zone wise recommended soybean varieties are enlisted in Table 10.

Table 10: List of soybean varieties recommended for different zone/areas

S.No	Zone	States	Recommended Varieties
1.	Central Zone	Madhya Pradesh, Bundelkhand Region of Uttar Pradesh, Rajasthan, Gujarat, North-West Region of Maharashtra	JS 23-03, JS 23-09, MAUS 731, Gujarat Soya 4, JS 22-12, JS 22-16, NRC 165, NRC 157, MAUS 725 (Maharashtra*), NRC 150, Phule Durva (KDS 992 Maharashtra*), JS 21-72, RVSM 2011-35, AMS 100-39 (PDKV Amba), NRC 142, MACS 1520, RSC 10-46, RSC 10-52, AMS-MB-5-18 (Suvarn Soya)
2 &3	Eastern Zone and Northern Hill Zone:	Assam, Meghalaya, Manipur, Nagaland, & Sikkim	RSC 10-71, RSC 10-52, Birsa Soya-4 (Jharkhand*), MACS 1407, MACS 1460, NRC 128, RSC 11-07 and RSC 10-46
4.	Northern Plain Zone	Punjab, Haryana, Delhi, North Eastern Plains of Uttar Pradesh, Plains of Uttarakhand and Eastern Bihar	Pusa Soybean 21, NRC 149, Pant Soybean 27, PS 1670, SL 1074, SL 1028, NRC 128, Uttarakhand Black Soybean (Bhat 202-Uttarakhand*) SL 979, SL 955, Pant Soybean 26 (PS 1572), PS 1368, PS 24 (PS 1477), VLS 89
5.	Northern Hill Zone	Himachal Pradesh and Hill Region of Uttarakhand	NRC 197, VLS 99, Him Palam Soya-1 (Himachal Pradesh*), Pant Soybean 25 (PS 1556), Shalimar Soybean-1 (J&K)
6.	Southern Zone	Karnataka, Tamil Nadu, Telangana, Andhra Pradesh, Southern Part of Maharashtra:	ALSB 50 (Telangana*), MAUS 725 (Maharashtra*), Phule Durva (KDS 992 (Maharashtra*) NRCMACS 1667, NRC 142, MACS 1460, NRC 132, DSb 34, KDS 753 (Phule Kimaya), KBS 23 (Karnataka*)

***notified only for the concerned state**

Source: ICAR-NSRI (2025).

Soils

Soybean grows best on **well-drained, fertile loam or clay loam soils** with a pH range of **6.0–7.5**. Heavy clay soils, saline, or alkaline soils are unsuitable. The crop is sensitive to both drought and waterlogging conditions.

ii. Land Preparation

Soybean requires a **well-pulverized, level, and weed-free seedbed.** One deep ploughing followed by **2-3 harrowings and planking** ensures fine tilth. Field should be well-drained to avoid stagnation, which can cause root rot and poor nodulation.

iii. Seed Rate and Sowing Method

- **Seed rate:** 65-75 kg/ha for varieties; 80-90 kg/ha for hybrids.
- **Spacing:** 30 × 10 cm (rainfed); 45 × 5-10 cm (irrigated).
- **Sowing depth:** 3-4 cm.
- **Sowing method:** Line sowing using seed drill or behind country plough ensures uniform population and facilitates intercultural operations.
- **Optimum plant stand:** 3.5–4.0 lakh plants/ha.

iv. Seed Treatment

- **Fungicidal treatment:** Treat seed with Thiram 2.5 g/kg or Carbendazim 2 g/kg or Mancozeb 3 g/kg to protect against seed and soil-borne diseases.
- **Biofertilizer treatment:** Inoculate with *Rhizobium japonicum* (5–10 g/kg seed) and *PSB (Phosphate Solubilizing Bacteria)* for effective nodulation and nutrient uptake.

- **Insecticidal treatment:** In areas with high white grub or termite incidence, treat seeds with Imidacloprid 70 WS @ 5 g/kg seed.

v. Manures and Fertilizers

Soybean is considered to be moderately exhaustive crop. Balanced nutrients application ensures better yield performance of soybean. The integration of 5-10 t Farm Yard Manure or 2.5 t poultry manure/ha along with the basal application of N: P2O5:K2O: S (as given in table.11) generally provides balanced nutrition for harnessing the yield potential of soybean.

Table 11: Fertilizer dose recommended for soybean

Zone	Recommended Fertilizer dose (NPKS kg/ha)	Fertilizer Sources
North East	25:100:50:50	56 kg Urea+625 kg SSP+ 84 kg MOP
North Plain	25:75:25:37.5	56 kg Urea+470 kg SSP+ 42 kg MOP
Central	25:60:40:20	56 kg Urea+375 kg SSP+ 67 kg MOP
Southern	25:80:20:30	56 kg Urea+500 kg SSP+ 34 kg MOP

Source: ICAR-IISR (2018).

vi. Weeding and interculture

Recommended herbicides in soybean given in table.12

Table 12: Herbicides recommended in Soybean

No	Type of weedicide	Chemical Name	Commercial Name	Quantity
1	Pre plant incorporation (PPI)	Fluchloralin 45EC	Basalin	2.22 l/ha
		Trifluralin 48 EC	Treflan, Trinetra, Tufan, Flora	2.00 l/ha
2	Pre-emergence (PE)	Metalochlor 50 EC	Dual	2.00 l/ha
		Chlomozone 50 EC	Command	2.00 l/ha
		Pendimethalin 30 EC	Stamp, Panida	3.25 l/ha
		Diclosulum 84 WDG	Strongarm	26 g/ha
3	Post emergence (POE) (10-12 DAS)	Chlorimuron ethyl	Cloben, Curin	36 g/ha
4	POE (15-20 DAS)	Imazethapyr 10 EC	Persuit	1.00 l/ha
		Quizalofop-ethyl 50 EC	Terga Super	1.00 l/ha
		Quizalofop -p-tefuryl 4.41 EC	Rengo	1.00 l/ha
		Fenoxaprop-p- ethyl 9EC	Whip Super	1.00 l/ha

Source: ICAR-IISR (2018).

While using PPI herbicides, proper soil incorporation of herbicide must be ensured and it should be used only on moist soil. In case of PPI or PE herbicide application, farmers are advised to intercultivate the soybean crop by *Dora*/ *Kulpa* in between 20 to 25 DAS.

To control the weeds effectively, it is very necessary to make the appropriate spraying solution and its uniform spray on entire area/weed foliage. Hence farmers are advised to use 500 litre of water per hectare along with recommended quantity of herbicides using *Flat Fan* or *Flood Jet nozzle*. It is also advised that, Farmers should not carry any intercultural operations (Dora/Kulpa) till 10 days after spraying of PPI or PE herbicides. Similarly, same herbicide may not be used every year.

vii. Irrigation management

Soybean is, by and large, grown as a rainfed crop during *kharif* season. Since last few years the distribution of rainfall was found to be uneven and erratic. Long dry spells, particularly during critical growth stages like seedling, flowering and pod fill affect the yield adversely. Hence, farmers are advised to apply

lifesaving irrigation during these critical stages in order to sustain yield levels. Farmers are advised to use BBF or Ridge and Furrow methods for soybean planting in order to mitigate the climatic adversities. Avoid waterlogging as it adversely affects nodulation and root health.

viii. Intercropping in Soybean

Soybean is grown throughout the country as rainfed crop during the June/July-October. It is also successfully grown as intercrop with cotton, sugarcane and other horticultural crops. Soybean + pigeonpea in 4: 2 combinations are most popular intercropping system in Maharashtra including Vidarbha region.

ix. Management of insect pests

Major insect pests of soybean include:

- **Girdle beetle (*Oberea brevis*)**
- **Stem fly (*Melanagromyza sojae*)**
- **Green semilooper**
- **Whitefly and aphids**
- **Pod borer (*Helicoverpa armigera*)**

Management practices:

- Seed treatment with Imidacloprid 70 WS @ 5 g/kg seed for sucking pests.
- Spray **NSKE 5%** or **Neem oil 3 ml/L** as a preventive eco-friendly measure.
- For pod borer and semilooper: Spray **Spinosad 45 SC@0.2ml/L** or **Emamectin benzoate 5 SG @0.4g/L**.
- For whitefly/aphid: Spray **Dimethoate 30 EC @1.7ml/L** or **Thiamethoxam 25 WG@0.3 g/L**.
- Install **bird perches (30–40/ha)** to encourage predatory birds.

x. Management of diseases

Major diseases include:

- **Soybean mosaic virus**
- **Rust (*Phakopsora pachyrhizi*)**
- ***Rhizoctonia* stem rot**
- **Bacterial pustule**
- **Cercospora leaf spot**

Management measures:

- Use resistant/tolerant varieties.
- Treat seed with **Carbendazim + Mancozeb (2 g/kg each)** before sowing.
- Spray **Propiconazole 25 EC @1ml/L** or **Hexaconazole 5 EC @1ml/L** for rust and leaf spots.
- Remove and destroy infected debris.
- Follow crop rotation with non-leguminous crops to minimize inoculum.
- Spray **Streptocycline 500 ppm + Copper oxychloride 0.25%** for bacterial pustule.

xi. Harvesting and Threshing

Harvest when **pods turn brown and leaves begin to fall**. Delay in harvesting causes pod shattering and seed loss. After harvesting, dry the crop for 2–3 days, then thresh and clean seeds. Dry seeds to **8–9% moisture** for safe storage. Oil extraction and refining are carried out in expeller or solvent plants. Processed oil and meal are marketed domestically and for export.

xii. Yield potential

- **Rainfed:** 15-20 q/ha **Irrigated:** 25-30 q/ha

xiii. Tips to get higher yields

- Use certified seeds of high-yielding, disease-resistant varieties.
- Treat seeds with fungicide and inoculate with Rhizobium + PSB.
- Ensure fine tilth and proper drainage.
- Sow at the proper time with optimum spacing.
- Maintain weed-free crop for the first 40 days.
- Apply fertilizers based on soil test recommendations.

- Irrigate at critical stages (flowering and pod filling).
- Adopt integrated pest and disease management.
- Avoid waterlogging; provide timely drainage.
- Harvest at physiological maturity to prevent shattering.
- Dry the seeds to 8–9% moisture before storage.

Castor

Castor (*Ricinus communis* L.) is one of the ancient and important non-edible oilseeds having immense industrial and medicinal value. It is an ideal candidate for production of high value industrial and oil feed-stocks because of the very high oil content (48-56%) in seed. The plant has unique ability to produce oils with extremely high levels (80-90%) of ricinoleic acid. Not only the seed and its products, but castor leaves, roots, flowers and stalks have various curative properties and other benefits. India is the largest producer and exporter of castor seed and oil, contributing more than 80% of global production.

i. Importance of Castor:

- Castor oil is used in lubricants, cosmetics, medicines, soaps, paints, coatings, biodiesel and many industrial applications.
- Oilcake (residue after extraction) is a rich source of nitrogen and is used as an organic manure.
- Castor crop is drought tolerant and suitable for dryland farming.
- High export potential, earning significant foreign exchange for India.
- Improves farmers' income due to demand from pharmaceutical and industrial sectors.

ii.Recent trends in area, production & productivity:

India contributes 80% of world castor production. Gujarat is the leading state (70-75% of area and production), followed by Rajasthan, Andhra Pradesh, and Telangana. According to Government 2nd advance estimates, all India castor production in 2024-25, castor was cultivated on 8.2 lakh hectares in India, producing 15.88 lakh tonnes with an average productivity of 1918 kg/ha.

iii. Management Practices:

a. **Land preparation:** 1 deep ploughing followed by 2-3 harrowings; fine tilth is needed.
b. **Sowing season:** *Kharif* (June–July), *Rabi* (first fortnight of October).
c. **Recommended cultivars:** Farmers are advised to procure good quality viable seeds of hybrid/variety (ICH-5; ICH-6; ICH-66; GCH-8; GCH-9) from authorized/registered seed agent. Farmers need to renew seed stock of hybrids every year and improved varieties once in 4-5 years.
d. **Seed rate**: 5 kg/ha (Hybrids).
e. **Spacing:** Proper spacing between row to row and plant to plant to ensure optimal sunlight, air circulation, and nutrient availability for healthy growth and higher yields. Spacing for rainfed crop 90x60 cm or 90x90 cm; Spacing for Irrigated crop: 120x60 cm or 120x90 cm
f. **Seed treatment:** Seed treatment helps to protect the plant from seed borne diseases like seeding blight, Alterneria blight and wilt. It can be done either with captan 3g/kg or carbendizam 2g/kg seed or *Trichoderma viride* 10g/kg seed.
g. **Thinning:** Remove extra/ overcrowded seedlings reduces the competition for water and nutrients and healthy plant grow. Thinning of excess plants to be taken up at 10 to 15 days after germination.
h. **Fertilizer management:**

Apply fertilizers based on soil test values for adequate and balanced nutrition. Incorporate 5 t/ha of well decomposed FYM/compost 2-3 weeks prior to sowing. In general, 40-60, 15-60, 15-30 kg NPK/ha is recommended for ranifed crop and
80-120, 30-60, 30 kg NPK/ha respectively, for irrigated crop along with 20 kg Sulphur for higher seed and oil yield. For rainfed castor, application of basal dose of 20 kg N followed by top dressing with 20 kg N/ha each at 35-40 DAS and 65-70 DAS depending on moisture availability. Whereas under irrigated conditions, top dressing with five splits are to be given. In soils deficient in Zinc and Iron, apply 10 kg zinc sulphate and 30 kg ferrous sulphate/ha.

i. **Integrated Nutrient Management (INM)**:

Integrated Nutrient Management (INM) combines the use of chemical fertilizers, organic manures and biofertilizers to ensure soil fertility, crop productivity and sustainability. For castor, application of 5 t/ha FYM or 1.5 t/ha of vermicompost or compost along with recommended NPK doses enhances soil health and nutrient

use efficiency. Biofertilizers such as *Azospirillum* and Phosphobacteria may be applied to improve nutrient availability.

j. **Intercropping systems:** Castor is usually raised either as a sole crop or mixed crop in *kharif* The remunerative castor based intercropping systems are: Castor+ redgarm (1:1), castor + cowpea (1;2), castor + black gram (1:2), castor +greengram (1:2), castor+ groundnut (1:5), castor + turmeric/ginger (1:5) and castor +chillies (1:8)

k. **Weeding**: Castor is very sensitive to weed compeitition. Intercultivation with blade harrow 2-3 times commencing from 25 days after sowing followed by 2 or 3 hand weedings at interval of 15-20 days effectively check weed growth. Pre-plant incorporation of herbicides such as fluchloralin@ 2l/ha; Pre-emergence application of alachlor @ 2.5 l/ha or pendimethalin @3.3l/ha mixed in 600l of water to be applied to soil under assured moisture conditions. Post emergence herbicides (Quizalofop-p-ethyl 50 g ai /ha) has been recommended for effective and economical control of grassy weeds.

l. **Irrigation**: Castor gives good response to irrigation due to its perennial nature. During *kharif* season, castor is mostly grown as rainfed crop. In case of prolonged dry spells, one protective irrigation either at primary spike development. For rabi and summer crops one irrigation is required immediately after sowing to facilitate uniform germination. Based on the soil type and growth irrigation can be given at 10-15 days interval. Irrigated crop requires 4–5 irrigations at branching, flowering, and capsule filling stages. Drip irrigation (@ 3 day interval) helps to save nearly 20-25% of irrigation water. At the same, water use efficiency can be doubled as compared to flood irrigation

m. **Management of important insect pest & diseases**Castor is attacked by a number of insect pests and diseases which impose a great limitation in realizing the potential productivity. The magnitude of the insect pest problem is quite high in Southern India where castor is grown mainly as rainfed crop, while it is low in Gujarat and Rajasthan under late *kharif* irrigated conditions. The important diseases and insect pests of castor and their management methods are given in (Table.13)

Table 13: Management of important insect pest & diseases and their management

	Symptoms	Management
Insect pest		
Castor semilooper	Defoliation of leaves	Neem oil 5 ml/l or profenofos 1ml/l
Capsule borer	Bores into capsules, seed damage	Thiodicarb 1g/lit or Spinosad 0.4 ml/l
Whitefly & Jassid	Sucking sap, leaf yellowing & dry	Dimethoate 1.7ml/l or sticky traps
Disease		
Gray mold	Pale, blotch-like spots, wool like mold on capsules/flowers	Collection and destruction, use resistant, Carbendazim 1g/lit or propiconazole 1ml/lit
Root rot/Die back	Wilting, root blackening	Seed treatment with *T. viride* 4g/kg seed
Alternaria Blight	Brown necrotic spots	Mancozeb 2.5g/lit or Copper oxychloride 3g/lit

Crop duration: Early maturing: 120–150 days; Medium/late hybrids: 180–240 days

n. **Harvesting and threshing:**

Castor, by nature is a multiple branching type. On an average, it produces 4 to 5 sequential order spikes over a span of 180 to 240 days, one each at an interval of about 30 days. The main spike is ready

for harvest within 90-120 days after planting. The subsequent pickings can be taken up at intervals of 30 days. Physiological maturity in castor is attained when some of the capsules in a spike turn brown in colour. The matured spikes are cut and dried in sun for a few days for easy threshing. For good seed filling, oil content and germinability, harvest when the capsules turn yellow and start drying. Threshing is usually done by either beating the capsules with sticks or alternatively by trampling with bullocks or tractor wherever possible. Power operated mechanical threshers are also available for the purpose.

o. **Selective mechanization:**

The impact of selective mechanization on critical operations like inter-cultivation (power operated weeders) and sowing (tractor operated/bullock drawn line marking and closing the furrow), harvesting and threshing (secateurs and power operated threshers) on productivity of castor revealed significant seed yield improvement by 5- 14%, under rainfed conditions. Selective mechanization reduced the labour requirement by

22-87 man days in different operations resulting in reduction in cost of cultivation and higher economic returns across locations.

p. Yield: *Kharif*: 10-15 q/ha;

Rabi: 20-35 q/ha;

q. Value addition

Castor stubbles and shelled capsules can be incorporated in to the soil or can be used in the preparation of vermicompost which in turn can be further applied to agricultural fields to improve the soil fertility. Castor leaves can be fed to eri silkworms (Ericulture) to produce 'eri silk' which resembles cotton and is called as poor man's silk. It has been proved to be an ideal subsidiary occupation to a large number of rural and tribal populations as it provides ample scope for employment and income. Nearly 30% defoliation is permissible and the same can be used in ericulture without foregoing economic yield. Besides, the farmers can be benefitted with an additional income upto Rs. 6000 to 7500/ha through ericulture which is a boon for rainfed castor growers.

Critical interventions for realizing higher yield

- Always use quality seeds (certified hybrid/variety seed) procured from authorized agencies.
- Avoid continuous cropping of castor year after year in the same field, particularly in the wilt endemic areas, and adopt at least 2year crop rotation.
- Sow the crop at appropriate time with monsoon rains.
- Treat the seed with recommended fungicides before sowing to ward off wilt and root rot diseases.
- Maintain optimum plant stand through adoption of recommended spacing and seed rate.
- Apply recommended fertilizer dose based on soil test values to ensure better crop nutrition and yields.
- Adopt recommended cultural practices.
- During *rabi* adopt drip-fertigation for realizing higher yield and economizing limited water.
- Adopt need-based measures for managing diseases and insect pests.
- Harvest the crop at appropriate time.

3.5. Commercial Crops: Cotton, Sugarcane, etc.

1. *Cotton*

Cotton is the most important fibre crop not only in India but globally. It provides the basic raw material (cotton fibre) to cotton textile industry. Cotton is one of the most important cash crop of India and plays a dominant role in the industrial and agricultural economy of the country. It provides the basic raw material (cotton fibre) to cotton textile industry. Cotton has been grown for fiber and its byproducts (seed, seed oil and cake) for over 6,000 years. Cotton is used as clothes, sheets, and towels, but cotton is also used to make things like rope, U.S. currency, paper, cooking oil, animal feed, packaging, and bio-fuels. The benefits and versatility of cotton are numerous.

i. Climate:

Tropical crop and thrives well in hot and humid climate with abundant sunlight. Lower temperature threshold for germination is 15.5°C with optimum temperatures ranging between 25-30°C during vegetative growth and 22-27°C during flowering and fruiting phase. It can tolerate upper temperature as high as 40°C, but does not do well if the temperature falls below 21°C. Abundant sunshine during the crop growth period particularly the period of boll maturation and harvesting is essential to obtain good quality produce. Cotton is highly sensitive to frost and it requires a frost free period of a minimum of 180-200 days. Therefore, its cultivation is confined to plains and extends from MSL to an altitude of 1000 m only.

ii. Rainfall:

Successfully grown in areas receiving an average annual rainfall ranging from 500 mm, of which 175-200mm should be received during crop growth period. If, during the fruiting period heavy showers of rain occur or heavy irrigation is applied, shedding of the flowers and young bolls results. At harvesting also high rainfall is not desirable since it not only affects the quality of lint but also delays harvesting and makes the harvesting difficult.

iii.Soils:

Cotton is grown on a variety of soils, ranging from well-drained deep alluvial soils in the north zone to black clayey soils of varying depth in the central cone and in the black and mixed black and red soils in south zone. Cotton is moderately tolerant to salinity and is sensitive to water logging hence, prefers well-drained soils. Crop performance is optimum with soil depth of 100-120 cm and optimum pH between 6.5 to 8.0.

iv. Land Preparation:

Plough 15-20 cm deep with MB plough, followed by 2-4 harrowings. The previous season stubbles should be removed, shredded and returned to soil or converted to biochar/ brickets for fuel.

v. Time of sowing:

Sowings start in the month of April-May and delays as one goes down south
Irrigated crop – March-May
Rainfed crop – June-July
Guj and MP – pre-monsoon dry sowings at the end of May or early June
TN – Irrigated and Rainfed crop – Sept/Oct, summer – Feb/Mar

vii. Seed rate: Hybrids – 1.0-1.2 kg/acre, Variety – 3 kg/acre

vii.Spacing:

Straight varieties
45-60 X 15 cm (*Rainfed*)
90-120 X 45-60 cm (Irrigated)
Hybrids
90-150 X 45-60 cm

viii. Method of Sowing:

Seed drill /behind the plough, dibbling (hybrids) or precision planting using pneumatic planter or inclined plate planter.
Depth of Sowing: 4-5 cm
No. of seedlings/hill: Varieties 2, Hybrids 1

ix. Gap Filling and Thinning:

For optimum plant population

Gap filling 10th day – pre soaked seeds or seedlings raised in polythene bags

Thinning – 3 weeks after sowing, removing excess seedlings, weak, diseased or damaged

x. Nutrient Management

a. Manures:

10 t FYM/ha

b. **Fertilizers: (N-P-K kg/ha)**

Desi Cotton : 20 to 40 – 20 - 20

American Cotton Varieties : 90 - 45 - 45

Hybrids : 120 - 60 – 60

Rainfed:

Desi : 40-20-20

American variety : 60-30-30

Hybrid : 90-45-45

Irrigated:

American variety : 100-50-50

Hybrid : 120-60-60

P_2O_5 – basal, N and K_2O – 3 equal splits 30, 60 and 90 DAS

Pocket placement of top dressed fertilizers

xi. Water Management:

Cotton cannot tolerate excess moisture in the soil and so frequent irrigation is not necessary. The crop must not be allowed to suffer from water stress during flowering and fruiting period. Excessive shedding of flower buds and young bolls may occur resulting in loss of yield. The crop cannot tolerate water logging conditions at any stage of growth. Critical Stages for irrigation/ moisture stress are Square formation, Flowering and Boll developing stage

xii. Weed Management:

First 50 - 60 DAS is the critical period of Crop Weed Competition. 5 – 6 intercultural operations should be done depending on the intensity of weeds. Pre-emergence application of Pendimethalin 38.7 % CS @ 700 ml/acre or Alachlor @ 1.0 L/acre or Diuron 1.5 kg/acre and post emergence application of Paraquat @ 1.0 L/acre.

xiii. Topping:

Removal of the terminal bud to check excessive vegetative growth is called topping. Level of topping or at what node topping is to be done will differ with cotton plant type. In MCV –5: Topping at 15th node level (70 – 80) DAS resulted in better yields, in MCV-7: 10 – 12th node (90DAS). Topping is done manually in India. In USA machines are used. Excessive vegetation growth can also be controlled by using chemicals which are growth retardant like cycocel (CCC). CCC restricts excessive vegetative growth, retards senescence, keeping the leaves green for longer time thus prolonging their effective period. The dosage of CCC is 40-60 ppm in American Cotton and 60-80 ppm in Desi cotton at 50 to 80 DAS.

xiv. Bud and Boll shedding:

It is a natural phenomena in cotton. Heavy shedding of flower buds and young bolls occur which is aggravated under adverse conditions of soil, climate and management under such situation. It may be as high as 60%. Under natural conditions 10 to 15% loss occurs. Reasons for bud and boll shedding: Un-favourable weather conditions such as reduced light conditions, excess or lack of moistures in the soils, cloudiness, high relative humidity, imbalanced nutrient supply, incidence of pest and disease, weeds alter the microclimate, physical injury -due to use of farm machinery. Using hormones like NAA, increases the supply of auxin to bolls and buds, thus the senescence is reduced. For retention of fruiting bodies, spraying of NAA /planofix @10-20 ppm at square formation (45 days) and flowering initiation stages (60 days) @ 0.3 ml of NAA 4.5%SL per litre of water is recommended.



Fig: Bud Shedding and Ball Shedding

xv. Harvesting:

Harvesting usually commences in the month of Nov. and extends to March depending upon sowing time and duration. Harvesting is done usually by manual labour i.e., hand picking the cotton from the open matured bolls. Since cotton is indeterminate type, flowering occurs in number of flushes hence all the bolls do not mature at a time and bolls come to maturing stage at intervals of 2-4 weeks period. Harvesting is done in 4-5 pickings as and when bolls are fully matured.

Precautions must be taken to maintain the quality of fibre at the time of picking. Picking needs good experience, care is taken that all the cotton from all segments should be removed in one stroke without leaving any fibre in the boll. Produce from each picking should be dried separately and stored separately. Kapas should not be contaminated with foreign materials like plastic, hair etc. at the time of picking and storing.

Yields:

Dryland crop : 4-6 q/acre
Irrigated Crop : 10-12 q/acre
Hybrids : 14-16 q/acre

*2. **Sugarcane***

i. Climate: A growing season which is long and warm with adequate rainfall or irrigation, long hours of bright sunshine and higher relative humidity. Ripening season of around 2 -3 months duration having warm days, clear skies, cool nights and relatively a dry weather without rainfall and higher difference in day (maximum) and night (minimum) temperatures for build up of sugar are required. Temperature: 24 to 30° C is ideal temperature. A rainfall of 600 to 3000 mm. High humidity with warm weather 45 to 65% + limited water supply is must at ripening phase. Sun loving plant, higher sunshine hours. Extreme cold conditions will arrests cane growth.

ii. Soils:

Moderately heavy and medium deep loams, good depth and drainage with no compactness.

iii. Land Preparation:

Plough 2-4 times with iron plough and pulverization to break the clods. Dug to a depth of 20 cm to facilitate drainage and deep root system

iv. Duration:

Duration of crop varies from **10-18 months**

- Kamsali crop : < 10 months
- Eksali crop : 10-12 months
- Adsali crop : 12-18 months

v. Planting Season:

December to end of March
Eksali crop - December to January middle
Adsali crop - August to September middle
Late maturing (12-13 months): Co 7219, Co7706
Mid-late maturing varieties (11-12 months): Co A 7602, Co T 8201
Early maturing varieties (9-10 months): Co 6907, Co 7505
Under rain fed conditions for planting in February: Co 6907, 81 A 99

vi. Spacing

Furrow with ridges
Row to row spacing varies from 60-90 cm
Adsali Planting : 120 cm row spacing
Early varieties' : 80 cm

Mid late varieties: 90 cm

vii. Seed rate

- Three budded setts : 12,000 (28-30 q/acre)
- 2 buds : 32,000 setts per acre

viii. Seed treatment

For the prevention of Pineapple disease and scale insect

Dipping setts for 15 mins in solution containing 150 g carbendazim and 600 ml of Malathion mixed in 300 L of water before planting

For the Prevention of Grassy shoot disease Hot water treatment of seed material at 52˚C for 30 minutes or treatment with aerated steam at 54˚C for 4 hours.

ix. Sugarcane Planting Methods

a. Planting on flat beds

Popular method in Northern India and in parts of Maharashtra

Shallow furrows of 8-10 cm deep are made.

Distance between two rows should be kept 75-90 cm.

Generally 3 budded setts are used to plant in the end to end planting system.

b. Ridge and Furrow Method

Areas with moderate rainfall but have drainage problem

Deep furrows of 10-15 cm deep in N. India, 20 cm in S.I

Particularly in heavy soils

c. Trench Method or Java method



Some coastal areas where the crop grows very tall and the strong winds cause lodging of cane

Trenches at a distance of 75-90 centimeters are dug, 20-25 centimeters deep

Gamma BHC 20 EC at the rate of 5 liters in 800-1000 liters of water per hectare is sprayed over planted setts

Furrow is covered by 5 -7 cm of soil and field is leveled by planking.

d. Rayungan method

A portion of field selected for Rayungan production is left at harvesting time. The top of the cane is cut off which results auxiliary buds begin to sprout. For quick and effective sprouting, fertilizer especially nitrogen in heavy dose is applied and field is irrigated. After 3 - 4 weeks sprouted buds are separated in single bud setts & transplanted on to ridges. This method is costly, usually used for gap filling.

e. Skip Furrow Planting

Common in Orissa, Hybrid of flat and trench method

Trenches are dug 45 cm apart & gap of 90 cm is left after each two rows

f. Sapling or Sprouting Method

Plants are sown in fertile soil with wide spacing, shallow planting, frequent irrigations and adequate fertilization. Tillers soon after they develop their own roots are separated from the mother plant and planted separately.

g. T-block Method:

Improved over Rayungan method

Stalks are cut off at its half length and planted vertically with node in the soil for rooting.

Planted ones and the mother stalks are adequately irrigated and fertilized

Upper buds of both Tjeblocks and mother cane, which sprout in due course of time, are planted by cutting them into setts, as rayungans



Fig: T – Block Method

x. Bud transplanting:

Sugarcane buds with half of its stalk can be planted in small polythene bags

After sprouting they can be transplanted in the main field.

Algin method of sugarcane planting

Upper most nodes are collected while striping the canes for crushing

Then planted in wheat field in rows after every 4 rows of wheat at 90 × 50 cm

Developed by Allahabad Agriculture Institute, Allahabad

Recommended Planting Methods:

Ridge and furrow method is easy and mostly followed.

In heavy soils furrows are irrigated soil is brought to more or less puddle condition and setts are pressed in the soil, which is called as "wet method".

At the time of planting buds should face upwards.

xi. Manures & fertilizers:

Recommended dose: 100-40-48 kg N: P: K/acre

FYM @ 4 t/acre must be incorporated 4-6 weeks before planting.

Green manuring with legumes.

Bio-fertilizers Azatobacter and PSB (Bacillus) @ 2 kg/acre and fungus (Aspergillus / Penicillium) or Press mud @ 1.6t/acre are also recommended.

When deficiency symptoms of Zn and Fe are seen, foliar sprays of ZnSO4 or FeSO4 may be recommended.

N First application should be given at 30 days of crop age, next at 60 and 90 DAP.

Entire Phosphorous should be applied basally. Potassium is applied at 45, 90 DAS.

Foliar Nutrition of urea @1-2.5% (10-25 g/L) & potassium @2.5% (25 g/L) under moisture stress is useful to improve yield and quality.

xii. Weed management:

Requires weed free for the first 90-100 days.

Manual weeding at 30, 60 & 90 DAP is effective to control weeds.

Trash mulch at 45 DAP @ 7-10 t/ha, 10 cm thick is effective.

Application of Atrazine @ 2kg/acre in 400 litres of water to be sprayed on the third or fourth day after planting, depending on soil moisture.

At 20 and 60 days of planting spraying of 2, 4-D (1.8 kg) + Gramoxone (1.0 lts) in 50 lts/acre is recommended.

xiii. Water management

Under severe stress the yield loss may go up to 60-70 per cent

Limited stress during ripening helps improve percent sugar content in cane

Critical stage for moisture stress is formative stage

Earthing up:

Earthing-up operation is also known as "hilling-up" converts furrows into ridges and ridges into furrows. Earthing-up is done at 45 - 120 DAP coincides with peak tiller stage. Manually or by using a bullock-drawn/tractor drawn furrower @ 120 DAP - checks tillering, provides sufficient soil volume for root

proliferation, promotes better soil aeration and provides a sound anchorage, preventing lodging @ 180 DAP may be helpful in preventing lodging.

Detrashing:

Detrashing refers to removal of unwanted bottom dry and green leaves at 150 DAP. Maintaining clean field, enhances air movement, an ideal micro-climate for unrestricted growth of cane, more food material is made available for stalk growth. Detrashing reduces the problem of infestation of insect-pests like scales, mealy bug. Minimizes rodents, rats, squirrels in the field. Detrashed trash can be used as mulch.

Propping:

Operation of tying the leaves together using the bottom dry and green leaves is known as propping. Trash without removing from cane is twisted to form sort of rope and cane stalks are tied together. This is known as trash-twist propping. Propping can be done for each row or two rows can be brought together and tied.

Ripening:

Ripening occurs between rapid growth and ultimate death of cane. Maturity stage: when sucrose exceeds 16% juice purity increases over 85% - cane is mature. When cane stalk is cut with a knife at above the middle portion, it end looks watery cane is unripe, if it sparkles slightly it is ripening. If the ratio of sugar content of top 1/3 to bottom one third is less than one cane is unripe when ratio is more than one – cane is ripe. Hand Refractometer is used to assess the maturity of standing crop by Brix reading.

Harvesting

Harvesting the crop at proper time is very important

Immature crop gives lesser sugar per cent and low yield.

Ratoon Management

The number of succeeding cane crops raised from single planting is “Ratoon”. Ratoon occupies 50-55% of total cane area in India. In India one or 2 ratoons are taken. The crop raised from planting cane setts is “Plant crop”. Plant crop is harvested the underground portion of stem stubble are left in the field. If harvesting is done unevenly stubble saving should be done.

After harvesting of plant crop, trash left in the field, should be burnt, to clean the field and destruction of eggs and pupae of pests. Intensity of gaps in ratoon is 10-30 per cent. Gap filling is done with young sprouts from stubbles or in poly bags or nursery with 30-35 day old. Thin or mid thin varieties are better ratooners than thick varieties. Plant crop should be harvested in Feb – March to ensure favorable re-growth of ratoon sprout.

Fertilizers: - 80 N + 24 P_2O_5 + 24 K_2O kg/acre are recommended for good ratoon crop. Nitrogen should be applied in 2 splits at ratoon initiation and 60 days after root initiation. Entire dose of P & K should be applied at ratoon initiation.

3.6. Fruit Crops: Mango, Sapota, Custard Apple, Amla, Grape and Pomegranate

1. *Mango*

Botanical name- *Mangifera indica* Family- Anacardiaceae
Origin- South East Asia Chromosome No. - 2n=40

i. Importance

- Most important fruit crops among the tropical and sub-tropical fruits grown in more than 110 countries. It is the
- It is the choicest fruit of India and said to be the National fruit of India and also called as the king of fruit. Cultivation dates back to 4000 years ago.
- It is cultivated in all over the India. From coastal areas to foot hills of Himalayas.
- It is rich in nutritional values and popularity to which no other fruit crops can match.

ii. History

Ancient literature – mention of this fruits in Sanskrit scripts like Ramayana, Mahabharata, Charaka Samhita, Shushkatha Samhista, Amarakosam.

- Alexander in 327 BC reported the cultivation of mango in Indus Valley.
- Hieun stang (632-645 AD) travelled in India more than 10 times.
- Ibn – Batuta (1325 – 1349)
- Ludovic –de- Varthena (1503-1508 AD) – described cultivation of mango in his travelogue.
- Akbar: Popularization of Mango in India "Lakhibagh" Orchard having 1 lakh mango trees, it is located at Darbangha.
- "Ain-e-Akbar" – Biography of Akbar, it shows the mango cultivation in India.

iii. Area and Production

- Mango cultivation is widespread in tropical and subtropical regions worldwide with major production in Indian states such as Uttar Pradesh, Bihar Maharashtra, Karnataka, Bihar, Orissa, West Bengal, Gujara, TN and Andhra Pradesh.
- India is recognized as the world's largest producer of mango, occupying 2.34 million hectares of land with an annual production of 20.9 million tons and an average productivity of 9 metric tons per hectare (India Stat, 2023).

a. Composition and uses

	Ripe fruit	Green mature fruit
1. Water	80%	90%
2. Protein	0.6%	0.7%
3. Fat	0.1%	0.1%
4. Carbohydrates	11.8%	8.8%
5. Fibre	0.7%	1.2%
6. Minerals	0.3%	0.4%
7. K	0.21%	0.08%
8. Ca	0.01%	0.01%
9. P	0.02%	0.02%
10. Fe	0.8mg/100g	4.5mg/100g

It is a richest source of Vitamin A

Riboflavin	50mg	30mg
* Vitamin A	480010	15010
Nicotinic acid	0.3mg	30mg

Thiamin	40mg	-
* Vitamin C	13mg	8mg
Energy	74 K Cal.	44K Cal.

Uses

h. Excellent table fruit, immature and green matured fruits are used for pickling, chutney, Amchur, Murabha.
i. Used for preparation of pulp, juice, jam, squash etc.
j. In Philippines and java the new flesh and tender leaves are used as vegetables.
k. Dried flower is used as medicine for stomach ache.
l. Mango seed oil and mango butter is also prepared.
m. Mango seeds are utilized for natural colouring and in the treatment of asthma.
n. Various parts of the mango plant possess therapeutic properties

o. Ripe fruits used for table purpose and processed products like squashes, syrups, nectar jam, jellies. Juice concentrates, wine, smoothies, chutneys, canned slices, chips, fruit leathers and powders.
p. Foreign exchange earner for India

5. **Varieties**: The cultivated mango varieties are grouped into 2 types.
1. Mono embryonic- All most all the cultivated varieties of mango
2. Poly embryonic.

There are more than 1000 varieties in India. Most of the Indian varieties are monoembryonic in nature. The polyembryonic varieties are Olour, Bappakkai, Bellary, Nekkere, Goa, Nileshwar dwarf, chandrakaran Kurukkan, Muvandan, Salem, kasargod, and foreign polyembrayonic varieties- Carabao, cambodiana, pico, Hoggins etc.

iv. Classification

a. Based on climatic adaptability

1. North Indian cultivars: Amrapali, Dashehari, Langra, Chausa, Mallika
2. East Indian Cultivars: Fazli, Himsagar, Langra, Madhulika, Zardalu Kishen bhog
3. West Indian cultivars: Alphonso, Kesar, Malgoa, Bombay green, Ratna, Sindhu, Pairi
4. South Indian cultivars: Banglora (Totapuri), Banganpalli (Benishan), Neelam, Manjira, Rumani, Mulgoa, Arka anmol, Mallika, PKM – 1

b. Based on ripening period

1. Early ripening varieties: Bombay green, Langra
2. Mid ripening varieties: Dashehari, Alphonso
3. Late ripening varieties: Amrapali, Mallika, Neelam, Totapuri

c. Based on fruit size

a. Very large fruit: >500g – Hathijhool, Fazli. Keitt, Haden.
b. Large fruited: (300g to 500g) – Beneshan, Totapuri, Mallika, Arka Arun
c. Medium large: (150g-300g) – Dashehari, Langra, Ratna, Sindhu, Alphonso, Bombay green,
d. Small fruited (100-150g) – Amrapali, Ratual
e. Very small (<100g) – Mitli, Gutli, Bhowari Chowras (70g)

v. Based on fruit utilization

a. Dessert purpose: Alphonso, Kesar, Mallika, Dashehari, Amrapali, Totapuri, Beneshan.
b. Juice purpose: Raspuri, Pairi, Malgoa
c. Processing purpose
   - Beverage preparation – Amrapali, Safeda, Arka puneet
   - Pickles – Appi midi, Konkan runchi, Pulian, Amlette, ashwina
   - Nectar – Amrapali, dashehari, sahib pasand
   - Pulp – Alphonso, Kesar Totapuri
   - Slice – Mallika, Alphonso, Benishan, Totapuri

vi. Based on cultivars suitable for root stock

a. Dwarf rootstock – Kerala dwarf, Vellaikolamban, Totapuri red small
b. Vigorous rootstock – Muvandan, Bappakai, Olur
c. Salt tolerant rootstocks – Kurukkan, Neeleshwar dwarf

V. Mango Varieties

Mango varieties exported from India: Alphonso, Kesar, Dashehari, Mallika

IIHR, Bangalore (Indian Institute of Horticulture Research)

- **Arka Aruna:** Banganapalli x Alphonso- Dwarf and Regular bearer, precautious, medium yields fruits are large with attractive skin colour with Red blush. Free from spongy tissue, suitable for high density planting.
- **Arka Puneet:** Alphonso x Banganpally- Plants are regular, bearer, medium sized fruits, attractive. Free from spongy tissue & fruit fly and excellent keeping quality
- **Arka Anmol: Alphonso x Janardhan pasand-** Medium vigourous, regular bearer, good yielder. Medium sized fruits, excellent keeping quality. Free from spongy tissue
- **Arka Neelkiran: Alphonso x Neelam-** Regular bearer, medium sized fruit, free from spongy tissue and xcellent peel colour

q. **Arka Udaya** :Amrapali X Arka Anmo) **Arka Suprabhath :**Amrapali X Arka Anmol

IARI: New Delhi

1. **Mallika :** Neelam x Dashehari- Regular bearer, large fruits with yellow colour, high pulp content, total soluble solids (TSS) is 24° Brix and Medium keeping quality
2. **Amrapali:** Dashehari x Neelam- Dwarf, regular, suitable for HDP (2.5 x 2.5m spacing), Fruits are yellow on ripening and good keeping quality and late maturity
3. **Pusa Surya:** Amrapali x Sensation - Regular bearer, heavy yielder, fruits are medium with attractive yellow peel with reddish tinge on surface. Very good TSS: Acid blend (good combination of sweet and sour) and good flavor and good shelf life
4. **Pusa Arunima:** Amrapali x Sensation- Semi vigourous, regular bearer, medium sized fruits, attractive red peel colour with mild flavour and ood shelf life

RFRS: Regional Fruit Research Station, Vengurla

1. **Ratna**: Neelam x Alphonso - Regular bearer, medium sized fruits with excellent quality, pleasand flavor and attractive colour and free from spongy tissue
2. **Sindhu**: Ratna x Alphonso - Regular bearer, medium sized fruits with appealing colour, good quality, stones are very thin (30mm) and seedless (Rudimentary seed)
3. **Konkan Ruchi**: Neelam x Alphonso- Regular, large fruits and suitable for pickling

MPKV: Rahuri

1. **Sai Sugandha**: Totapuri x Kesar

FRS: Sanga reddy

1. Manjeera: Rumanik x Neelam- Dwarf, regular and prolific yielder/bearer
2. AU – Rumani: Rumani x Neelam

FRS: Kodur

1. Neelgoa: Neelam x Malgoa
2. Neebuddin: Neelam x Humayuddin
3. Neeleshan: Neelam x Benishan

CISH: Lucknow

1. Ambika : Amarapali x Janardhan pasand
2. Arunika : Amrapali x Vanraj\

TNAU- periyakulum: PKM 1 and PKM 2

Commercial Varieties

Alphonso/ Badami: A leading commercial variety of Maharashtra and Karnataka. Suitable for humid coastal climate. Having good keeping quality and suitable for table and canning purpose. It is susceptible to spongy tissue and Biennial in bearing.

Banglora/ Totapuri/collector

A commercial variety of south India and it is regular in bearing. Quality is poor but good keeping quality. It is an early variety and susceptible to stone weevil.

Dashehari:

It is mid season variety with fibreless flash. Have good keeping quality. Suitable for canning and cold storage and alternate bearing, highly susceptible to malformation

Benishan/Banganpally

Adopted to and regions, fruits are medium in size, flattened, fibreless, regular to irregular bearer and good yields and good keeping quality.

Raspuri/Pairi

Commercial variety of south and western India

Fruits are medium in size, early variety with alternte bearing

Neelam

Cultivated in Tamil nadu, It is a late variety, regular bearer, It has good keeping quality. Being a late variety, fruits are infested by stone weevil

Langra: It is cultivated in North & Eastern, midseason variety. Poor keeping quality, alternate bearer

Khader: A synonym of Alphonso, Best suited for dry regions of north Karnataka. Quality is superior, fruits are large in size

Mulgoa

A late season variety with good quality fruits and fruits re large in size

It is a shy bearer (no. of fruit is very less)

vi. Propagation

a. Sexual methods: By seeds
b. Asexual methods:

- Grafting
- Budding
- Cuttings
- Layering

✓ **Grafting**

- **Soft wood grafting:** t is the commercial method of grafting

We have to do the grafting in current season growth (growth take place recently)

Select procured scion (1 week before)

Wedge grafting should be done on 10-12 months old seedling root stock

Keep seedlings under mist house (85-90% success)

Usually followed in months of August – September

- **Epecotyl/stone grafting:** Commercially practiced in M.H, KA, Kerala. This is considered as efficient, economic and rapid method of propagation in mango.

Rootstocks used are very young (15-21 days)

Select the procured scions

Give a cut at epicotyl region. (5 cm above the stone)

Followed by wedge grafting (stone is still attached in the seedling)

Young grafted plants are shifted to poly bags keep it in mist house.

It is performed successfully in June-July months.

- **In-arching/Approach grafting:**

The one year old rootstalks are suitable for this method

For the ease of grafting the mother tree should have lower spreading branches. In the absence the raised platforms are prepared to bring scion shoot and stalk together.

The bark of 5cm length, 2mm depth is removed by means of sharp grafting knife of both stalk and scion.

They are tied together tightly by polythene strip.

After 45-60 days of grafting a 'V' shaped notch is given half way to both stalk and scion just below the graft union. Leave it for two weeks, after two weeks deepen the notch to ⅔ or ¾th of thickness of shoot.

After two weeks graft is separated.

- **Veener and side grafting:**

1 year old root stocks are used

10 days of before practice, we have to do pre-curing of scion

Top working:

40-50 year old mango tree is beheaded

New sprouts are coming out (4to 5 years later)

We can perform grafting on 4-5 years old new sprout on 7 cm away. The new sprouts acts as root stock

It make the old tree more reproductive, commercial etc…
It is a process called Rejuvenation
It is done on old unproductive, senile, decreased and which have undescript origin
It is a very commercial practice in cashew
Budding: Patch, Shield and Forket Budding can be tries with medium success.

vii. Soil requirement

Mango grows in all soils with good depth 2 meter minimum and good drainage except black cotton soils. Alluvial, lateritic red loamy soils are suitable, slight acidic soils are preferred. Avoid extremely sandy, rocky, calcareous, clayey, water logged and black cotton soils. Optimum PH is 5.5 to 7.5 and avoided clay, silt saline soil conditions. Can tolerate salinity up to 4.5 ds/m.

viii. Climate requirement

Mango thrives well in tropical and sub tropical climate. It can be grown from sea level to an altitude of about 1400 meters. The optimum temperature range is 24 ^{0}C to 27 ^{0}C. It can be grown in areas with rainfall from 25cm to 250cm, High rainfall before flowering – higher vegetative growth. Frequent rains and high RH – high pest and disease. Medium humidity water stress or rest 2-3 months before flowering improves flower bud formation.Dry cool winter @ flowering and Bright sunny days @ fruiting is ideal

Flowering season: South India: November – December – January
North India: February – March

ix. Cultivation: Mango can perform better in both tropical and sub tropical climatic condition.

x. Land Preparation:

- Deep ploughing, harrowing, leveling; gentle slope for drainage.
- Square system of planting.
- **Spacing of mango tree:**
- - 10 m x 10 m = 100 trees/ha
- - 10 m x 8 m = 125 trees/ha
- - 10 m x 5 m = 200 trees/ha
- 12x12m (wider spacing) – 69 plants/ha
- 10m x 10m in dry zones to 12m x 12m in heavy rainfall areas; Vigour of the variety also to be considered. Pit size= 90 x 90 x 90 cm^3 is ideal
- Pit size:- 0.5m^3 in light soils to 1.0m^3 in heavy soils
- Open the pits prior to monsoon (April & May) and expose the pits to sunlight.
- Pits exposed, filled with organic manure & top soil. Dusted with Aldrin 150 g/pitor
- All the pits with 25kg FYM and 2.5kg single super phosphate (SSP), 1kg murate of potash also we can give neemcake minimum of 1kg.
- 0.5% Termex solution can be added to pits for termite problem.
- Planting – at centre of pit and Graft joint above soil

xi. High Density Planting: 5m x 5 m (400 plants /ha)

For high density planting, the distance can be 5x3 or 5x2.5 or 3x2.5 or 2.5x2.5m.

In To avoid wastage of lands go for high density planting (to utilize the land effectively). It is popularized inIndia (in case of mango) on variety of Amrapali (dwarf) by IARI. Spacing is – 2.5 x 2.5m can accommodate 1600 plants/ha.

Practices to control the spreading & height

1. Dehorning:
   - Plants are allowed to grow for 10 year
   - After 10 year, in 11th year remove the shoots or branches in the tune of 25% to 50%
2. In order to go for HDP, dwarfing rootstocks can be used. Those are
   - Vellaikolamban
   - Olur
3. Dwarf varieties or hybrids: In India hybrids like
   - Amrapali (2.5x2.5m)
   - Sindu (5x5m)
   - Arka Aruna (5x5m)
4. Can use growth regulators to reduce the growth of tree eg: CCC (Cycocyl), Cultar

Planting: Different for different climatic conditions

South India: June – September
North India: July – September

Planting and aftercare

- One year old healthy grafts are planted with the onset of rains.
- The best time for planting all over India is during the monsoon season June –July when the humidity level is high.
- Graft union above ground level. Stake the plants to make them grow straight.
- After planting each plant should be protected from the stray cattles by fencing
- Intercultural operations are equally important bearing mango filed.

xii. Watering

Watering has to be done depending on climatic condition, should be given 2 to 3 days upto 2 to 3 years. For new plants 30 lit/week. For a bearing tree 120 lit/plantper week.

xiii. Training & pruning

In initial years of its establishment it should be trained (open centered)

- Distribution of sunlight is equal since it is trained in open centered.
- Cut the main stem after a specific height 4-5 evenly sized and branched branches are retained after removing other uneven branches.

xiv. Terminal flowering: Normally mango trees require very less or no pruning however, the training of the plants in the initial stages is very essential to give them proper shape. Flowering takes place on terminal flowering. In current season growth the mango doesn't flower only in mature shoots mango gets flowered so pruning is restricted to removal of cris-crossed branches, decreased branches. If branches are pruned vegetative flush will increase, the mango will not flower since it flowers terminally.

xv. Manuring and fertilizers

- It is evergreen tree, since the tree is large they require large amount of manures and fertilizer. Especially C: N ration goes on reducing so it should be maintained and balanced. If N is less and C is more it goes to flower. If N is more and C is less it give vegetative growth. Mango is an irregular bearer about 25kg of manure per tree.
- Fertilizer depends upon the age of the plant.

Age	N	P	K
1 year	75g	20	70
2 year	750	40	140
10 year	750	200	700

Go on doubling every year up to 10 year

From 10 year the NPK should be restricted to 750, 200 and 700 respectively.

Dosage of fertilizers:

1st dose: (June – July) – 50% N and K

2nd dose: (September – October) – remaining 50% N & K full dose of P

Application of fertilizers

Active root zone in mango is – 1.2 – 2.4m from the base of mango tree (periphery of tree). The application of fertilizer should be done in active zone. Depth of the ring in active zone is – 30 cm (root density is more at that region) Breath of the ring is -60 – 90cm.

xvi. Fertilizer Requirement

73g N (170g urea), 18g P_2O_5 (112 super phosphate), 68g K_2O (114g muriate of potash)/plant/year of age from first to tenth year, continuation of tenth year dose thereafter. Two splits:- ½ N+P+K in June-July; ½ N in October. Applied by broadcasting in the basins leaving 30 cm from the tree trunk, followed by hoeing into a depth of 15cm. IIHR –Bangalore bearing trees maybe given 750g N, 200g, 200g P2O5 and 1150g K2O/year/tree. It is better always to apply organic manures during October. Watering should be done soon if no rains. Micro- nutrients- Ca, B, Zn, Fe applied to soil or in the form of foliar spray.

xvii. Irrigation

Initial days – 2-3 days interval, 2-5 year – 4-5 days interval, 5-8 year – 10-15 days interval from 5th to ten year – 5-6 days interval, >10 year – 10-15 days interval.

Irrigation should be completely stopped prior to flowering (2-3 months prior to flowering) in absence of H_2O the vegetative flushes of mango is converted into flowering buds. So it should be preferably dry during fruit bud differentiation (FBD).

FBD (Fruit bud differentiation) is usually occurs in a month of Oct – November

xviii. Inter cropping

- Preferably intercrops are single season crops like vegetables, pulses, cereals. In initial of 5-6 years we can go for intercropping and intercrops – Banana, Papaya, Pineapple ideal

Inter culture: Cultural operation practices during cultivation in young orchards

1. **Weeding:** Regular weeding should be done. Plough the orchard in every 3 months. Can cultivate legumes in ploughed spaces
2. **Types of ploughing:** May – June: Deep ploughing – soil can expose to sun so we can control pest and diseases. It is repeated in September – October.

xix. Flowering and Sex ratio: Start from February extends upto march**.** Mango bears flower on the terminal shoots**.** Produces flowers and bears fruits mostly on terminal buds of shoot

Flowering in mango is influenced by genetic and environmental factors:

- The internal factor that governs and controls the entire phenomenon of flowering in mango is the maturity of an age of its vegetative growth.
- The shoots which are about 8-10 months old and cease growing atleast 4 months prior to flowering season are capable of producing flower buds
- Flowering is preceded by the differentiation of flower buds in shoots which finally give rise to fruit.
- However in some to the regular bearing variety (Neelam, Totapuri, Rumani) the size and maturity of shoots don not play an important role for determining the fruit bud differentiation.
- Generally the fruit bud differentiation (FBD) occurs during October – December months.

Fruit set and development: Mango is known for poor fruit set and % of fruit set varies from 0.001 to 10%**.** The growth curve follows single sigmoid patterns

Fruit drop: Mango exhibit maximum fruit drop among all the fruit cops (90-99%)

There are reports that only 0.01% of pollinated perfect flowers set fruits.

Main causes: Lack of pollination, low stigmatic receptivity and **u**nfavourable climatic condition – Rains, wind, cloudiness**.** Incidence of pest and diseases – Mango hoppers, Mealy bugs, Powdery mildew, Anthracnose. Hormonal imbalance in the developing fruits.

Control measures:

1. Good orchard management.
2. Regular irrigation and plant protection measures from fruit set up to development.
3. Application of growth regulators like NAA (25-40ppm).
4. 2,4-D @ 10-15ppm or CCC (Cycocyl) @ 200ppm

These have to be sprayed immediately after fruit set helps to reduce fruit drop considerably.

xx. Harvesting and yield

Mango fruits are ready for harvesting in 90-100 days after fruit set.

- Matured green fruits are harvested and ripened under ambient condition (stored in room temperature for ripening). Delayed harvesting cause the spoilage.
- Maturity of the fruit is judged based on size, shape, colour and TSS (Total soluble solids) and specific gravity.

- Manual harvesting of individual fruits with long pole having cutting blade fitted with nylon net to hold the harvested fruits.
- It is advisable to harvest mango fruits with 1 cm peduncle. To avoid rupture of the resin ducts, which results in undesirable blemishes (scars)?

Tapka method

Traditionally followed by farmer to judge maturity when few fruits fall from the tree.

Yield

xxi. A 5 year old tree : 15-20 fruits/tree/year

10th year : 400-600 fruits/year

20th year : >1000 fruits/year

Precooking should be done by placing the fruits under shade immediately after harvest to remove the field heal.

1. Air cooling: Under the shade or using air providing equipment
2. Hydro cooling: by using cool water
3. Vaccum cooling: under vaccum condition

Grading: Grouping the fruits into different classes depending upon size, shape and colour.

Europian market:

Extra class : 551-800g, Class I : 351-550g, Class II: 200-350g

Packing: In Indian markets - Wooden crates**,** Bamboo baskets **and** CFB boxes (most commonly used)

Plant Protection

xxii. Pests

a. **Mango Hoppers:** *Ideoscopus clypelis, Ideoscopus nitidular* – It is the serious pests of mango.



Symptoms:

Adults and nymphs suck the sap, tender shoots, leaves and panicle. Leads to flower shedding. The panicle becomes dried and fruit setting is reduced.

- Hopper secrets honey dew on which sooty mould grows on leaves and panicles.

Control

- Spraying before flowering with carbaryl @ 4g/litre.
- melathion @ 2ml/litre
- OR Manocrotophos @ 1.25ml/litre
- OR Phosphomidon @ 0.5ml/litre
- It has to be repeated after fruit set

Biological control

- Predator: Coccinellids feeds on the nymphs of mango hopper
- Pathogen like: (Entomophygous pathogen)

b. Stem borers: *Bactocera rufimaculata*

Symptoms:

- The grubs feed inside the main trunk and branches
- Adults emerge during July – August
- Dry excrete emerging from the tunnels helps to identify the pest

Control measures

- Cleaning the tunnels and covering with monocrotophos soaked in cotton
- Apply carbaryl at the rate of 5g/hale and plug with mud or soil
- Apply kerosene dipped in cotton to the infected portion (crude method)
- Celphos tablet (Aluminium phosphate) at the rate of 3gm/hole.

c. Shoot borer

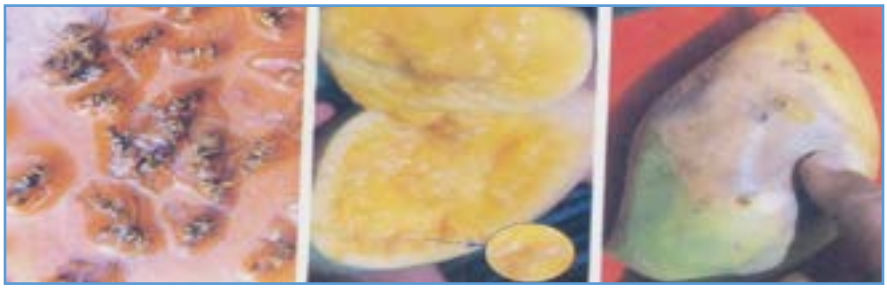
- The caterpillar's bores young mango shoots from terminal end and bore down to a depth of 10-15cm resulting in shoot wilting and drying. The incidence is severe in April.



Control
Spray carbaryl @ 2g/lit 2-3 times
Ekalux @ 0.05%
Monocrotophos @ 0.04% at fort night interval (15 days) from emergence of new fleshes.

d. **Fruit fly:** *Daucus dorsalis*

This is a serious pest which has hindered the export of mango from India to western countries. Adult lays eggs in clusters of 150-200 under the peel of fruit just before maturity and ripening the maggots feed on the pulp and convert it into off smelling rotten smelling liquid and the affected fruits drop off.



Control

- Collect and destroy the fallen fruits (prevent further spreading)
- Ploughing of interspaces during summer months to expose the hibernating pupae (hide below the soil)
- Use of pheromone traps having methyl eugenol. 100ml + 0.1% melathion or any other insecticide during April-June.
- Early harvesting of fruits
- Irradiation
- Vapor heat treatments (VHT)

e. **Mealy bugs:** *Drosicha mangifera*

- Specific to mango. The nymphs emerging in December, January from soil climb and settle on young shoots, twigs, flowers and young fruits. They suck the sap and affected plant parts dry up.



- **Control:**

Conventional

1. Dig the soil and mix Methyl Parathion dust @ 2% or 250g in the basal region during summer.
2. Banding tree trunk with slippery alkathene sheet in November – December (pest cant climb on tree)
3. Make sticky bands at 30-40cm above the ground with rosin and castor oil or grease and coal tar

Chemical treatment:

1. Spray 0.2% carbaryl or Manocrotophos @ 0.04% to kill nymphs on shoots.

5. **Mango stone / nut weevil:** Tunnelled cotyledons in mature fruit. Fruit dropping at marble stage. Faecal matter in the pulp and exit hole on matured fruit. Avoid growing Sweet varieties (alphonso, totapuri, neelam) and late varieties. Collection and destruction of infested fallen fruits. Ploughing orchard after fruit harvest to expose hibernating adults. Hot water treatment of fruit for specified period at 60°C kills the weevil inside the stone.

Spray Acephate 75 SP 1.5g/lit. Or Lambdacyhalothrin 5 EC 2.5 ml/lit at marble size stage of fruits, followed by deltamethrin @ 1 ml/L after 2-3 week

Red Tree Ant/Tailor Ant

Ant live inside the nest made by joining the leaves by silken threads produced by grub.Nest – chambers – food materials like live scale insects – honey dew secretion.Cutting and burning of nest. Spray application

f. **Gall midge**: Several species reported damaging mango

Eggs laid on under surface of leaves. On hatching maggots bore inside leaf tissue – small raised wart like galls. Deformed - drop pre-maturely

- If infestation is severe, spray dimethoate 2 ml/lit
- Phosphamidon – 1 ml/lit
- Monocrotophos – 2 ml/lit

xxiii. Diseases

a. Powdery mildew – *Oidium mangifera*

Congenial conditions:

- Warm humid weather and coal nights
- Flowers and newly set fruits are covered with grayish white powdery marks resulting in cassation of growth and shedding of flowers and fruits.

Control:

- Sprauing wettable sulphur/sulfex @ 0.2% at an interval of 10 days

1st spray – before flowering
2nd spray – after fruit set
OR contaf @ 2ml/litre

b. Anthracnose: Collatotrichum gleosporides

It is serious disease in humid and high rainfall areas at a temperature of 24-32°C.

Symptoms

- Brown spots are noticed on leaves and stems which further spread and coalesce and the affected part dries.
- Flower panicles dry and shed

Control:

1. Spraying Bordaux mixture of 1% concentration or Carbandazin @ 1g/litre

c. Mould

The development of fungus on leaves, twigs and inflorescence especially on the honey dew secreted by hoppers resulting in formation of black sooty cover on the infected area.

Control:

- Control mango hoppers by spraying dimethoate @ 1.7ml/liter.
- Spray sulphur 3g/liter, before spraying of fungicide one water spray should be given. Mix the fungicide in starch source (Maida/Gujji) and spray.

d. Red ant, *Oecophylla smaradina*

Nests should be removed and destroyed mechanically or by spraying any of the contact insecticides

- Monocrotophos 2ml/lit or DDPV 100EC 1ml/lit

e. Grey Blight : *Pestalotia mangiferae*

- Brown spots develop on the margin and at the tip of the leaf lamina. They increase in size and become dark brown. Black dots appear on the spots which are acervuli of the fungus.
- Survive on mango leaves for over a year. Spreads through wind borne conidia.
- Remove and destroy infected plant parts.
- Spraying copper oxychloride 0.25 Mancozeb 0.25% or Bordeaux mixture 1.0%.

f. Stem end rot: *Diplodia natalensis*

Prune and destroy infected twigs and spray Carbendazim or Thiophanate Methyl (0.1%) or

- Chlorathalonil (0.2%) as fortnightly interval during rainy season.

g. Bacterial canker disease (*Xanthomonas campestris pv. mangiferaeindicae)*

xxiv. Physiological disorder of Mango

Biennial bearing/Alternate bearing/Irregular bearing/Erratic bearing

In mango most of the varieties exhibit a clear pattern of cropping. i.e., Biennial bearing, which indicates in the on year optimum or heavy fruiting followed by an year of little or no fruiting.

The year of optimum or heavy fruiting is called as 'on year' and the year of little or no fruiting is called as 'off year'.

Causes

1. The genetic character of the variety
2. Adverse climatic conditions i.e R.H., heavy winds, low temperature etc.
3. Cultural operations followed
4. Pest and diseases
5. Sex ratio: male to perfect flowers
6. Occurrence of improper pollination
7. Bearing nature of the tree (Terminal/lateral bearing)
8. C:N ration of the shoot
9. Hormonal balance in the shoot: level of auxins and ABA (inhibitor), lower levels of Gibberellins – promote vegetative shoots.
10. Maturity of the shoots

Control/Management of Biennial bearing

1. Proper care and maintenance of orchards in a healthy stage judicious and timely manuring, irrigation and plant protection measures.
2. De-blossoming
   In one year to promote flowering in the off year it is successfully practiced.
   Spraying of NAA @ 500 ppm at full bloom stage.
3. Pruning: Pruning in on year (during July to august) to increase emergence of number o shoots.
4. Chemical regulation
   a) Application of cultar (Pachlobutrazole) @ 10g a.i is mixed in 5 litre of water applied in a ring of 15cm depth dug at 60cm away from the tree trunk.
   b) It should be applied in August.
   c) It is followed in Alphonso.

Technology-

Paclobutrazol (PBZ) and uniconazole widely used in fruit crops like mango, effectively controls vegetative growth and enhances flowering and yield, especially in alternate bearing cultivars.

It acts by inhibiting gibberellin biosynthesis, increasing cytokinin, root activity and the C: N ratio. While soil application in September-November is common, it's long persistence in soil and mixed effects on nutrient uptake raise concerns.

Application of Paclobutrazol @ 10 g a.i. for non-bearing trees during first fortnight of September will induce flowering and fruitset yield during off years.

Mango malformation

- First reported in Bihar (1891)
- Common in all the north Indian states
- South Indian states are free from this problem
- It is found in Bombay green, Chausa, Dashehari, Amrapali
- The economic losses vary between 5-20%
- Malformation is the production of thick vegetative shoots at the growing tips and transformation of floral parts into a compact mass of sterile flowers.

Two types

1. Vegetative malformation
2. Floral malformation

Vegetative malformation

Swelling of buds and formation of small shoots with short internodes and the apical end results in witches broom like appearance or vegetative shoots.

Floral malformation

Pennicles become malformed with short and thick rachis giving the infloranscense a cluster appearance mostly with only male flowers.

Causes

- Fugal infections – *Fusarium maniliformne – Fusarium salani*
- Infection by mites: *Aceria mangifera*
- Mycoplasma – MLO's (Mycoplasma like organisms)
- Nutritional anomalies/imbalance

- Hormonal imbalance – low level of auxin – Higher level of gibberellins promote malformation
- Malformin – component responsible for malformation

Control

- Spray NAA @ 200 ppm during October (flower bud different)
- Manual removal of all the affected parts or shoots followed by two sprays of captan @ 0.2% - Melathion @ 0.1%
- Adoption of timely cultural operations
- Use of good quality/healthy mother plants
- Spray with antimalforme__ like – Glutathion, Ascorbic acid (Vit. C) @ 2.2g/litre (amla/Aonla)
- Use of resistant variety

3. **Spongy tissue/Soft centre:** eg- Alphonso

Spongy tissue is a no edible sour, yellowish spongy like patches with or without air pockets developing in the fruit during ripening.

This disorder is serious in Maharashtra, Karnataka, Gujrath, Andra Pradesh.

Losses are of a tone of 35-55% in Alphonso depending on age of tree, season time of picking, location, maturity of fruit and environmental condition.

Other varieties susceptible are: Vanraj, Jamadar, Suvarna Rekha, Mallika

Causes

1. Pathological reasons : *Bacillus* species
2. Varietal susceptibility
3. Biochemical reasons
4. Nutritional aspects like NPK,Ca, Mg
5. Soil moisture content
6. High sunlight and atmospheric temperature
7. Orchard should be located in E – W direction
8. Convective heat

Convective heat arising from the soil is the main cause of damage at maturity stage during April – May. The soil temperature rises to above 55.8°C as a result of solar radiation. The resulted convective

heat 1st touches apex and the fruit hanging down the trees and the pulp gets heated resulting into spongy tissue.

9. Delay in harvesting

Control

- Establish tail growing shade plants in the borders of mango orchard
- Sod culture rather than clean cultivation – growing of grass in orchard reduces the temperature of soil and also convection heat
- Mulching with straw (basin)
- Post harvest dipping of fruits in ethephon @ 500 ppm
- Early harvesting of fruits

Black tip

This disorder is observed commonly in North-Indian states. Blackening and hardening of distal ends of fruits affected fruit show premature ripening and reduced market acceptability. The incidence was found more near brick kilns. The factories where bricks are prepared by mud) gases are released like Co_2, Sulphur dioxide, acetylene in fumes.

Control

- Permitting brick kilns away from orchards
- Increasing chimney height: 15-18mt.
- Spraying with borax (0.6%) before flowering, during flowering and at fruit setting stage
- Spray with sodium carbonate 2% immediately after fruit set.

Other minor disorders

1. **Internal necrosis**

- Browning of flesh in the fruit when still attach to the tree
- Found more in immature fruits and the fruits drop prematurely
- Cause: Boron deficiency – mainly in sandy soils

Control:

- Application of borax 500g/tree (soil application), borax @ 1%: Foliar spray

2. **Clustering /Jhumka**
   - This malady is characterized by a cluster of fruitlets at the tip of the panicle giving an appearance of bunch tip called Jhumka
   - These fruitlets are dark green with deeper curve in the sinus beak region compared with normally developing fruitlets
   - One of the main reason for clustering is the adverse climate during Feb –March particularly the low temperature.
   - The incidence of Jhumka can be reduced by spray of 200 to 300 ppm NAA during November &lesser use of pesticides in the mango orchard during full bloom.

3. **Leaf scorch – Nutritional disorder:** Identified by the development of brick red color towards the tip and along the margins of old leaf ultimately tissue collapses to necrotic patches. It is caused by flurine deficiency which inhibites the potassium intake. Use of Sulphate of potash as source of potassium can check leaf scorch
4. **Fruit cracking – deficiency of Boran and Calcium**

Taper tip: In this disorder, usually the distal end of the fruit is affected showing intensification of the normal green colour in fruits tapering abruptly which are often curved. The affected fruits are smaller in size and are easily detachable from the stalk. It has been observed in cultivars like Dashehari, Bombay green, Bombay yellow & Lucknow safeda.

5. **Fruit pitting** disorder is characterized by formation of small sunken pits in equal proportion on the peel of the fruits on all the sides when they have half grown. The malady is result of boron deficiency &poor orchard management
6. **Jelly seed: In** this disorder the pulp surrounding the stone disintegrates completely. Turning to jelly like mass. In severe cases there is development of internal cavity & affected fruits when cut give bad odour.The disorder is detected only *when fruits are cut as they look normally external. However , in severe cases the beak is soft to touch*

Production technologies of Sapota

B.N: Achras Zapota, Syn: Manilkara achras. Fam: Sapotaceae Chr.No: 2n= 26.

1. Importance

Sapota or sapodilla (*Manilkara achras*), popularly known as sapodilla and *chiku*, is an important tropical fruit. Introduced in India in 18th century. It is a delicious tropical fruit valued for its sweet fruits in India. Known for gummy latex which is used as gum. Product is extracted from trunk and unriped fruit is referred at chuckle.

Origin and distribution: Origin: Tropical America (Mexica)

Native to tropical America especially from south Mexico or Central America cultivated in West Indies, Philippines, Malaysia, Indonesia, Srilanka and India. In India, Sapota cultivation was taken up for the first time in Maharashtra in 1898 in a village named Gholkward. India is considered to be the largest producer of sapota in the world. In India, Sapota is commercially grown in Karnataka, Gujarat, AP, WB, Maharastra and TN. Production wise Karnataka stands 1st and followed by Maharashtra, Tamil Nadu, Andhra Pradesh and West Bengal. It gives high economic returns

2. Present Area, Production and Productivity of Sapota in India

- Area – 1.63 lakh ha
- Production- 14.95lakh MT
- Productivity – 9.1 MT/ ha
- Percentage of total fruit area-2.3%
- Percentage of fruit Production-1.8%

3. Composition and uses: It is a rich source of CHO: 1.48g, Protein: 0.7g,Fat: 1.1g Ca: 28mg, P: 327mg, Fe: 2mg, Ascorbic acid: 6mg

Uses:

1. Sapota is good source of sugars, protein, fat, fibber and minerals (Ca, P, and Fe).
2. Sapota is a delicious dessert fruit.
3. Fruits can be dried and made into nutritious powder which can be used in Milk shakes and sweets.
4. In countries (Indonesia) Young leafy shoots are used in salads or as vegetable.
5. Sapota is supposed to be medicinal also seeds as diuretic, bark as tonic, antipyretic, febrifuge and in curing biliousness and febrile attacks.
6. Commercially used as fresh fruit, in the preparation of juice, jam, jelly.
7. Used for manufacture of Industrial glucose and pectin
8. Preparation of chickle which is used as base material for chewing gums

4. **Soil**: Sapota can be grown in almost all types of soils, grows well in deep alluvial, sandy loam, red laterite and medium black. Proper drainage should be provided. It can stand the presence of salts in the soil or irrigation water to some extent. It is sensitive to high lime content in the soil. Calcareous soils (Ph 6-8) give good crops of Sapota.
5. **Climate:** Sapota being a tropical fruit, can be grown from MSL to1200mtrs. It prefers warm and moist weather. Under high attitudes fruits are of inferior quality. Optimum temperature b/n 25-34^{0}C. If temperature> 40^{0}C - there is a possibility of fruit drop and scorching. Dry and strong wind do cause damage to flower and fruits. Rain fall of 125-250cm is optimum.

6. Species, types and cultivars: Sapota cultivars are grouped into 4 types based on nature of branches and colour of foliage as follows.

a. Trees with erect growing habit: Branches appearing in whorls, leafy dark green, broad and oval, fruits large and superior.

c. Trees with drooping habit: Branches in whorls, leaves light green narrow and elliptical, fruit small, inferior.

D.Trees with spreading habit: Branches irregular, leaves dark green, broad and oval, fruits medium to large, superior.

e. Trees with spreading habit: but with inferior quality fruits.

It is a slow growing over green tree growing to a height of 9m flowers are borne on tgerminal shoots in leaf axils of past season growth. Fruit is berry. Flowers as Protogynous (They are self incompatible is highly cross pollinated. In these stigma become receptive before the anther studs its pollen (of same flower).

7. Cultivars/ varities:

Kalipatti-commercially grown in Maharashtra, Gujarath, North Karnataka. Has spreading branches, oval shaped fruits, fruits appear singly-superior.

Chhatri: Similar to kalipatti with droping branches in whorls not that good.

Dhola Diwani: Whitish oval fruits with superior quality

Long: Has narrow and small leaves, fruits long poor bearer.

Bhuri or Bhuripatti Medium bearer, fruits large superior.

Jingar: Medium sized tree, small leaves, and fruits in clusters.

Vanjeet: Slow growing, knots on stems shy bearer, superior.

Pala: Popular in AP and TN fruits small, oval, heavy bearer in clusters.

Kirthabharati: Popular in AP. Fruits small to medium with 4-5 ridges, oval, superior, withstands long transport.

Dwarapudi: Popular in AP. fruits round like cricket ball, superior.

Cricket ball: Popular in TN, Karnatataka, Maharastra, WB AP. Fruits large, round, superior, shybearer.

Oval: Fruits small to medium, oval, inferior shy bearer.

Vanivalasa: AP, fruits oval, medium sized, medium quality.

Calcatta Round: WB, Karnataka, AP fruits large, medium quality.

Jonnavalasa-1: AP fruits medium, ovate, superior and no ridges

Jonnavalasa-2: AP, fruits medium, ovate, depression at stalk end, whitish flakes on skin eight ridges superior.

Baramasi: WB, Bihar, UP fruits medium, round medium quality.

Pot Sapota: Fruits small, oval, superior, bears in pots itself

Gavarayya: AP, TN fruits small with varied shoulders 8-10 ridges, superior.

Thagarampudi: TN fruits medium to sized round or oval, superior, good for export.

Ayyangare: TN fruits medium to large, round or obovate, rose scented, superior.

Table 1: Sapota varieties/ hybrids developed in India

Variety	Parentage	Shape	TSS(Brix)	Fr.weight(g)

CO-1	Cricket Ball x Oval	Oval	18	125
CO-2	Clonal selection from Baramasi	Obovate to round	23	200
CO-3	Cricket Ball x Vanivallasa	Oval	24.2	-
PKM-1	Selecation from Guthi	Oblong	NA	NA
PKM-2	Guthi x Kirthabarti	Obong	NA	NA
PKM-3	Kalipatti x Cricket Ball	Oblong	NA	NA
PKM-4	Clone of PKM	-	-	-
DHS-1	Kalipatti x Cricket Ball	Oblong	25	150
DHS-2	Kalipatti xCricket Ball	Round	23	180

8. Propagation and Rootstocks: Sapota is mainly propagated by vegetative methods-Approach grafting and soft wood grafting is commercial practice on Rayan or khirni (Manilkara hexandra) Stocks. Other stocks used are: 1.Sapota seedlings, 2.Adams apple (*M. kauki*), 3.Mahua (*M.latifolia*), 4. Mee Tree (Bassia Longifolia), 5. Star apple (Chry sophyllum cainito) and 6. Miracular fruit (Sideroxylon dulcifieum). Among the different rootstocks rayan / Khirni is the most vigorous and productive rootstock. 1 year old seedlings are used as root stock for grafting

9. Grafting time/period: Approach grafting during: February (Jan-March). Soft wood grafting during: May-July**.** Air layering using 10,000 PPM (1BA+NAA) good rooting. . Building is also practiced it is cheap & easy method, single bud is collected from well matured shoot and budded Air layering- not practiced of oozing of latex inhibits root formation.

10. Planting: Prepare land by ploughing and harrowing. Dig pits of above 1m x 1m x 1m at a distance of 10m x 10m or 12m x 12m apart. Fill the pits with top soil and mixed with 25 kg FYM, 2 kg Single Super Phosphate and 100 g Folidol dust. Plant the grafts in the middle of the pit keeping graft joint above the ground level. After planting staking should be done for proper support. The planting should be done during rainy or winter season. High density planting with 5.0mx5.0 m spacing improves yield. It is better to have a wind break around the Sapota plot. Best season is monsoon season.

11. Training and Pruning

It is trained on central leader system. Should remove periodically the water suckers from the rootstock. Pruning is not advisable and it is restricted to dead, decayed, diseased criss cross branches since it bears flowers in past season growth. For existence one better to remove the lower most branches on the trunk up to 60-90cm as they will be touching the ground and mostly unproductivities. Stock sports should be removed from time to time. No regular pruning is needed for Sapota.

Manuring: Bearing tree of 11 years is given 400gN, 160gP and 450gK per year in addition to 30kg FYM and graded doses are applied from the beginning according to the growth of the plant. Application of more 'N' is reported to increase the yield. Manuring should be done in 2 spilt doses coinciding with the mansoons.

Age of the tree	Nitrogen	Phosphorus	Potash
	(grams /tree)		
1-3 Years	50	25	75
4-6 Years	100	40	150
7-10 years	200	80	300
11 years and onward	400	160	450

The first half is applied in the beginning of the monsoon (June-July) and the remaining half the dose at the end of the monsoon (September-October). Fertilizers are applied in a shallow circular trench 15-22cm deep, 15cm wide and 60-90cm away from the trunk. After application, the fertilizers are covered with top soil and irrigated.

If the soil deficient of "K: the fruits become hard and unripe is known as mummification, small fruit sized and finally fruit may drop. This disorder is commonly associated with older plants, neglected orchards.

11. **Irrigation**: Sapota can tolerate drought to some extent but irrigations help in improving the yield. Regular irrigations should be given from planting till the plant establishes well. Later irrigations may be according to need and soil and weather conditions. Insufficient irrigations result in dropping of flowers. Drip irrigation can be more useful
    Young plants are watered regularly during dry season and at long breaks in the monsoon, winter and summer at an interval of 6-12 days. In areas where there is water scarcity, drip or pitcher irrigation systems can be effectively practiced.

13. Intercultural: Intercrops like banana, papaya, leguminous vegetables can be grown profitably during the pre-bearing period. Weeding should be regular. Frequent weeding or mulching is necessary for first few years. Application of 2 kg bromacil and diuron 2 kg /ha as pre-emergence spray is effective in controlling weeds for a period of 10-12 months

14. Flowering and fruit set: However, there are two main seasons of flowering i.e. March-April and September-October and hence, two harvesting seasons. Flowering thought the year the flowering may start from 2nd and 3rd year after planting but the economic yield can be obtained from 7th year onwards. Maximum flowering is seen in month of June, flowers appear in leaf axil and they are perfect flowers. Pollination is by wind.

Problem of fruit set is common shedding and low fertility causes fruit drop,>50% fruits drop from plant after anthesis. To improve the fruit set application of 100PPM SADH, Planofix- 300PPM is also recommended to reduce the fruit drop and to produce large size fruit. To get higher fruit set and retention of the fruits, GA, Ethrel, CCC, and Planofix were tried on Cricket Ball cultivar. Planofix at 300 ppm and GA_3 100ppm resulted in the highest fruit retention and largest fruits. NAA at 25-100 ppm at flowering and at 15 days interval resulted in fruit set.

15. Fruit maturity and harvesting:

Sapota fruits mature in about 9-10 months from flowering. The fruits ripen after harvesting and have to be harvested after fully maturity. Fruits are to be harvested at fully maturity stage. Since Sapota is a climacteric fruit, it improves quality after harvesting. The fruits to be harvested must be fully matured and maturity can be judge by several external symptoms.

- Fruits at full maturity develop a dull orange or potato brown colour.
- A mature fruit when scratched shows light yellow streak instead of a green streak.
- Brown scaly material disappears from the fruit surface.
- As the fruit matures, the milky latex content is reduced.

- The dried spine like stigma at the tip of the fruit falls of easily when touched
- Fruits are harvested either by hands or by using fruit pickers.
- To avoid bruising of fruits, they are collected in gunny bags and lowered from trees. Fruits should be harvested with stalk intact.
- Peak harvesting periods are Jan-Feb and May-June in Maharashtra and March-May and Sep-October in Karnataka and AP. Sapota normally produces fruit throughout the year.

16. Average yield will be;

3 year – 100 fruits, 5 year-250 fruits, 7 year-700, fruits, 8 year-800 fruits, 10 year- 1000 fruits, 11 year-1500 fruits, 15 year-2000 fruits, 30 year-2500-3000 fruits/plant/year. Large sized cultivars like cricket ball, Calcutta round give small no of fruits but will be sold at higher rates. 15-20 tonne/ha.

19. Post Harvest Management

Grading is mainly based on size and shape of the fruits. The fruits are graded into three categories depending on their size viz. large, medium and small. The fruits are highly perishable and can be stored under ordinary condition for a period of 7-8 days after harvesting.

20. Ripening and storage: fruits ripen after harvest in about 4-13 days depending upon cultivar. Ripening can be hastened by treating with ethrel (250-750ppm). Between 12-14^{0}C fruits ripen slowly and keep well for

about 5 weeks, Ripe fruits can be stored at 2-3^{0}C and 85-90% R.H. for 6 weeks and firm fruits for 8 weeks at 3 to 5^{0}C and 85-95% R.H. storage life 21-25 days by removing ethylene and adding 5-10% CO_2 to storage atmosphere. The fruits are dipped in GA (300 ppm.) and Bavistin (1000 ppm.) solution at a pre-packing stage in order to extend the storage life of the fruits.

In some cases, the produce after harvesting is packed in wooden containers and transported to the urban areas for sale. Wooden boxes prevent damage of ripened fruits and fetch better price in urban areas.

21. Physiological disorders

i. Fruit depression:

- Development of a depression or furrow towards the calyx end usually appears immediately after heavy rainfall & is aggravated by high intensity of irrigation.
- The fruits do not develop into their normal shape.

Control measure

- Avoiding over irrigation can check this malady.

ii. Mishaped fruits: Mainly due to high temperature, high rain falls.

iii. Corkiness of fruits: Cause: The fruits exposed to intense sunlight do not ripen uniformly, developing corkiness during winter. This is probably due to killing of hydrolysing enzymes by alternating moisture accumulation and heating of fruit surface in winter. Thus its trees need to grow vigorously

iv. Oblongation of fruit

- The shape of fruit is related with number of seeds in it which depend on conditions for pollination at anthesis. High temperature and rainfall during flowering cause oblongation of fruits.
- Therefore, cultivation of sapota in areas with extreme summer temperature should be avoided.
- **Fasciation:** Flattening of shoots **Cause:** Multiple causes

v. Wilt or die back

- Wilt or die-back is common where sapota cultivation is being extended to traditionally rice-growing regions.
- Due to anaerobic conditions in monsoon and post-monsoon season in such areas wilt is of common appearance aggravated by *Fusarium* spp.
- This can be controlled by effectuve drainage facility before planting

vi. Pests and Diseases

a. Stem borer (*Indarbela tetraonis*). The grub of this small beetle bores into bark of the Sapota trunk and feeds on the living tissue inside the bark. The chewed bark is seen on the hole.

Control measures:

1. Kill the insect by thrusting a stiff wire into the tunnel.
2. Plug the hole with a wad of cotton in kerosene at 0.1 percent and plaster with wet mud. This treatment
3. Creates suffocation inside the hole or tunnel which results in death of the insect inside.

b. Bud / fruit borer: Larvae bore the flower buds as well as fruits resulting into severe damage to the fruit



- **Control:**
- Spray Dimethoate @ 1.7ml/litre

c. Leaf minor: The tiny caterpillar of a grayish moth mines into the surface of young leaves. Affected leaves curl up, mines are seen on the surface of leaves and sometimes caterpillars are found inside the mines. Later on, affected leaves get destroyed, dry up and fall.

Control measures: Spray once or twice Dimethate (30ml in 18 liters of water) or Malathion (30ml in 18 liters of water)

d. Mealy bug: (Phenacoccus icerjoides), It is sucking insect. It is a small, over in shape with a cottony white, waxy on the under surface of leaves and base of the fruit near the fruit stalks. They suck the sap and secrete large quantities of sugary sub stones. Leaves have a block coating which gives thema sickly appearance.

Control measures: Spray dimethoate at the rate of 30ml in 18 liters of water. Try to keep free sapota plantation from red onts because these help in distributing mealy bugs from one tree to another. Red ants are effectively controlled with a dusting of a mixture of BHC 5 percent with sulphur in the proportion of 2:1.

e. Scale insects: (Pulvinaria psidil). They suck the sap by infesting along the sides of midrib and surface of leaves and twinges. These scales are green or grown in colour and oval shaped.

Control measures: Spray Dimethoate or Malathion at 30ml in 18 liters of water.

f. Fruit borer (Virachola Isocrates). Borer attacks on fruits and some times buds which can easily be detected by seeing the latex which comes out on the surface of the infested fruits, the latex later crystallizes.

Control measures:

1. Spray 0.05 Malathion
2. Spray 0.01% Fenvalerate/0.01% endosufan.

g. Leaf webber

Leaf webber can be controlled by spraying Phosalone 35 EC 2 ml/lit.

h. Hairy caterpillars: Hairy caterpillars are effectively controlled by spraying Chloropyriphos 20 EC or Quinalphos 25EC or Phosalone 35 EC 2 ml/lit of water.

Diseases

a. **Leafspot: (Phoecophleospora indica).** The causal fungus results in dark brown, the adjacent spots on leaves. When infection is severe, the adjacent spots become large irregular whitish patches. In severe caser, the defoliation of leaves may be noticed.

b. **Leaf spot and Sooty mould**



Control measures:

1. Spray -78 @0.2% at an interval of 30 days.

2. Grow resistant varieties like Co-1, Cricket Ball. The varieties Co-2 & Kalipatti are torerant, but calcutha round is susceptible.

c. **Sooty mould (*Capnodium sps*):** Sooty mould is incited by Capnodiuor: The causal fungal disease develops on the honey like excretion by scale insects and mealy bugs.

Control measures:

1. Spray Zineb @ 40 g in 18 liters water.
2. Spray starch on the leaves, in one or two days it get drops off along with sooty mould in the form of flakes. spray mancozeb @ 2g/litre

d. **Flat limb (*Botryodiplodia theobromae)***

Symptom: In young stems instead of normal growth flattening takes place. On this flatted stem can see the small sized leaves with small petioles. This is a sporadic disease. In a plant 1 or 2 branch or in whole plantation 1 or 2 plants are affected.
Management: Cut the affected stems and burn and cut portion paste with COC 0.3% to avoid dieback

Production Technologies of Custard apple

Annona squamosa L., a member of the Annonaceae family with a chromosome number of 2n=14, is commonly known as custard apple. Native of Tropical America

1. Importance

The Custard apple is also called as '**fruit of poor people**' and '**evening flower scent bearing fruit crop**'. Among annonaceous fruit, custard apple is most favourite in India. The term custard apple may be applied to all Annona species producing edible fruits. In India custard apple holds significant importance among annonaceous fruits, renowned by different names like Sitaphal, Sugar apple, and Sweet sop. It is grown on marginal lands and hillocks with minimum inputs. India is one of the major producers of custard apple

2. Genetic Resourses

- *Annonas squmosa* (Sugar apple, sweetsop, sithapal): Tropical America found in wild parts of Andhra Pradesh, Hyderabad.
- *Annona reticulate* (Bullocks heart, ramphal, bull's heart): Tropical America found in Bengal, Assam.
- *Annona atimoya* (Atemoya): It is a Man made hybrid found in Egypt, Israel and Australia.
- *Annona muricata* (Sour sop, guanabana, mamphal.): Tropical America and West Indies, some parts of Maharastra, Namilnadu.
- *Annona cherimola* (Cherimoya, cherimola): Tropical America mainly in Maharastra Nilgiri hills and Nandi Hills.
- *Annona diversifolia* (Ilama, whiteannona): Tropical America cultivated in sub tropical South India.

3. Composition

The custard apple is a rich source of carbohydrates, protein, fiber, and essential minerals such as calcium, phosphorus, iron, and vitamin C. with 104 Kcal of energy, the fruit contains 23.5 grams of carbohydrates, 70.5 per cent moisture, 1.6 grams of protein, 0.9 grams of minerals, 3.1 grams of fiber, 17 milligrams of calcium, 47 milligrams of phosphorus, 1.5 milligrams of iron per 100 grams of fruit pulp. Its high phenolic and antioxidant content makes custard apple pulp valuable for pharmaceutical industries (Shrivastava *et al*., 2013).

4. Uses

- It contains 20% of sugar. Used as a table fruit
- Custard apple is rich in carbohydrates, proteins and minerals like calcium, phosphorus and iron.
- It is a good source of vitamins A&C.
- Its calorific value ranges from 822 to 1050 k cal per kg as compared with 741 of mango. Pulp mixed with milk or icecream
- Ripe fruit of custard apple are generally used as a table fruit.
- Even un-riped fruits are directly backed on fire & eaten in Andhra Pradesh.
- The fruit pulp can be used in ice creams, confectionery, bevarges & certain milk products.
- Preservation in the form of jelly, jam& other products is also possible for short duration.
- Preserved as jam, jelly or other products
- Fruits, seeds, leaves and roots have medicinal value both in Ayurvedic and Yunani
- Seed oil used in soap and paint industry
- Has inseticidal properties against Rice Tungro Virus

- Seed cake contains 4% N and is beneficial as mannure

5. Medicinal use

- bioactive compounds, mainly flavonoids, alkaloids
  - acetogenins,
- Acetogenins are potential anticancer property compounds as they cytostatic have effect.
- Flavonoids found in seeds, roots, bark
- Stems are potential chemopreventive agents, given evidence that they decrease tumour incidence.
- Ethanol extracts of cherimoya seeds are used as insecticides and antiparasitic properties.
- The roots are used to treat acute dysentery, depression and spinal marrow diseases.
- Skin disease, intestinal worms and inflammation of the eye.
- Used in folk medicines. Pharmaceutical research has found antifungal, bacteriostatic, antimalarial
- Acetogenins are thought to have anti-HIV and anti-cancer effects.

6. Origin and Distribution

Scientific Name	Common Name	Origin
Annona squmosa	Sugar apple, Sweetsop, Sithapal	Tropical America
Annona reticulate	Bullocks heart, Ramphal, Bulls heart	Tropical America
Annonas atimoya	Atemoya	Found in Egypt, Israel and Australia
Annonas muricata	Sour soup, Guanabana, Mamphal	Tropical America, West Indies
Annonas cherimola	Cherimoya, cherimola	Tropical America
Annona diversifolia	Ilama, White annona	Tropical America

- Custard apple is believed to be a native of the West Indies but it was carried in early times through Central America to southern Mexico.
- It has long been cultivated and naturalized as far south as Peru and Brazil .It is commonly grown in the Bahamas ,and occasionally in Bermuda and southern Florida
- Apparently, it was introduced in to tropical Africa early in the 17th century and is grown in South Africa as a dooryard fruit tree.
- In India, the tree is cultivated especially around Kolkata, and grows wild in many areas .It has become fairly common on the eastcoast of Malaya, and more or less throughout Southeast Asia and the Philippines, though now here is it particularly esteemed. Eighty years ago it was reported as thoroughly naturalised in Guam, in the Pacific, though it is not known in Hawaii.
- The custard apple has been growing in India for time immemorial. It is found growing wild in sub-tropical and tropical parts of India.

Among annonaceous fruits, custard-apple is the most favourite in India. Its plants come up unattended in parts of Andhra Pradesh, Assam, Bihar, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Rajasthan and Tamil Nadu as a scrub or hedge plant. Of late, custard apple has gained commercial significance and exclusive orchards are emerging in Andhra Pradesh and Maharashtra.

7. Area and Production

In India custard apple holds significant importance among annonaceous fruits, renowned by different names like Sitaphal, Sugar apple, and Sweet sop due to its exceptionally sweet and delicate flesh, making it a delicacy in dry regions, with production of 3.87(000 M T) and a growing area of 45,000 ha (Anon., 2021) whereas, Karnataka produces 7.26 (000 MT).

Table 2: Species and Cultivar

Species	Commercial Varieties
Sugar Apple -*Annona squmosa*	Balanagar, Red sitaphal, Red sugar apple, Barbados, British guinea and mammoth.

Atemoya -*Annonas atimoya*	Pink's mammoth, Island gem, Bullock's heart.
Cherimoya- A.*herimola*	Golden russet, Pink's mammoth, Lisa, Libby.
Soursop -*Annonas muricata*	Morado, Lisa.
Ram phal - *Annona reticulate*	ArkaNeelchalVikram,APK-1, NMK-1,2,3,Tikal

8. **Varieties/Cultivars of Custard apple**

Depending on external fruit colour, custard-apple is distinguished into green, red and yellow. But green ones are by far more common and popular than the other types. Balanagar, Barbados Seedling, British Guinea, Kakarlapahad, Local Sitaphal, Mahaboobnagar, Saharanpur Local and Washington are some of the varieties with green skin.

Balanagar

- Green Skinned fruits with medium size.
- High yielding type. TSS 20.7° brix

British guinea

- Fruit weight is about 151gm and 37.9%pulp.
- 17.9% total sugar.

Mammoth

- Fruit weight about 183g/fruit.
- TSS content :23%,acidity 0.19%
- Good quality fruits.

Barbados seedling:

- Fruits having high sugar content.
- Fruits having green rind, orange yellow margins.
- Late season variety.

Red sitaphal:

- This variety originated as a chance seedling.
- Fruits are dark pinkish.
- Having average quality and more number of seeds.

Kakarlapahad:

- Very high yielding variety.
- It is very sweet and crispy in nature.

APK (Ca)1:

- Released from RRS, Aruppukottai, TN during 2003.
- Yield-14.9kg/tree.
- Fruits are medium in size, heart shaped and TSS 24.5*Brix.

Tropical sun:

- Released from Australian custard apple growers association (ACAGA).
- Suitable for home gardens.
- Ripening at room temperature.

Washington: This is an introduced variety. The fruit is large, pulpy, few seeded and greenish white in colour. Bearing is sparse.

Island Gem: This is an Australian variety. The fruit is very large in size, smooth surface, very large segments, very pulpy very delicious, few seeded, greenish white in colour, pulp very sweet, excellent flavour, bearing is sparse fruits irregular in shape, keeps for about a week.

Pink's Mammoth: This is a variety of Atemoya, introduced from Australia. The fruit is very large, ovoid, pulpy, delicious, veryfew seeded and greenish pink in colour, smooth surface, has very broad and round segments, excellent in quality, bearing is poor. Fruits are irregular in shape. Fruits keep for about a weak after ripening without damage.

NMK 01 Golden : This is popular, high-yield farmer variety, known for its golden skin, sweet creamy pulp and drought tolerance, developed by farmer Navnath Kaspate in India, offering big harvests in dry regions

and gaining popularity for home gardens and commercial farming due to its early fruiting and disease resistance.

Thar Amrit: A new high-yielding custard apple variety for dryland
Other varieties are: NMK Arvi, NMK Samruddhi, Purandhar.

Important hybrid varieties:

ArkaSahan (2001): *Annona atemoya× Annona squamosa. (Island gem × mammoth)*. Released from IIHR, Bangalore. A hybrid Arka Sahan has slow ripening (6–7 days), better shelf-life (2–3 days), less number of seeds (10/100g fruit weight) and high brix (31°). On an average its fruits weigh 210g each. A 6-year-old plant yields 17kg fruits.

African Pride: *Annona cherimola× Annona squamosa.* Having good quality fruits.

Atemoya: This is a hybrid between Seethaphal and Cherimoya. Atemoya grows to a height of about 5-6m and has luxuriant growth. Hence, planting distance must be 7m x 7m. Ripe fruits are whitish green in colour, juicy, delicious and pulpy with an excellent acidic flavour. Very few seeded. Keeping quality good, can be kept even upto 10 days. Bearing is erratic. For every 8-10 plants of Atemoya, one custard apple plant should be planted in the middle to act as polleniser plant, otherwise the bearing of Atemoya will be poor and erratic. Atemoya fruits will come to harvest from October to December

9. Climate and Soil

- Custard apple is adapted widely to tropical climate and prefers moderate winter and high humidity during flowering time.
- Trees cannot withstand frost and prolonged cold weather.
- Continuous rains during flowering and fruit set results in poor yield optimum rainfall is 60-80cm.
- Strong wind causes limb damage, heavy flower drop and fruit damage.
- Trees grown in wide variety of soils including sandy, marginal and waste land.
- Fertile, well drained sandy loam soils with neutral to slight acidic Ph give better performance.
- Heavy soil and waterlogged conditions are not suitable.
- Water stagnation leads to shrivelling of branches and sudden death of plants.
- . It is typical of stony soils along rivers, along the coast and on fallow land, as well as on hills and slopes.

10. Propagation

Both by sexual and asexual method. For genetic uniformity higher yield of better quality fruits clonal propagation is must. Vegetative propagation- Budding and grafting, Stooling and Cuttings.

Grafting: insitu cleft grafting is used, best rootstock are *Annona cherimoya* and *Annona squamosa*
Budding: Patch, Shied and clip budding

Establishment of Orchard

Table 3: Spacing adopted for different Annona species

Scientific name	Common name	Spacing adopted (m)
A. cherimola	Cherimoya	6 x 4 to 8 x 6
A. squamasa	Custard apple	3 x 3 to 5 x 5; 4 x 4; 5 x 7
A. muricota	Soursop	4 x 4 to 8 x 8
A reticulate	Bullock's heart	5 x 5

11. Planting

- Land is prepared by ploughing, harrowing, leveling and removing weeds.
- The custard apple fruits are planting in the square or triangular systems.
- Pits are made of 50-60 cubic cm, pits are filled with top soils and 25-30kg FYM.
- Spacing:4 ×5m
- Time of planting: During June-July. After 1or 2 rains the saplings are planted in the centre of the pit.

- Shading, staking and watering should be done to protect grafts after planting in the main field.
- Pit size : 60×60×60 cm

12. High density planting systems: 3.0X3.0 m

13. Manuring and Irrigation: Application of nutrients to custard apple depends upon the soils and climate conditions. Custard apple trees are well response to fertilizer application in terms of increased vigour, production and quality. In the absences of water in post monsoon period 2-3 irrigations help in better quality of fruit and higher production. Irrigation – 2-3 irrigations before the onset of monsoon to promote fruit set and 1-2 irrigation after the monsoon to increase fruit size.

Manuring and fertilizers- 250gN:125gP:125gK per plant

Table 4: Recommendation of NPK fertilisation for custard apple

Age after planting (years)	Nitrogen (g/plant)	Phosphorus (g/plant)	Potassium (g/plant)	Organic manure (kg/plant)
1-2	75	50	50	25
3-5	150	100	100	25-50
> 5	250	125	125	50

14. Pruning

Pruning is one of the most crucial practices that influence the vigor, production and quality of fruits in custard apple. Not only can pruning enhance fruit quality, but it is also necessary at an early stage to establish a strong framework in order to enlarge the fruit bearing area before the tree becomes weakened and loses both fruit size and quality. Therefore, consistent annual pruning at the fruit bearing stage may help to encourage excellent, healthy branches that will give the greatest amount of fruit bearing area and good fruits

Selective and mild pruning of deadwood and very old branches should be carried out to avoid congestion and encourage well-spaced branching. Severe pruning is detrimental for the plant growth. Yellowing of leaves starts as the harvesting season of fruits ends. The leaves begin to drop with the onset of winter and fresh growth occurs in spring. Flowering occurs singly or rarely in small clusters mostly on current season's growth and occasionally on old wood.

15. Training

Strong tree frame work in custard apple is obtained by training young plants during the initial stages of growth. Keeping single stem upto 50-70cm height and then inducing scaffold branches in all directions makes good frame work of tree. To avoid crowding, proper space among the branches is maintained by removing criss-cross and overlapping branches. Training to a single stem is the only option when rootstock is employed

16. Flowering and fruit set

Plants starts bearing after 3-4 years of planting. Flowering period commences from March-April and continuously to July-August, the peak time is April – May. An average plant bears about 2000 flowers and the fruit set is about 2-3%. Very low fruit set in custard apple is a problem under natural conditions, 1-8% fruit set is reported. The main reason for poor pollination is due to dichogamy, hypogamy. The external factors like high and low humidity prevailing at the time of flowering, soil moisture stress. Hand pollination can be done for better fruiting. Fruit can be improved by application of growth regulators, GA(50 ppm) at blooming stage, Biocil (1ml/litre) just prior to flowering.

17. Maturity indices

- Change in fruit colour from dark green to light green.
- Yellowish white colour developed between the segments.
- Initial cracking in carpels.

18. Harvesting and Yield

Plucked when fruit is still firm and plumpy otherwise gets damaged due to splitting instead of ripening. Should harvest when fruits have attained light green colour. Every fruit has to be examined every alternate day to judge the stage of maturity. Harvesting starts from August and continues till December.

19. Yield

- Tree starts yielding from 3rd year. Single crop (4-5 pickings) in August to October in south India and September to November in North India.
- A well managed grown up custard apple can produce 80-100 fruits/tree.
- Older tree rarely exceed 100 fruits/tree unless hand pollination.
- The 8 year old seedling yield an average of 149 fruits per plant and 18.7 t /ha.
- Arka sahan hybrid produces 25 tonnes fruits/ha.

20. Handling

- Ripen very soon after harvest, normally at 15-30° C.
- The fruits should be wrapped in perforated polyethylene bags.
- To distant markets fruits should be wrapped in strong piece of paper and allowed sufficient ventilation.
- Could be stored for a week when treated with 8% wax emulsion in combination with 400 ppm 2,4-D and 2,4,5-T.

21. Post harvest technology: Fruit has very poor shelf life, therefore for distant markets comparatively harder fruits has to be harvested. Arka sahan has better shelf life.

22. Physiological disorders

Fruit Cracking

This usually happens from a heavy rainfall or irrigation after a prolonged day spell. Evenly distributed irrigation schedule and constant and uniform moisture level in the soil will reduce this problem.

i. Stone fruit

- Neglected trees and plants under moisture stress conditions enter into dormancy, well in advance before harvesting of all fruits is over.
- Remaining fruits turn brown, become hard and further development ceases leading to retainment of them on trees for prolonged time**.**

23. Management: Proper management practices like timely application of fertilizers and irrigation.

This **mummification** of fruits appears to be a natural thinning mechanism, especially during periods of drought. Tree decline caused by water stagnation is another problem. Such trees shrivel and drying of old branches takes place and they die suddenly. Stagnation of water during heavy rains should be avoided.

Woodiness: Presence of woody seed pockets and gritty lumps in flesh and brown pulp indicating discolouration of pulp**.**

Management: Using dwarfing rootstocks of *A.squamosa* or dwarfing rootstocks of *A.cherimola*. Maintenance of enough Ca concentration in leaves and fruits.

Plant protection

a. Fruit borer: *Heterographis bengalella*

Symptom of damage

- Caterpillar bore into the fruits and make tunnel inside
- Feed on the internal content of the fruits
- Affected fruits fall to ground
- Black coloured caterpillar

Management

- Collect and destroy the damaged fruits
- Spray endosulfan 0.07% or malathion 0.1% two times once at flower formation and second at fruit set

b. Fruitfly:*Bactrocerzonata*

Symptom of damage

- Maggot bore into the semi ripened fruits
- Feed on the inside fruits
- Affected fruits – shriveled, malformed, rot and fall off
- **Larva -** Yellowish apodous maggots.
- **Adult -** Light brown with transparent wing

Management

- Collect fallen infested fruits and dispose them by dumping in a pit and covering with soil.
- Provide summer ploughing to expose the pupa
- Immersion of fruits in hot water (45 to 470 C) for 60 minutes to kill eggs and maggots
- Monitor the activity of flies with methyl eugenol sex lure traps.
- Use bait spray combing any one of the insecticides and molasses or jaggery 10 g/l,
    - fenthion 100EC 1ml/l,
    - malathion 50EC 2 ml/l,
    - dimethoate 30 EC 1 ml/l,
    - Carbaryl 50 WP 4 g/l.two rounds at 2 weeks interval before ripening of fruits.
- Prepare bait with methyl eugenol 1% solution mixed with Malathion 0.1%.
- Take 10 ml of this mixture per trap and keep them in 25 different places in one hectare.
- Spray malathion 50 EC at 0.1% or fenthion 100 EC at 1ml/lit
- Field release of natural enemies *Opius compensates* and *Spalangia philippines*

c. **Tailed mealy bug**: ***Ferrisa virgata***

Symptoms of damage

- Adults and crawlers – setting on leaves, young shoots and fruit (between segments)
- Yellowing of leaves
- Reduction of fruit size and do not fetch premium price in the market

- **Nymph:** Yellowish to pale white.
  Adult: Females apterous, long, slender covered with white waxy secretions

ii. Management

- Collect and destroy the mealy bug infested leaves, shoots and fruits
- Spray dichlorvos 0.05%, two times at new flush and shoot formation and second at fruit set.
- Release *Cryptolaemous montrouzieri* beetles @ 10/tree.

Diseases

Leaf spot - *Alternaria* spp. Anthracnose - *Colletotrichum cingulata*
Fruit rot- *Phytopthera citrophthora* Bacterial wilt - *Pseudomonas solanacearum*
Root rot- *Armillaria mellea, Rhizoctonia* spp.

Fruit rot (*Glomerella cingulata*)

The fruit infection takes place both from blossom end as well as stem end side as dry brown spots.

Control: Apply Carbendazim/Thiophanate 1g/lit and Chlorothalonil/Mancozeb 2g/lit during rainy season.

Leaf spot
Symptoms:

- Small yellowish spots first appear along the leaf margins, which gradually enlarge and turn into brownish patches with concentric rings.

- Severe infection leads to drying and defoliation.

- Dark brown-purplish patches appear on the infected fruits and rachis just below its attachment with the shoots.

Production Technologies of Aonla

B.N - *Emblica officianalis / Phyllanthus emblica* **Origin: Tropical Asia**

Family: Euphorbiaceaea **Chromosome level -2n= 28 Type of fruit -Capsule**

1. Importance

Aonla or Indian gooseberry is also known as Indian amla. It is an important crop of Indian origin which is grown throughout North West Indian plains. It is very rich from nutritional point of view being next to Barbados cherry in terms of vitamin C content (500-750mg/100g pulp)which is not oxidized due to presence of tannins and even it is least destroyed during storage. Besides, it has an excellent medicinal value. It can be grown successfully in arid climate and in the soils of higher pH and poor fertility wastelands.

Tree is hardy and of medium height. However, seedlings tree can attain height up to 30m. it is evergreen, however, leaf shedding takes place during February-March. Tree trunk is smooth and whitish which resembles guava.

Fruit of 21st century: Owing to its hardy nature, sustainability to various wasteland and high productivity, it has high production potential with low maintenance cost and enormous therapeutic and nutritive values.

2. Chemical constituents

- These fruits are reputed to contain high amounts of ascorbic acid (vitamin C), and have a bitter taste that may derive from a high density of Ellagitannins, such as Emblicanin A (37%), Emblicanin B (33%), Punigluconin (12%).
- The active ingredient that has significant pharmacological action in the plant has been designated 'phyllanemblinin' by the scientists in India.
- Aonla also contains punicafolin other polyphenols, such as flavonoids, ellagic acid, and gallic acid.
- The nutritive elements per 100g of edible portion of aonla are as follows:

3. Composition: Natural Capsule of Ascorbic acid and Amritphal

- Moisture: 81.2%
- Protein: 0.5%
- Fat: 0.1%
- Mineral matter: 0.7%
- Fibre: 3.4%
- Carbohydrates: 14%
- Calcium: 0.05%
- Phosphorous: 0.02%
- Iron: 1.2%
- Vitamin-B: 30mg/100g
- Vitamin-C: 600mg/100g
- Nictonic acid: 0.2mg/100g

Use:

Culinary use

- The amla fruit is eaten raw or cooked into various dishes, such as dal (a lentil preparation) and amle ka murabbah, a sweet dish made by soaking the berries in sugar syrup until they are candied.
- In South India, its fruits are used to make pickle.
- It is traditionally consumed after meals.
- Tender varieties of the fruit are used to prepare dishes as well.
- In the Batak area of Sumatra, Indonesia, the inner bark is used to impart an astringent, bitter taste to the broth of a traditional fish soup known as **holat**.

Medicinal use

- Aonla fruit is highly valued among indigenous medicines. All parts of the plant are used in various Ayurvedic medicine herbal preparations, including the fruit, seed, leaves, root, bark and flowers.
- Its fruits are a rich source of vitamin 'C' and so it proves to be an effective medicine against scurvy.
- Powdered dry fruits is mixed with an equal quantity of sugar and consumed thrice daily with milk, to remedy scurvy.
- The juice obtained from its fruit, when consumed regularly, stimulates the pancreas to secrete insulin and reduces the sugar level in blood

- It is known to be excellent in preserving eyesight. It is also beneficial in treating conjunctivitis and glaucoma, by reducing intraocular tension.
- The oil prepared by using this herb is excellent for hair health and prevents graying.
- It is considered to be a good remedy against heart diseases.
- It is acrid, cooling, diuretic and laxative.
- Dried fruits have been reported to be useful in diarrhoea, dysentery, anaemia, jaundice, dyspepsia and cough.
- Trifla and Chavanprash are well-known indigenous medicines in Ayurvedic system using aonla.

Aonla is valued as an anti-scorbutic, diuretic, laxative, alterative and antibiotic. It is being used to treat respiratory and cardiac problems, rheumatism, scurvy and ageing ailments. If consumed regularly it improves immunity and vigour (kayakalp). Apart from chayavanaprash, a large number of medicines are being prepared from aonla viz., Triphala, amrit kalash, Trilax, Amla plex, Neutrale, Tylophora plus, etc.
Processing industry: The processing potentiality of aonla fruits is yet to be fully tapped. The fruits are made into preserves (morabba), candy, dried chips, tablet, jellies, pickles, powder etc., aonla can be a substitute for habitual gutka user. Aonla supari can easily replace pan gutkha, which is good for health.

4. Origin and history

- The aonla tree is native to tropical Southeast Asia (Indo-China), particularly central or southern India, Pakistan, Bangladesh, Sri Lanka, Southern China.
- Aonla is known and grown in India for last 3500 years.
- In India, domestication of aonla was first started in Varanasi, Uttar Pradesh with the initiative of Maharaja of Kashi.
- Those brought from Varanasi were named as 'Banarasi' and those brought from Gujarat were known as Francis and later on as Hathijhool because of its drooping branches.
- A seedling of Banarasi, with prolific bearing and flat fruits was named as Chakla and now it is known as Chakaiya.

5. Distribution

India ranks **first** in the world in area and production of this crop.

- Apart from India it is grown commercially in Sri Lanka, Pakistan, China, Malaysia, Bhutan, Thailand, Vietnam, USA (Hawaii & Florida).
- In India, It is commercially cultivated in Uttar Pradesh, Uttarakhand, Gujarat, Maharashtra, Rajasthan Tamil Nadu, Andhra Pradesh, Karnataka, Bihar, Haryana, Madhya Pradesh, Rajasthan and West Bengal (Pathak 2003).
- In Uttar Pradesh, its cultivation is more common in Pratapgarh, Varanasi, Sultanpur, Azamgarh, Jaunpur, Agra and Bareilly.
- Of which, Pratapgarh (Aonla belt) is a leading district of aonla cultivation on commercial scale throughout the country
- In last two decades, there has been tremendous increase in the area under aonla cultivation across the country, utilizing the wasteland.
- This has resulted in efficient utilization of resources leading to better income to farmers, nutritional security coupled with enhanced employment and rehabilitation of wastelands.

Table 5: Area and Production :(2019-2020)

India	Area	Production	Productivity
Fruits	6.664 m Ha	99.069 m MT	14.87 MT/Ha
Aonla	95000 Ha	1.107 m MT	11.65 MT/Ha
Leading in	UP	UP	AP

6. Varieties/Cultivars Banarasi - An early-maturing variety and it has less number of female flowers and has self incompatibilty hence it is a shy-bearer, prone to heavy dropping of fruits with poor keeping quality. **Chakaiya** – Fruits are fibrous and hard, smaller in size and also have a tendency to bear heavy crop in alternate years.

Francis - It is fibreless and has moderate keeping quality. It highly suffers from severe incidence of fruit necrosis.
Francis (Hathi Jhool) : An old cultivar, erect and tall growing with drooping branches .Fruit is large, flattened, oval, skin smooth, greenish yellow in colour. The flesh is soft, nearly fibreless. Keeping quality is very poor. It is highly susceptible to fruit necrosis thus not suitable for preserve making
Kanchan (NA-4) - A seedling selection from Chakaiya .It is heavy and regular bearer with medium-sized fruits, having higher fibre content. It is preferred by industries for pulp extraction and manufacturing of various products.

Krishna (NA-5) - Seedling selection from Banarasi and It is an early maturing variety

Amrit (NA-6) - A seedling selection from Chakaiya, prolific and heavy bearer and It is ideal for preserve and candy, owing to low fibre content.

Neelam (NA-7) - A seedling selection of Francis, it is precocious, prolific and regular-bearer. This is an ideal variety for preparation of products and has a great commercial promise. **NA-7 is suit for high density planting.**

NA 9 (Amrit) : Seedling selection from Banarasi. Good keeping quality and Suitable for Preserve and candy making.

Balwant (NA-10) from Banarasi : It has semi spreading growth habit, fruits yellowish green with pink tinge, highly astringent, good keeping quality, early, moderate bearer and moderately susceptible to necrosis.

Narendra Aonla – 9: Selection from Banarasi and suitable for preservation

Narendra Aonla - 10: Selection from Banarasi and suitable for dehydaration and pickling

Luxmi-52: Developed by CISH, Lucknow

Balawant: Selection from Banarasi variety. Early Variety with better salt tolerance. Flesh is fibreless

Goma Aishwariya (2007, CIAH, Bikaner) - It is an early and drought tolerant. The average yield potential is 105 kg/tree. Recent variety from CHES Godhara, Clonal selection of NA-7. Early variety, drought tolerant.

Gujarat Aonla 1/ Anand-1: Realesed by Anand Agricultural University in 1994. Average yield: 100-140 kg/tree/year. High yielding and better quality (high vitamin C) fruit. Fruits are bigger in size (43 g). Pulp with medium TSS (16.33ºBrix)
Anand-2 & 3: Trees are tall with upright growth habit. It is moderate bearer having 2-4 female flowers per branchlet.Fruits are small to medium, skin rough with medium keeping quality. Shelf life of fruit is very good. It is suitable for powder making.
BSR-1/ Bhavanisagar: It was developed at Agricultural Research Station, Bhavanisagar of Tamil Nadu Agricultural University, and Tamil Nadu. Selection from Thimban. **Self fruitful, heavy bearer with crop round the year**. Fruits are medium in size (27g) with flat stylar end and round calyx end. The juice has a TSS of 18.10 brix. High demand by ayurvedic industries.

7. **Soil:** Amla is a hardy plant, crop is not very specific in its soil requirement and it can be successfully grown in variable soil conditions.Well drained **fertile loamy soil** is the best. It is highly tolerant to salinity and sodicity of soil and cultivated in a **pH range of 6.0 -9.5**
8. **Climate:** Amla is a subtropical fruit but can also be grown successfully in semiarid and tropical regions receiving annual rainfall 350-500mm. A mature tree can tolerate freezing as well as high temperature of 46ºC. Soon after fruit set in spring, remain dormant throughout summer without any growth thus making it a highly suitable crop for arid zones. Warm temperature seems conducive for the initiation of floral buds but dry spells result in heavy fruit dropping and delay in initiation of fruit growth. It can also be grown I semi-arid to arid regions.
9. **Propagation**
   Propagated by **seeds as well as vegetative methods**. Vegetative methods are the best because seed multiplication brings wide variability in seedlings. It can also be propagated through **patch/ modified ring budding.**

Budding is easy and more common to other method of vegetative propagation. Budding done from **mid may to mid august** gives a better success. Shield, forkert and patch are more common methods of budding. Cutting and layering are successful in aonla.

Under rainfed semi-arid conditions of **Gujarat**, in-situ patch budding in May- June before onset of rain, gives more than 94 % success and survival. In- situ patch budding is more efficient and practical followed by soft wood grafting and ring budding in semi-arid region of India. This method takes less number of days for sprouting and had better vegetative growth in terms of length and vigour of sprouted shoot. Six months to one-year-old seedlings obtained from 'Desi' (Local) aonla tree are being used as rootstock**.**

10. Establishment of orchard

Planting is done during rainy season (July-August). However, it can also be done during March-April.

11. Planting

- Land is prepared by ploughing, harrowing, leveling and removing weeds.
- Grafted or budded aonla plants are planted 8 x 8 m apart during July-August or February.
- In aonla orchards, ber, guava and lemon are ideal filler plant.
- Hedge-row planting is also being tried keeping row-to-row distance of 8m, while plant-to-plant distance is reduced to 4-5m.
- Planting time : July-August
- Spacing: **8 × 8 m.**
- Pit size : 60×60×60 cm

12. High density planting systems

- There are different high density planting systems, i.e., double hedge row, square, hedge row, pair and cluster system can be applied in aonla cultivation to gain more remunerative effect from orchard.
- Based on the experiment carried out at Godhra, Economic yield/ ha (255.90 q/ha) can be obtained from double - hedge row planting system (260 plants) with an increment of 132.39 per cent over square system of planting(100plants) during 10th year under rainfed conditions of western India.
- Double hedgerow system is very effective tool to get qualitative and quantitative productivity and economic return per unit area to the rest of the planting system under rainfed condition.

13. Training/Pruning (Canopy Management)

Aonla tree does not require regular pruning but in early years for getting proper shape and development of strong frame is necessary for which young plants are trained to single stem up to the height of about 0.75 m and 4-6 well spaced primary branches with fairly wide angle should be allowed to grow at regular space all around the trunk. Plants should be trained to **modified leader system**. Subsequent pruning consists of removal of dead, infested, broken, weak or overlapping branches after the harvest of the crop should be followed. Limb breakage in aonla cultivar in NA-7 has been observed at many places due to over bearing, hence for retention of optimum crop load, balanced canopy should be ensured.

14. Rejuvenation and Top working

- There is a tendency of over lapping of canopy between 10 and 12 years of age depending on the nature of variety unless the canopy is maintained by trimming and thinning.
- Plantation which have overlapping branches lead to dead wood development decline in yield in later years.
- Such plantation can be rejuvenated through canopy redevelopment.
- Inferior old tree of aonla can be rejuvenated into superior type by doing top working.

Senile orchard, heading back of branches, Headed back tree with plastic film Tree growth after 5 months of heading back , Better canopy after top working

15. Irrigation

- Drip irrigation is appropriate which can save water up to 40-45%.
- Established aonla orchards in general do not require irrigation particularly in normal soils.
- However, irrigation at 15-20 days interval is desirable in dry summer particularly during early years of orchard establishment under wasteland conditions.
- In the bearing plantation, First irrigation should be just after manuring and fertilization (January) before flowering.

- Irrigation should be avoided during flowering (mid-March to mid-April) period.
- Irrigation at 10-15 days intervals should be given particularly in the salt-affected soils. Basin system of irrigation is well-suited for aonla.

16. Manuring and fertilization

The dose of manures and fertilizers depends upon soil fertility, age of plant and production. A dose of 10 kg farmyard manure, 100 g N, 50 g P and 100 g K should be given to one years old plants of aonla. A dose of 100kg FYM, 1000g N, 500g P and 1000g K should be given to ten year old plants of aonla. Full dose of FYM and P and half of N and K should be given in tree basin during January-February. The remaining half should be applied in August. In sodic soils, 100- 500g of B and zinc sulphate should also be incorporated along with fertilizers as per tree age and vigour.

FYM: 20-40kg/tree/year along with

Fertilizer	**N**	**P**	**K**	**Urea:**	**SSP:**	**MOP (g/tree/year)**
1-2 year	75:	50:	50	170	: 300	: 100
3-5 year	150:	100:	100	340	: 600	: 200
5th + years	300:	200:	200	700	: 1250	: 335

Foliar spray of 0.6% borax solution thrice at 10-12 day interval during September– October will control internal necrosis.

Management of Orchard

Since the fruit remains dormant in summer, the soil should not be disturbed during that period. However, legumes and green manure crops can be grown during rainy season as inter crop. Fertilizer application with nitrogen, phosphorus and potassium are recommended for fruit retention, better quality and higher yield. Aonla trees are hardy and stand very well against drought making irrigation a minimum input for the crop. However, the crop will be benefited if 2-3 irrigation are given at the time of full bloom and fruit set.

17. Intercropping: Aonla Cultivation a deep-rooted, deciduous tree with sparse foliage, is an ideal plant amicable for 2- or 3-tier cropping system. Fruits, vegetables, flowers and a few medicinal and aromatic plants are well-suited for intercropping in aonla orchards.

Some models are: aonla + ber (2-tier), aonla + guava (2-tier), aonla + ber + phalsa (3-tier), aonla + dhaincha + wheat or barely and aonla + dhaincha + onion/garlic/fenugreek

18. Flowering and fruit set: Flower bud differentiation in Banarasi aonla was observed during the first week of March and flowers started opening from the last week of March. There is no self incompatibility in aonla due to high percentage of staminate flowers. The fruits remain in dormancy for about three and half months in cv. Banarasi dormancy discontinues from last week of July 10th first week of august and fruits start developing gradually in the initial stage but rapidly during the month of September.

Flowers open in the morning whereas dehiscence of pollen grain occurs in the evening between 4 and 6 pm. Only 30% pollens are viable in cultivar Banarasi and at room temperature these become non-viable within10 days. Stigmatic receptivity starts after three days of opening of female lowers and stigma remains receptive only for 18 hr. pollination occurs through wind as well as by honeybees.

19. Maturity indices

- The colour of fruit changes during ripening. The fruits are normally light green at first but on maturity and ripening, the colour becomes dull, greenish yellow or rarely brick red. Translucent exocarp.
- Change in seed colour from creamy white to brown is an indication of fruit maturity.
- The mature fruits are hard and unyielding to the touch and so are well suited for bulk harvesting as well as distant transportation and marketing.
- For getting attractive price, fruits should be picked at proper stages of maturity and handled properly.

20. Harvesting and Yield

Fruits become ready for harvesting by November-December and can be harvested up to February. Harvesting should be done in early or in late hours of the day. The method of harvesting is hand picking of individual fruits. Individual fruits are plucked by climbing on the tree with the help of pegged bamboo or ladder. Shaking of trees are not good practice as its leads to spoilage. Aonla trees start bearing fruits from 3rd year after budding. However, the economic bearing (commercial yield) commences from 5th year and may continue to bear for 60-75 years of age under well-managed conditions.

While harvesting, fruits should not drop down on the ground. Fruits can be stored for 7-8 weeks keeping temperature at 32-35^{0}F and R.H of 85-90%

21. Yield: The average yield is about 125q/ha. An income of Rs. 12,500/ha can be obtained.

- The crop yields about **100 kg/tree** annually.
- An aonla tree may bear (yield) 100-120kg/tree, or giving 15-20 tonnes/ha.
- Average **200 kg/tree from grafted plants**.

22. Post harvest technology

Aonla fruits can be processed into number of products. The most suitable recipe determined by organoleptic evaluation for some of the important products is presented in this presentation. Stapes to be consider during processing -Fruits selection, Grading, Cleaning, Pretreatments and Processing

23. Pulp Extraction Technique

- Extraction of aonla pulp from aonla fruits is necessary for processing of various products.
- Fruits are first heated in water for about 10 min. to separate the segments from the stone.
- It also helps in removing astringency.
- Pulp is extracted by addition of water equal to the weight of segments and passing through pulping machine.

The pulp is used for preparation of beverages, jam and sauces. If pulp has to be preserved, it should be heated to 75^0 C, potassium Meta bisulphate (2 g/kg of pulp) should be mixed thoroughly and the pulp should be filled in clean sterilized bottles and sealed. Grading: Based on sizes – Large, Medium & Small

24. Grading and Storage

Amla fruits are graded into 3 grades: Large sized, small sized and blemished fruits Large sized, sound fruits are mostly utilized for preserve and candy, Small sized for chyavanprash and trifala and blemished fruits for powder and shampoo making. Aonla fruits can be stored for 6-9 days at ambient temperature. However, with a salt solution it can be stored up to 75 days.

25. Physiological disorder

i. Internal fruit necrosis: Francis variety is highly susceptible followed by Banarasi. It is characterized by browning of innermost part of mesocarpic tissues followed by browning of the epicarp. In severe cases, mesocarp of affected fruit turns black and becomes corky and gummy pockets develop. This is due to deficiency of boron.



Internal fruit necrosis

Control measures: Spray 0.6% borax or Zinc sulphate (0.4%) + Copper sulphate (0.4%) during September to October thrice at an interval of 10-15 days.

ii. Fruit drop occurs at different stages.

First wave: Fruit drop commences from April-May due to lack of pollination and fertilization. The first drop is the highest as 70 per cent of the flowers drop off within three weeks of flowering.

Second wave: The second drop is that of young fruitlets at the time of dormancy break (June-Aug.).

Third wave: It is due to embryological and physiological factors and it is spread over the entired period of the fruit development. It starts from later half of august and continuous up to harvest.

Control measures:
Use of NAA and GA3 in combination with thiourea during mid- may and mid-July may provide an effective solution to minimize yield losses in aonla caused by heavy Fruit drop

26. Insect pests
i. Bark-eating caterpillar: *Indarbela tetraonis (Moore)*

It is identified by the presence of irregular tunnels and patches covered with silken-web consisting of excreta and chewed up wood particles, on the shots, branches, and trunk. Shelter holes may be seen particularly at the joints of shoots and branches. The young shoots dry and die, giving sickly look to the tree.

Management

- Detect early infestation by periodically looking out for drying young shoots. Kill the caterpillars mechanically by inserting the iron spike in shelter holes made by these borers at early stage of infestation.
- In case of severe infestation, remove webs and insert swab of cotton wool soaked in 0.025% dichlorvos or inject water emulsion of chlorpyriphos (0.05%) and plug the holes. The larvae are parasitized by entomogenous fungus *Beauveria bassiana*

ii. Fruit Borer *(Deudorix isocrates)*
Symptoms of damage: Larva bores into the fruit in different phases-Young larva(tender fruits),Grown up larva (matured fruits).Infested tender fruits turn brown initially, and become black later.Fruits start decaying from one side, which gradually spreads all over before they fall off.
Management: Collection and destruction of damaged fruits. Remove alternate hosts- pomegranate, guava, sapota. **Ovipositional deterrent**- Neem oil 3% or NSKE 5%

iii. Bark Borer (*Indarbela tetraonis)*

Symptoms of damage: Make tunnels in the main trunk and branches. Larvae construct loose irregular webbing of silken threads. Deterioration of vitality.

Management: Keep orchard clean. Collect loose and damaged bark & destroy. Kill larvae by inserting iron spike or wire into hole. Spot application of 10 ml fenthion in 1 lit of water

Other pests are:
1. Gall caterpillar - *Betousa stylophora*
2. Leaf rolling caterpillar - *Garcillaria acidula*
3. Aphids - *Cerciaphis emblica*

26. Diseases

i. Ring rust- *Ravenella emblica* syd.

Ring rust appear as circular or semi-circular reddish solitary or gregarious spots on leaves.Later brown to black colour pustules , measuring 10-20 mm diameter appear on infected fruit. Cultivars Krishna, Kachana, Chakaiya and Narendra Aonla-7 are susceptible .This can be managed by spraying 0.2% mancozeb

ii. Anthracnose - *Glomerella cingulata*

Circular spots on fruits with concentric rings and center bearing dark coloured fungal mass. Managed by spraying Blitox 0.3% or captaf 0.25% or Bavistin 0.1%

Other diseases
1. Penicillium Fruit Rot - *Pencillium indicum*
2. Blue mould - *Penicillium citrinum*
3. Soft rot - *Phomopsis phyllanthi*
4. Black Soft Rot- *Syncephalastrum racemosum*

Production Technologies of Grape
Botanical name: *Vitis vinifera L.*

Family : Vitaceae

Sl. No.	Character	Euvitis	Muscadina
1	Bark on the stem	Slips and becomes loose and clears off as it matures	Don't slip
2	Tendrils	Forked and Bifid/trifid tendrils	It is not forked
3	Fruit clusters	Enlongated	Small and short clusters
4	Berry attachment	Berries do not drop from the clusters even after maturity	Berry is droop from the cluster as and when they ripe

Chro. No. : 38
Origin : Black sea to Caspian Sea
Type of fruit : Berry
Edible portion : Pericarp and Placenta. Study of grapes is known as viticulture

Importance

Grape is an important sub-tropical fruit crop in India and commercial fruit of the world. An India an average productivity of grape in India is 16.95 tonne/ha highest in the world. Grapevine *is* a horticultural crop which is used worldwide for production of wine and canning, raisin making, table grapes, dried fruits and grape juice.

1. **History:** It is a deciduous crop. Its natural habitat is temperate climate

It is one of the most ancient fruit crop known to mankind. Even before the wheat and Barley ie > 7000 BC.

- According to De-condolle (1886) the cultivation of grape in Egypt goes back to 4000 BC.
- In India the grape is known since long as mention of fruit is there in several ancient treaties like charaka samhita, shushrut samhita between 1356-1220 BC.
- Mention of land suitability for grape growing is found in Kautilyas – arthashastra (4 BC).
- Commercial varieties were introduced to India by invaders from Iran and Afghanistan. MD Bin Tughlaq introduced Bhokri, Fakri, Sahebi varieties in 1338 AD
- Commercial cultivation of grapes in India started in 20th Centaury and South Indian Viticulture started only around 1940.
- However, grape was known in ancient India though it was not commercially cultivated until the 14th century.

2. **Area and Production**

In 2023, India's grape area was an estimated 162,000 hectares with a production of 3,477,000 metric tons. Maharashtra leads with the largest area and production, followed by Karnataka. Globally, India ranks among the top ten grape-producing countries.

Sl. No.	State	Area ('000 ha)	Production ('000 MT)	Productivity (mt/ha)
1	Maharashtra	118.986	2488.911	24.0
2	Karnataka	36.568	787.070	14.8
3	Tamilnadu	1.997	49.153	16.8
4	Telangana	0.304	9.643	21.0
5	Mizoram	0.002	0.017	9.7
6	Andhra Pradesh	2.341	46.820	20.8
7	Others	1.3	16.6	12.5

Source: Anon, 2022

3. **Taxonomy:** 2 subgenera, 3 important species
   1. Vitis Vinifera - European grape > 90% cultivation
   2. Vitis labrusca - American grape

4. Composition and uses

Grape is rich in antioxidants

Water : 70-80%
CH_2O_S : 15-25%
Glucose : 8-13%

Fructose : 7-12%
Pectin : 0.01-0.10%
Organic acids : 0.3-1.5%
Tartaric acid : 0.2-1%
Malic acid : 0.1-0.8%
Citric acid : 0.01-0.05%
Mineral components: 0.3-0.6%
It is a very good source of Vitamin A & Vitamin B complex.

Uses

1. Used for table and juices purpose
2. Used for the preparation of raisins, wines and dry fruits
3. Preparation of vinegar, grape pomace (the material left out after the extraction of wine)
4. Grape seed oil is used in paint industries. It is having medicinal value
5. Wine making (90 % in western world)
6. Production of vinegar used as pickling agent
7. Cake used as cattle feed and poultry feed
8. Medicinal value used in treating cancer
9. Red wine consumption lower bad cholesterol and increases good cholesterol
10. Resveratal (active component having anti carcinogenic property and present in grapes) also it is an antioxidant and it reduces the heart released diseases and cholesterol. Grape pomace used in brandy

There are >10,000 varieties in world, in India 1,000 varieties are cultivated

5. Grape varieties based on purpose

- **Table grapes**: Beauty Seedless, Perlette, Delight, Pusa Seedless, Thompson Seedless, Cardinal, Anab-e-Shahi, Early Muscat, Gulabi, Black Champa and Cheema Sahebi.
- **Raisin grapes**: Thompson Seedless, Pusa Seedless, Black Corinth, Muscat of Alexandria and Kishmish Beli.
- **Juice grapes**: Banglore Blue, Beauty Seedless, Early Muscat, Champion and Black Champa.
- **Canning grapes**: Thompson Seedless, Perlette and Pusa Seedless.

Wine grapes: Muscat Canelli, Bangalore Blue, Black Champa and beauty seedless.

Red Wine grapes: Red Cabernet Sauvignon, Red Shiraz, Red Zinfandel, Red Merlot Red Pinot Noir and Red Cabernet Frank

White wine grapes: White Chardoney, White Sauvignon Blanc, White Chenin Blanc, White Vgni Blanc, White Cleirette, White Vermantino

Arka Krishna	Black Champa x Thompson Seedless	20-21%	Juice	---------
Arka Hans	Bangalore Blue x Anab-E-Shahi	18-21%	Wine making	---------
Arka Kanchan	Anab-E- Shahi x Queen of the vineyards	19-22%	Table purpose and wine making	'Muscat' flavour
Arka Shyam	Bangalore blue x Black Champa	---------	Wine making and table purpose	Resistant to anthracnose
Arka Neel Mani	Black Champa x Thompson Seedless	20-22%	Wine making and table purpose	Tolerant to anthracnose
Arka Shweta	Anab-E-Shahi x Thompson Seedless	18-19%	Table purpose	Good export potential
Arka Majestic	Angur Kalan x Black Champa	18-20%	---------	Good export potential tolerant to anthracnose
Arka Chitra	Angur Kalan x Anab-E-Shahi	20-21%	Table purpose	Tolerant to powdery mildew
Arkavati	Black Champa x Thompson Seedless	22-25%	making raisins and wine	---------
Arka Soma	Anab-E-Shahi x Queen of vineyards	20-21%	White desert wine	'Muscat' flavour, Tolerant to

				anthracnose, mildew downy and powdery
Arka Trishna	Bangalore Blue x Convent Large Black	22-23%	Wine making	Resistant to anthracnose and tolerant to downy mildew

IARI, New Delhi

1. Pusa Navrang :Madeleine Angevine x Rubired
2. Pusa Urvashi : Hur x Beauty Seedless

The following is the categorization of NRCG, Pune germplasm

i. White seeded : 85 accessions in the field
ii. Coloured seeded : 160 accessions in the field
iii. White seedless : 44 accessions in the field
iv. Coloured seedless : 22 accessions in the field
v. Rootstock accessions : 24 accessions in the field
vi. Accessions maintained in polyhouse : 65 Accessions

6. Grape growing regions of India

Region I: Mild temperate to subtropical region of North India Punjab, Haryana, U.P, Rajasthan, Delhi.
Popular varieties: Early maturing variety – Perlette, Beuty seedless, Anab –e-shahi, Pusa seedless. Varieties undergo dormancy from November – February due to cold weather.Single pruning and single cropping is practiced in North India

Region II

Comprises parts of Peninsular India. The areas are Telangana, Roal seema, North interior Karnataka, Western Maharashtra. (Bijapur, Bagalkot , Bellary, Raichur) (Pune, single, satara, Kolhapur, Nashik, solapur Aurangabad, Ahmad Nagar. Here vines do not undergo dormancy. They are pruned twice (April & October). Double pruning and single cropping is practiced.

Important Var: Thompson seedless, Sharad seedless, Sonaka, Tas-e-Ganesh, Flame seedless, crimson seedless etc
Region III: Grape growing regions of Tamil Nadu, Bangaluru, Kolar, Tumkur, Mysore. Vines do not undergo dormancy. They are pruned twice (April & October). Double pruning and double cropping. Two crops are harvested in an year.

Important var: Bangalore blue**,** Gulabi**,** Bhokri**,** Anab-e-shahi

7. Climate and Soil

It can come up in all the conditions. t is deciduous in nature in temperate region. Evergreen in other regions. Coastal and high humid and high rain fall areas are not suitable in grape cultivation.

V. vinifera sps. Prefer long warm to hot dry summer and cool winter -1600 – 3500 Degree days is required (Heat units). Heat units = Av. Mean daily temperature above 10°C x No. of days (Degree days). Ideal temperature is 15 - 35°C

Rain fall – Rains during blooming affects adversely to the fruit set. Rains during fruit maturity results in spoilage well distributed 900mm rainfall is good for grape cultivation of the humidity rises the incidence of Downy mildew increases.

Soil: Can be grown in wide range of soils if climate is suitable. Sandy loan with god drainage, fairly fertile with good organic matter are best suited. Optimum pH organic matter are best suited. Optimum pH is 6.5-7.5. Heavy soils, very shallow soils, ill drained alkaline soils are not yet al suitable.

8. **Propagation:** Hard wood cuttings are the commercial method

Cuttings are prepared from 1 year old shoots (1 year old cuttings) these are collected during pruning. Cuttings are 20-30cm length with 3 to 4 nodes are prepared and treated in 500ppm IBA which gives good rooting with > 90% success. Cuttings are planted in polythene bag or nursery beds. When they sprout shift these cuttings

in to the field. When there is a problem of soil like nematodes, the cuttings are used as rootstock (5-6 month). 5-6 month old root stocks are allowed to grow in the field for 1 year and grafting is practiced in those root stocks. Wedge grafting is followed widely in grape cultivation

Grafts on standard rootstocks.

Tissue culture / *in vitro* techniques through shoot tip culture, nodal segments are standardized for certain varieties / rootstocks for speedy multiplication.

Micropropagation protocols were standardized in varieties (Red Globe, 2A clone, Crimson seedless and Italia) and rootstocks (110R and 1103 P).

While, using root stocks, grape can be propagated by chip budding or grafting.

Role of rootstocks in viticulture

It impart vigor for the improvement of yield and quality. Resistance to salinity alkalinity, drought. Phylloxera resistance, (Phylloxera is a root feeder in Europian countries) Nematode resistances. Some types are

a. Nematode resistance rootstock
- Dogridge (*Vitis champini*)
- 1613 (Solonis x Othella)
- Sal creek / Ramsey(*Vitis champini*)
- 1616 / Solonis Riparia *(V. solonis* x *V. riparia)*
- Freedom , Harmony

b. Phylloxera resistant rootstock
- Riparia Glorie (seedling selection from *Vitis riparia*)
- St. George /Rupestris St. George *(Vitis rupestris)*
- Coudera 1202 (Mourvedra x rupestris No.1)
- Teleki 5-A *(V. berlandieri* x *v. riparia)*
- 3306 and 3309

c. Salinity tolerant rootstock: Salt creek, Dogridge,1613 and 99

d. Drought tolerant rootstocks
- 110 Richter and Ruggeri – highly tolerant
- 1103 Panlsen, SO4 and 99 Richter - tolerant
- St. George – tolerant

RS-9 - Suitable high density plantings and for valleys and coarse-textured soils

Site Selection and Preparation

- ✓ Grapes require full sunlight.
- ✓ Adequate drainage and moisture retention required.
- ✓ The best soils are loams or sandy loams with added organic matter.
- ✓ Grapes grow best in soil with a pH range of 5.5 to 6.5.
- ✓ Repeated ploughing, weeding, removal of stones field should be levelled. Commercially - square/rectangular system.

9. **Planting**: Pits can be of 1 m cube and filled with mixture of soil and manure. One year old plants are planted pruning the stem to 2-3 buds. Spacing varies according to the method of training and variety from 1.2 to 5.0 m X 2.5 to 6.6m. Planting density of 4545 vines/ha produced highest yield. Pendal system requires maximum spacing. As the plant grows staking should be provided. Best time for planting is Jan-Feb for rooted cuttings and October for unrooted insitu planting.

Spacing

- Vigorous var.
  Bower system: 3.6 x 3.6m and Telephone system: 3.6 x 3.0m
- For medium and low vigour varieties. Head system: 3.0 x 2.4m. Y system: 3.0 x 2.4m (10x8'), 3.0 x 1.8m (10x6feet)

Commercially trench planting is followed

Trench: 0.5m – width

0.75 – 1m – Depth
Trenches should be filled with Top soil to Neem cake, SSP
Planting season – Jan – June
For insitu grafting rooted cuttings are planted in Jan – February

For insitu grafting unrooted cuttings are planted in June – July

Unrooted cuttings take 10-12 months for graftings in insitu

- Rooted cuttings take 4 – 5 months for grafting.

10. **Training:** Any training system used should:

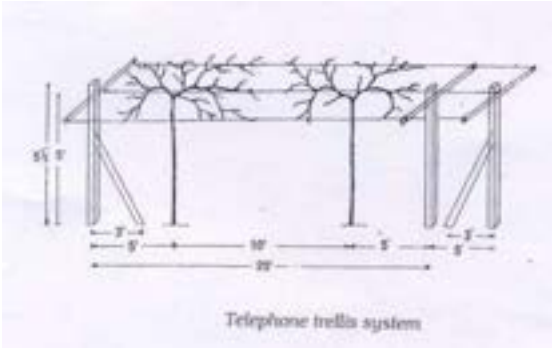
- Provide for easy operations like pruning, cultural, plant protection and harvesting.
- Distribute the following area uniformly all over.
- Provide good leaf exposure to light.
- Not be requiring bigger cuts on the permanent wood and
- Maintain the vitality of the vine for many year popular methods of training are:
- Head system (Single Stake) - Best for Beauty seedless, perlette, Delight and gold, spacing will be minimum- least expensive.
- Bower system (Arbour or pergola or Pandal): Most expensive- gives maximum yield & high cost benefit ratio. Requires maximum spacing between lines.

- Kniffin System (4- arm): Suitable for Beauty Seedless, Early Muscat, Banqui Abyad, Perlette, Bhokri and Delight.
- Horizontal trellies(T-bar): Y System
- Gable System: Connecting the side arms of adjacent vines- comparable with Pandal System.

Many training systems are in vogue in India, but the most popular are,

a. **Bower System**
   - High productive potential, bower was a very popular system of training in the past.
   - It is highly suited for vigorous varieties like Anab-e-Shahi, Bangalore Blue and Gulabi.
   - Varieties like Thompson Seedless and Tas-A-Ganesh where vine vigour and excessive foliage density affects the productivity adversely, this system is not popular.

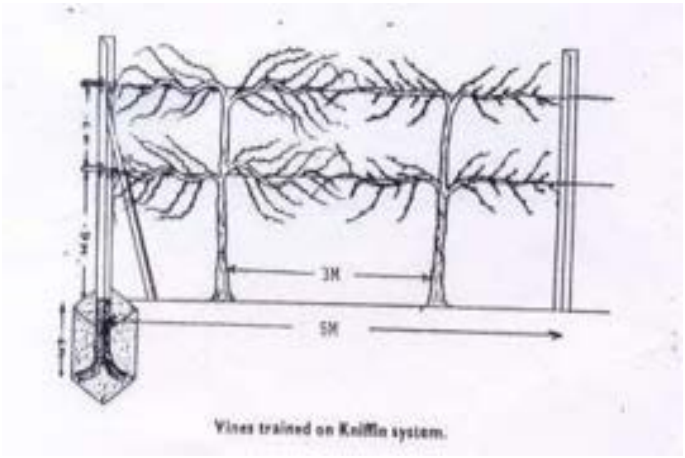
b. **Telephone System**
   - T-trellis is used in this system of training. With three top wires and 'T' shaped supports.
   - This system is followed for moderately vigorous varieties like Thompson Seedless and other seedless cultivars.
   - About 25-30 percent of the vineyard area in Maharashtra.
   - Yields in this system are less than the bower.
   - In very hot and dry places, sunburn of the berries



c. **Kniffin System/Espaliar System (1850)**

- Two arm kniffin
- Four arm kniffin

By William kniffin the 4 or 2 lateral branches are hanging freely on the system no support is given



Vines trained on Kniffin system.

d. **Overhead/Telephone system**

- North India – Single pruning single cropping
- South India – Double pruning single coping
  One pruning in summer (April)
  Second pruning in (October)

e. **Flat Roof Gable System**

- Combining the advantage of bower and the extended Y systems and eliminating their disadvantages.
- An inter-connected Y trellis forming a flat roof gable is being adopted.
- This system is followed for vigorous vines (vines grafted on rootstocks). The bunches are protected from direct sunlight and well exposed to sprays of pesticides.
- Popularity among the growers in Maharashtra, Andhra Pradesh and Karnataka.

f. **Y – method (Most practiced)**

Advantage

- Better exposure of canes to sunlight
- Avoiding direct to exposure of fruiting bunches to sunlight
- Good aeration inside the canopy
- Less pest and disease threaten
- Ease of operations (thinning, pruning etc.)
- Easy movement of intercultural implements/equipments
- Root to root distance (rows) 8'-10'

g. **Head System: Adapted for low vigorous variety**

- It is a least expensive and used for high density planting

11. **Pruning**: Pruning is an important operation in making the vine productive and vigorous. In North India, grape vines are pruned only once a year during December-January Pruning only half of the canes for fruiting and half for renewal spurs. In south India, vines are pruned twice a year. March-April (Back pruning) Pruning is for vegetative growth (renewal spurs) and canes are pruned to 1 or 2 buds only irrespective of the variety (June in Tamil Nadu) Sept-Oct Pruning (for different numbers of buds depending upon the variety (December in TN). Under Coimbatore conditions 2 crops are taken in a year pruning for fruit only two times.

Prevailing pruning practices in India

1. **Single pruning single cropping:** North India, Temperate region of the world, pruning time is late winter (Jan-February), fruiting in June – July.
2. **Double pruning single cropping:** Followed by most of the commercially grape growing. States of India – Maharashtra, Andra Pradesh, Gujarat, North Karnataka.

Time of pruning

1. April Pruning/Foundation pruning, summer pruning/Back pruning/Growth pruning.

2. Winter pruning/October pruning/Forward pruning/Fruit pruning/Fore pruning.

3. **Double pruning double cropping:**

Followed in South Karnataka, Tamil Nadu, Bangalore blue, Anab – e – Shahi, Gulabi

Time of pruning

- November – December – cropping during March – April
- May – June – cropping during August – September

Terminologies

1. The main stem of the plant is known as - Trunk.
2. Shoot – New growth of current season.
3. Cane – past season matured shoot.
4. Lateral – side branch from shoot/cane.
5. Spur – Basal portion of the cane left after pruning.
6. Fruit Spur – Spur intended to bear fruit.
7. Renewal Spur – Canes cut back to one to two buds to induce vegetative growth.

Double pruning single copping

Summer pruning/April pruning/Back pruning/Foundation pruning

This is done immediately after harvest of the crop in summer (April). The vines are forced to undergo rest for about a month. During this period water is with held to concentrate the reserves in the matured parts of the vine. All the fructing canes are pruned back to spurs to retaining only one basal nodes. This is called as summer pruning/Foundation pruning. We are removing the all shoots and going back to older stage completely back pruning.

October pruning/Winter pruning

Buds on the shoots growing from these spurs differential into floral primordial and the shoots matured in about 5 months. These matured shoots are pruned for fruiting b4 the onset of winter. This pruning is called as forward pruning/winter pruning/October pruning etc. All the matured shoots are subjected for fruit pruning. After 20-22 days of pruning flowering occurs and fruit set takes place 40-45 days after pruning. Fruit bunches will be ready for harvesting after 90-100 days from pruning

Bud Forecasting

After 15-20 days of October pruning the farmers go for bud forecasting to test which bud is going to give the fruit the farmers select 20 canes from different place of their orchard and send those to the lab. The cut cane should reach the lab within 48 hrs. Otherwise there will be lose of moisture. The lab Technitioners test each buds under the microscope and detect the minute bunches in those buds and make an average eg: if the 9th bud is average we should have to cut the shoot after 9th bud will give fruit.

Practices after back pruning

- Restrict the shoots to only 5/m^2 of the bower area. In case of extended Y system of training, restrict the shoot number to 10/every running meter of the cordon.
- Remove the weak or over vigorous shoots at 3-4 leaf stage.
- Spray CCC @ 500 ppm on the shoots at 5 leaf stage.
- Pinch the shoots to 7 leaves at 9 leaf stage of the shoots.
- Spray maleic hydrazide @ 500 ppm on the shoots at 5 leaf stage on the new shoot (7+5 leaves from the base of the shoot).
- Impose soil moisture stress at 7+5 leaf stage.
- Top the shoots to 15 leaves (7+8) when the shoots start maturing.
- Apply potash @ 100 kg/ac at the initiation of shoot maturity. This will help in cane maturity and increasing its diameter.

Practices after forward pruning

- Remove thin canes which are less than 6 mm in diameter.

- Swab only the apical 2 to 3 buds of the cane with 1.5 per cent solution of hydrogen cyanamide or black Bordeaux containing 4 per cent thiourea.
- Retain one or two bearing shoots only on each cane. If the cane diameter is more than 8 mm, retain two bearing shoots, but only one shoot if its diameter is less than 8 mm diameter.
- Encourage the shoot growth by applying more nitrogen and water until one month after fruit set.
- Thin the berries and clip the clusters to reduce the number of berries in relation to the thickness of the cane.
- Retain 16 berries in a cluster per every mm diameter of the cane.
- Position the shoots to provide shade to the bunches on the South – West side of the canopy.

12. Manures and fertilizers: 20-25tone/ha. Petiole is used for the nutrient analysis

Fertilizer:

Sl. No.	Pruning System	Nutrient	Days after April pruning			Days after October pruning		
			0	30	60	0day	30	60
1	Single pruning single cropping	N				50%	50	-
		P				100	-	-
		K				-	50	50
2	Double pruning single cropping	N	40%	-	-	20	20	-
		P	60%	-	-	40	-	-
		K	-	40%	-	20	20	20
3	Double pruning double cropping	N	20	20	10	20	20	10
		P	50	-	-	50	-	-
		K	-	25	25	-	25	25

1. Thompson seedless : 300:500:1000g/plnt/yr : NPK
2. Anab –e – Shahi : 500: 500 : 1000g/plnt/yr : NPK

Micronutrients

Mg: 0.3%
Zn : 0.2-0.4%
Fe : 0.1% (Ferous sulphate)
Bo : 0.1 – 0.2% (Borax)

Fertilizer application through foliar spray or fertigation in the form of water soluble substances. 60-75 cm away from the base of vine. {19:19:19, 13-0-46, 12-6-0, 0-0-50} water soluble fertilizer applied usually at the time of fruit maturity.

Nutrient deficiencies

- Mg deficiency: potash induce the Mg deficiency
- Symptoms: Intervinal chlorosis
    - Blossom end rot
    - Rachis cracking
    - Purpling/Bronzing of leaf margins
- Zn, Fe, Mn deficiency: Intervinal chlorosis
- Ca deficiency: Blossom end rot
- Boron deficiency: Cracking of fruits

13. Irrigation: Grape requires less water during fruit bud formation and more water during berry growth. Berry growth stage at 5-7 days intervals, prior to harvesting water is withheld for at least 8-10 days to improve fruit quality. Summer pruning to the onset of rains at weekly intervals and thereafter at 10-12 days intervals until winter pruning. Operating the drip entire trench @ one hour / day once in 2 days for heavy clay soils, every day for light sandy soils.

Water requirements under drip are

1-40 days after summer pruning -48000-60,000 liters/day
41-100- days after summer pruning-24000-32,000/litres/day
101-winer pruning days after summer pruning- 15000-20,000 liters/day

1-45 days after winter pruning 20,000-24,000 liters/day
46-75 days after winter pruning -20,000-24,000 liters/day
76-100 days winter pruning 48,000- 60,000 liters/day
101- Harvest summer pruning 36000-48000 liters/day

14. Special horticultural operations

1. **Crop regulation:** Excessive bunches have to be tinned: 60-70 bunches are retained per plant. Or canes per sqm or 1 cone/square feet.
2. **Girdling:** Removal of complete ring of bark from any part of vine. Normally 5cm thick bark should be removed 2 feet from the ground level. It improves the beny weight, TSS by inhibiting nutrient transportation.
3. **Ringing**: Removing complete ring of bark from any part of vine such as shoot, cane or arm or trunks. Ringing interrupts the downward passage of carbohydrates through the phloem. Berry size and crispiness are increased.Girdling is done at 4-5 mm diameter. Girdling will ensure a TSS content of 20°B.

15. Use of growth regulation

1. **Auxins:** Used to reduce flower and berry drop. NAA @ 10 ppm
2. **Gibberellins:** GA_3 - 1st application (spray): 20 ppm before flowering.
   2^{nd} spray: 40 ppm after flowering (excess no flower and fruit is thinned)
   3^{rd} dipping: 50 ppm GA_3 + 10 ppm CPPU – CPPU N-2-chloro-4-pyridil-4-phenyl urea.

- Elongation of berries.

3. **Ethrel @ 1000 ppm:** to remove/shedding of leaves immediately after harvesting _____ Manually it is not possible.
4. **Dormax** (Hydrogen cynamide) @ 2% used for bud breaking used after April and October Pruning applied as smearing. Should done manually.

16. Intercultural: Daincha and sun hemp can be grown as intercrops to check weed growth paraquat (7.5lit/ha) as post emergence application controls weeds effectively.

Pandal system discourages weed growth to maximum extent. Mulching with paddy husk will reduce weed growth, water requirement and improves the quality of yield. Spraying CCC at 500PPM at five leaf stages after back pruning increases fruitfulness. GA at 10PPM spray 22-25 days after for pruning elongates the clusters. Dipping of clusters in 60PPM GA at bajra grain to red gram sized berries increases berry size. Girding the fruit bearing shoot also improves berry size. 1g grape production requires 16-26cm^2 leaf area.

17. Flowering, Pollination and Fruit Set

Grape vines flower in about 18-20 months.
Flower- panicles, Flowering in the matured grape vine consists of the formation of Primordia.

At the time of flowering, the cap of the flower falls from the flower. This is known as Blooming or calyptra fall stage.

In south India, bud burst for vegetative growth takes place in April-May and that for fruiting during October- November.

Fruit bud is initiated in 20-30 days after bud burst depending on varietal character and climatic conditions.

Pollination is essential for seeded varieties for fruit set, while in seedless cultivars embryo aborts leading to seedlessness, known as 'sternospermocarpy'.

Fruit: True berries; anthocyanin compounds giving rise to red, blue, purple, and black (dark purple) coloured grapes

A few varieties show parthenocarpic fruit formation.

18. Stimulative Parthenocarpy

Where pollination acts as stimulus and seedless berries develop without fertilization is seen in varieties like Black Corinth.

Stenospermocarpy

In a few seedless varieties like Thompson Seedless, Beauty Seedless, Pusa Seedless, Perlette and Delight, Stenospermocarpy takes place in which fertilization occurs followed by embryo abortion after some time.

19. Harvesting and yield: Grape is a non climacteric fruit so must be harvested at correct stage of maturity. A degree day from full bloom gives a correct indication of maturity. Early cultivars require about 1600-2000 degree days and late cultivars about 3000 or more. A cluster having underdeveloped seedless berries

known as "shot barriers" or mummies. These will be very sweet in taste.

Maturity indices:

- Formation of waxy layer on berry
- Development of typical yellow/golden yellow colour, Softening of berry
- Easy detachment of berry on pulling, TSS – 18-20°Brix, Sugar acid ration: 20-50

Grape starts yielding from 2-3 years and continues for more than 20-25 years. Average yield will be about 25-30 tonnes/ha but higher yields of 60-75 ton/ha also possible with good management.

Grapes are packed in corrugated fibre guard (craft paper coated within layer of mixture of sodium bisulphate and a plastic polymer) improve their storage life.

Grapes can be stored guard or for 7-12 weeks under controlled atmosphere with 15-25% Co2 and at 0-1^{0}C. Precooking is done in 2.2 – 4.4°C for 6-24hrs. Shelf life: In ambient condition store for 4-6 days can be extended by store in 0-1°C, R.H. 90-95% store for 2-3 months.

For export: Berry diameter: 16-18mm and TSS: 16-22°Brix, Bunch wt: 350-600g**,** Berry should be below level of recommended dosage of fungicides and insecticides. Size of the box 50x30x12cm (5kg)**.** Those boxes are usually packed along with the sachets of polythene grape guard. It releases so, in the boxes it prevent the development of fungal diseases.

Utilization of grapes in India

Table grapes: 76.5 - 79.5%	Juice: 1.5%
Export: 2.96%	Wine: 0.5%
Raisin: 17-20%	

20. Preparation of Raisins

Methodology

Caustic soda treatment (NaoH)

- Separate healthy bunches
- Wash in clean water
- Dipping of bunches in 0.3% boiling caustic soda (93-100°C) For 3-4 sec (cracking of berries)
- Dip in cold water
- Fuming with sulphur ie, 2-3mg/kg of bunch for 2-3 hrs (prevent fungal infection and helps in retaining colour)

Ethyl oleate treatment

Bunches are dipped in solution of ethyl oleate 1.5 – 2.0% and potassium carbonate 2-2.5% for a period of 4-5 minutes (helps in cracking of berries) here raisins develop greenish brown colour (1st grade raisin)

Shade drying: Treated with ethyl oleate and dried in made for 3-6 days. Treat with sulphur. Left it in shade for 15-20 days.

Drying in electric heaters: Hot air oven is used. Sulphur treated bunches are spread in electric driers at a temp. of 70°C for 3hrs. Dry in 50°C for 16-20 hrs. Moisture content of raisin – 15-16%. TSS: 2.3 – 24°brix and recovery percentage – 25% i.e. from 100kg grape use will get 25kg raisin.

21. Pests

1. **Thrips: Seirtothrips dorsalis:** young and adults suck the sap from young leaves resulting in drying and death of new growth.

Control: Spraying systemic insecticides like- Confidor @ 0.5-1ml/litre and Melasystox @ 1.3ml/litre

2. **Mealy bugs: Ferrisiana Virgata:** Eggs layed on old woods adults and nymphs hibernate beneath the bark of stem. They suck the sap from all parts of the vine. Sooty mould develop from secreted honey dew. Infected leaf show drying symptoms.

Control: Spraying ovisicle like methomyl @ 28/litre and Nuwan @ 2ml per litre
Biological control agent can be used.

3. **Flea Beetles** (*Scelodonta strigicollis)* Tender shoots and tendrils, mature leaves and roots causing damage to the emerging shoots.North India, from May onwards, south and west India, synchronises with the pruning.Control: Neem based, azadirachtin concentrations in formulations viz., 50000 ppm at 1ml / l, while 10000 ppm and 3000 ppm at 2.5 ml and 5 ml per liter . Carbaryl 50 WP @ 2 ml/l or Imidacloprid 200 SL @ 0.3 ml/l.
4. **Stem borer** (*Celosterna seabrator Fbr.)*
   - Makes holes on the main stem and arms.
   - Affected parts turn yellow and mottled and ultimately dry and drop down.
   - Maximum during November to April.

   Control: Injecting Dichlorvos solution into the hole followed by sealing with mud or cow dung mixed with Copper Oxychloride in 1:3.

   Spraying orchard with Quinalphos (0.06%) + Dichlorvos (0.08%).
5. Scales
6. Leaf roller
7. Mites
8. Nematodes
   - Control by drenching/carbofuran granule @ 5g/plant
   - Using nematode resistant root stock

Bird: Antibird nets of reflecting tapes are used.

22. Diseases:

1. Downy mildew: *Plasmopara Viticola*



A. Downy mildew infected leaves. Left (upper surface): **Reddish brown patches** with yellow hallow. Right (lower surface): **White downy or cottony** fungal growth.
B. Advanced stage of infection: **Curling** and **withering**. Abundant white, downy sporulation on the surface of infected areas.
C. Infected inflorescence.
D. Infected fruits: **"Fuzzy"** white fungal growth on the berries.
E. Advanced stage of infection: **Mummified berries**.

Symptoms are seen on all parts of plants especially in young leave and shoots. Small yellow light spots appear on upper side of leaf turning to dark brown leads to necrosis and death.



Disease is severe in cool humid conditions

Control: Spray bordaux mixture and Ridomil mz @ 0.1%

2. Powdery mildew: Uncinula necator
- Symptoms are seen on all parts of plant
- Small whitish patches develop
- Gradually turns to grey then to dark brown. Affected leaf falloff
- Vine shows wilting
- Berries become shrivelled and loose marketability

Control:
- Spraying wetable sulphur 0.75-1.25g/litre
- Kerathane : 1 ml/litre

3. Anthracnose: Severe in rainy season under high humidity and temperature. Infection starts with small grey spots on all parts leaf, stem, berries etc. there turn brown and black leading to death of infected area.

Control: Spray bedaux mixture 1% 3-4 times after April pruning.
Black Rot (*Guignardia bidwelili)*

- The disease is more destructive in warm and humid areas than cooler and drier ones. The disease has been reported from southern India. It attacks all green parts of the vine, particularly berry clusters.

- On leaves, **red brown irregular shaped spots** develop in which black fruiting structures of the fungus are produced in concentric rings.
- **Small, dark, elliptical cankers** are produced on shoots, tendrils, cluster skin and petioles.
- Affected berries on maturation change to **hard black wrinkled mummies** covered with **pycnidia** of the fungus.
- Removal of affected plant parts, mummified berries, pruned materials and their destruction by burning is recommended.
- Fungicides used to control black rot include Bordeaux mixture, folpet and maneb, fenarimol and mancozeb.
- Benomyl, captafol, captan and ferbam may also be used for control of black rot of grape.

Grey mould rot: Grey mould rot is the most widespread and important Disease of grapes. Occurring wherever the crop is grown.

- The early stage of fruit-rotting is called 'slip-skin' since, when the flesh is first invaded, the overlying skin becomes loose and is easily detached.

- A brown discoloration occurs, and later there may be copious production of grey- brown spores.
- A humid atmospheric favors development of whitish mould growth without spores.

- Control
  - Strict hygiene in the vineyard is necessary to minimize the amount of crop debris.
  - The efficacy of fungicide applications depends on correct timing (starting pre-bloom).
  - If biological control can be used early in the season, then the number of chemical treatments be reduced.
  - Important post-harvest measures include careful handling, prompt and rapid cooling, and the use of sulphur dioxide.

23. Physiological disorders

- Barrenness of vine

- Unfruitfulness and rudimentary panicle
- Water berries
- Shot berries
- Post harvest berry drop
- Bud or flower drop
- Berry cracking and rotting
- Pink berries
- Pendant berries

Water berries: These berries lack normal sugar, colour, flavour and keeping quality. Berries are normal in size but the flesh is no firm, dull colour and watery.

Reasons: Over cropping, Inadequate nourishment to berries in a cluster.
Control: Eexcessive irrigation and nitrogenous fertilizers should be avoided during berry development. Potash application during berry growth period. Trimming off affected berries during harvest is a common practice, although labor intensive.

Short berries: Berries become smaller, round, seedless as compaired to normal berries in a cluster. Occurs either due to poor pollination, fertilization defective flower parts or due to inadequate flow of carbohydrates into the set berries.

Reason: Boron deficiency, Improper GA application, girdling (improper)

Control: Application of boron and Proper girdling & GA application

Pink berries: Commonly seen in Thompson seedless. Berries become pink during ripening and spreads to entire bunch making bunch unattractive. The berries are watery and collapse within few days of harvest. Incidence is more in places where large decimal fluctuations of temperature during February.

Control: Prune the vines in last week of October or First week of November. Give sufficient potash. Treat clusters with 10ppm BA – Benzyl Adinine.

Hen and Chicken: Normally due to boron and zinc deficiency

- Uneven development of berries. It referes to a situation where in the old berry surrounded by many short berries.

Reason: Defective fertilisation. Exogenous apple can of GPH, deficiency of Zn, Bo. **Control:** Application of Zn & Bo before bloom

Blossom end rot: deficiency of Ca. Blackening of fruit at blossom end Bloossom a plack suskan spot develops at the blossom end of the berry which lateron spreads + water sealed and rot Calcium deficiency.
Interveinal chlorasis: Mn, Zn or Fe deficiency-0.2%.
Stalk necrosis: Calcium deficiency.
Bud, flower and berry drop: girdling 10 days before full bloom, 500PPM ethrel at ripening NAA 100PPM at 10 days before ripening, Reducing irrigation during bloom, Benzyl adenine 200PPM, 4-CPA 20PPM-for thinning.

Bud killing: Excessive nitrogen.
Mummification: Though the etiology of mummification in grapes is not known (due to complex factors), the affected water berries in severe cases, shrivel and dry at the time of harvest leads to mummification. Proper cultural management practices can also reduces the intensity. Avoid direct sun light exposure of bunches.

Constraints in Grape Production Development

Although grape cultivation is considered as highly remunerative, the area under grapes is not increasing due to the following constraints.

Heavy initial investment for establishing a vineyard. High recurring costs in vineyard management. Narrow variety base and lack of diversity in utilization of the germplasm available in grape growing countries. High risk of losing the crop due to unprecedented changes in weather. Soil and water salinity and drought in the hot tropical areas. Short period available for ripening in the north. Very low proportion of export quality grapes. Wine is not a popular drink at present. Marketing problems in table grapes.

24. Challenges for Grape Cultivation

Grape is traditionally, a temperate region crop and in India it is grown in tropical belts for fresh consumption and processed products and thus faces many challeges on different fronts. In coming years, challenges may become tougher due to shift in climate, changing global scenario and associated factors

a) Climate change, Changes in consumer behavior and preference
b) Labour shortages and wage hikes and Higher cost of inputs
c) Competitive world markets and Availability of resources.
d) Issues of quarantine and Soil health issues.Genetically modified grape

Production technology of Pomegranate

B.N.: *Punica granatum* Lin (grainy apple) Family: Punicaceae Origin: Iran
Chromosome No. : 2n= 18 Type of fruit: Balausta Edible portion: Juicy Seed coat

1. Importance

Pomegranate is one of the important fruit crops, which has high nutritional and medicinal values . It is being grown for its fully luscious grains called Arils, the fruits are very attractive with sweet acidic taste. It is used medicinally as a remedy for intestinal problems. The juice of pomegranate is good for heart diseases – hypertension, hardening of arteries and lowering of cholesterol. Rich in antioxidants it offers protection agaisnt cancer. The fruit is high in vitamin C, potassium, good source of fiber andlow in calories. It is highly

remunerative crop , has high market potential (local and export markets). Because of its versatile adaptability, hardy nature, drought resistance, steady yield and good keeping quality and therapeutic values are the main features for its popularity.

2. History

- In Buddhism, the pomegranate is considered a blessed fruit. In Judaism, it represents sanctity, fertility and abundance.
- Ancient Indian Ayurvedic medicine traditionally used pomegranate to lower fever. In Greek medicine the flowers were used to treat diabetes, while the root and bark were used to stop bleeding, dysentery and heal ulcers. The ancient Egyptians used the fruit to combat intestinal worms.
- For over 4,000 years humans have cultivated pomegranates for their medicinal properties. Traditional healers experimented with its juice, seeds, leaves, flowers, bark, roots and skin.
- Pomegranate is one of the "seven kinds" mentioned in the Bible which Israel was blessed with long ago. It grew in the region for thousands of years and is very much adapted to it: it sheds its leaves in the cold of our winters, while it sprouts in early spring when temperatures rise.
- Because of its decorative value in Israel, its selection was done mainly for external appearance, not so much for eating quality. Nice colour and crown are very important characteristics of the fruit.

3. Origin and distribution

Iran is the centre of origin for pomegranate and **National fruit of Iran.** It is distributed in Spain, Morocco, Egypt, Afghanistan, China, India, Japan and USA. The estimated global cultivated area under pomegranate is around 3.0 lakh hectares with a production of 3.0 million tonnes. Leading pomegranate producing states in India include Maharashtra (62%), Karnataka (20%), Gujarat (9%), Andhra Pradesh (3.8%) and Madhya Pradesh (3.6%). National Research Centre for Pomegranate is located at Sholapur, Maharashtra.

4. Area, Production and Productivity

The area under pomegranate in India is around 2, 20,000 ha with a production of 27, 95,000 metric tonnes. In Karnataka, pomegranate is cultivated on an area of 27,260 ha with an annual production of 3, 28,920 tonnes (Anon., 2020) mostly in the dry regions of Bijapur, Tumkur, Kolar, Belgaum, Dharwad, Chitradurga and Bellary.

5. Uses

- Pomegranate is rich in carbohydrates (14%), calcium, phosphorus, iron, vitamin C and arytenoids.
- The edible part of pomegranate is a juicy outgrowth of the seed called the aril.
- It is liked for the cool refreshing juice and also valued for its medicinal properties. The juice is useful for patients suffering from leprosy.
- The bark & rind of the fruit are commonly used in dysentery and diarrhea.
- The dried seeds of pomegranate give important condiments called 'Anardana.' Tannin is obtained from fruit rind, stem & root bark and leaves.
- The flowers, yield red dye, which is used for dyeing cloth. One pomegranate fruit supplies about 40% of an adult's daily Vit-C requirement.
- It is also rich in Riboflavin, protein, fat, sugar, pectin, Ca & Iron content.
- The fruit of pomegranate is balausta which is a modified form of berry.

Species

1. Punica protopunica

Found wild in Socotra Island (Yemen)

2. Punica granatum: 2 subspecies

Chlorocarpa – found in Trans Caucasus

Porphyrocarpa- found in central Asia

The tree is deciduous in temperate countries, while it is evergreen in tropical and subtropical regions. The fruits are borne terminally on short spurs, arising from mature shoots. Tree is hardy and bushy having a tendency of developing multi-stems.

6. Soil: It can be grown on diverse types of soil. The pomegranate is not very particular about its soil requirement. The deep loamy and alluvial soils are ideal for its cultivation. It can tolerate soils which are loamy and slightly alkaline. It can thrive well on comparatively poor soils where other fruits fail to grow.

Pomegranate can also be grown in medium and black soils. It is rated as salt-hardy fruit plant. However best yield & quality of fruits could be obtained in deep heavy, loamy and well drained soil with pH range of 5.5 – 7.5.

7. Climate:

- Pomegranate crop prefers dry climate grows up to an elevation of 1800 meter and especially during fruit development stage, prolonged hot and dry climate is mandatory for better growth and yield.

- The Optimum temperature for fruit development is 36°C to 38°C.Pomegranate fruits are easily damaged in humid climatic conditions by pomegranate butterfly and will not develop sweetness in the fruit.
- The plants withstand considerable long period. The plant withstand considerable amount of drought but does well if provided with irrigation.

8. Important varieties and hybrids

Ganesh: MPKV, prolific bearer, very large fruits, yellowish red rind, pinkish aril with soft seeds. Commercial cultivar of Maharashtra, the average yield ranges from 8-10kg per tree.
Arakta: MPKV, Fruits are smaller than Ganesh, having dark red arils with soft seeds.
Mridula: MPKV, Ganesh x Gul Shah Red, has all the characters of Ganesh except that the arils are dark red and softer than Ganesh. The average fruit weight is 250-300 grams.
Muskat: The fruits have red rind with pink coloured arils and weigh 300-350 grams.

Jyothi (GKVK 1): Selection from Bassein seedless, fruits are large with attractive colour having dark red arils. The seeds are very soft with high pulp and juice contents. Fruits are borne on the inner side of the canopy and thus do not get damaged due to sun scorching.
Ruby: IIHR, Bangalore, the mature fruits resemble cultivar 'Ganesh' with respect to shape and size. However, the rind of this variety is reddish brown with green streaks containing red bold arils. The fruit weighs 270g with an average yield of 16-18 tons/ha.
Dholka: Large fruits, yellowish red rind with pinkish white aril, popular cultivar of Gujarat.
Kesar/Bhagwa: The arils are attractive and glossy dark red in colour, export variety.
Amlidana: Ganesh x Nana, best for tropical climate, short trees, suitable for HDP.
Other varieties: Bassein seedless (Karnataka), G-137, P-23, P-26, Yercaud 1, Co 1, RCR 1, Jalore seedless (Rajasthan), Paper Shelled, Spanish Ruby, Bedana, Bedana Bosec, Khog, etc.
Hard seeded varieties: Kandhari, Alandi/Vadki and Kabul.

Alandi or Vadki: It is commonly grown in Maharastra and Gujarat. Fruits are of medium size, blood reed or deep pink flesh with sweet, slightly acidic juice. The seeds are very hard.
The other varieties popularly grown are – Dholka, Kandhari Kabul, Muscat, Jodhpur red, P-23, P-26 and G-137,
Bhagwa: Selection from F2 progeny of crosses between Ganesh × Gul-e-shah red a Russian cultivar. Earlier it was Ruling variety in Maharastra. Fruits are attractive with glossy red thick skin blood red aril. It has soft seed and high TSS. It has good shelf life (15-20 days) and tolerant to fruit cracking. Yield-30-40 kgs/tree. Tolerant to thrips and mites.
Phule Bhagwa Super

Deep red aril colour , Soft seeded (Mellowness 1.18 kg/cm²), Sweet in taste , Average weight of fruit (271.00-299.00 g), Deep saffron colour , Glossiness and external appearance, Mature in 175-180 days, Average yield of 24kg/tree. TSS is 15.42% and acidity is 0.37%

Hybrids: Mirdula: Ganesh X Gulsah Rose Pink
Ruby: Ganesh X Kabul X Yercaud
Araktha: Ganesh X Russian seedless

Bhagwa: (Shendria, Ashtagandha, Kesar)
Jyothi: Basin seedless X Dholka
Amlidana: Ganesh X Nanha

Hybrid – Ruby: Ganesh X Kabul X Yercard: Developed by Indian Institute of Horticulture Research, Bangalore. The fruits resembles like Ganesh variety with reddish brown skin with green stripes on skin, soft seeded with bigger size and red coloured arils, heavy yielder (16-18 t/ha).

9. **Propagation**: Presently, pomegranate is successfully propagated by hardwood stem cutting and air-layering.

Stem cutting: Cuttings are collected from high yielding plants one year old & fully matured shoots. About 25-00cm long cutting should be planted by removing leaves and treating the bottom end of cuttings with rooting hormone (IBA - 2000ppm) and inserted in the soil; Plants will be ready in 55-60 days. Set in beds with 1-2 buds above the soil for 1 year.
IBA 5000 ppm by quick dip method improves rooting

Air layering – Pomegranate may also be propagated by air layering. Air layering is carried out in the month of **May/June**. In this method a 1-2 year old, healthy, vigorous, mature shoot of 45-60 cm in length and pencil thickness is selected. A circular strip of bark about 3 cm wide just below a bud is completely removed from the selected shoot.

Rooting hormones like IBA & NAA 50mg each in Lanoline paste are applied over this portion. Moist sphagnum moss is packed around this portion and tied with polyethylene sheet to prevent the loss of moisture. Application of such hormones promotes early rooting. Light brown roots are visible through the polythene wrap in the month of July-August.
The bottom of the uppercut can be treated with IBA 10,000ppm for better rooting
Why Tissue Culture Pomegranate also practiced

- Traditional growing areas are facing problem of disease (Bacterial Blight)
- Production & productivity are not increasing
- Disease free planting material is not available

10. **Planting Seasons**
    - Pomegranates are planted during February-March months (during spring) in sub-tropical regions.
    - In tropical regions, pomegranate plantation is done during the months of July-August.
    - Air layering is done usually during the rainy season and during November-December months.

Planting Methods in Pomegranate Cultivation

There are two methods of planting followed in pomegranate cultivation, viz. square method and pit method.

Square Method: This is more commonly followed cultivation method. The inter-plant distance depends on the climate and soil type. In case of very light soils, a distance of 4-5 meters is maintained.
Pit System

- Pits of dimensions 60X60X60 cm are dug a month before the actual cultivation. They are left open for solarization for a period of two weeks.
- To protect from termite invasion, the sides and the bottom of the pits are dusted with 5% carbaryl dust.
- After 2 weeks the pits are levelled with topsoil mixed with farmyard manure and super phosphate.
- Once the pits are levelled with soil they are watered so that the soil settles down. The air layers or cuttings are then planted and staked. The next irrigation is done immediately after this planting step.

Planting

- ✓ Land is prepared thoroughly during onset of monsoon.
- ✓ Time =Subtropical- spring (February–March) Tropics - July-August.
- ✓ Planting of 1-2 year old rooted cuttings in centre of pits and provide support with staking.
- ✓ Square system and pit system planting is widely practiced
- ✓ Pits of 60-75cm^3 at a spacing of 5.0x4.0m, planting should be done during monsoon

High-density plantation: 5m × 2m (1,000 plants/ha), 5m × 3m (666 plants/ha),
5m × 4m (500 plants/ha) & 5m × 5m (400 plants/ha).

11. **Irrigation**

Newly planted orchard requires frequent and regular irrigation, during flowering and fruiting, orchard should be irrigated regularly to avoid cracking of fruits and for better development of fruits. Drip irrigation is good for effective utilization of water in pomegranate orchard

Manure and Fertilizers: Pomegranate is a hardy plant but it responds well to manure and fertilizers. About 20 kg FYM & 50 kg FYM/Tree for bearing trees/year, along with 400gN: 200g P:200g K/Tree for pre-bearing plants full dose of P , K and 3/4th of N should be given at the time of bahar (flower induction) treatment, remaining 1/4th of N given at 1 ½ months after fruit setting. At the age of 8-10 years this dose should be doubled.

Table 6: Manuring and fertilizers (g / plant

Age	N	P	K
After I year	250	125	125
II year	500	125	125
III year	500	125	250
IV and above	625	250	500
FYM – 20kg per tree every year in addition			

Foliar spray of 0.25% ZnSO4, FeSO4, and MnSO4 and 0.15% boric acid increased yield

12. **Training and Pruning of Pomegranate Plants**

- The plant should be allowed to retain 4 main stems from the ground level.

- Prune ground suckers, water shoots, criss-cross, dead, dry and infected branches and twigs regularly.
- The main stem should be stopped at a height of about 70 cm to induce branching.
- The tree is given a balanced shape during the initial 2–3 years by proper selection of secondary and tertiary branches.
- Downward-growing branches and crossing branches should be removed.

- While pruning, care should be taken to disinfect the secateurs with Dettol (1%) or sodium hypochlorite (1%), so that infection may not spread from on plant to other.
- After the tree is trained, much pruning is not required as the fruits are borne on one year-old branches (short branches). However, water sprouts and the dry branches should be removed.
- After about 10 years, old main stems should be renewed by cutting back to make it more productive.

Training – Single stem or multi stem system

Single stem: By removing all the side shoots, single stem is left. This operation begins at the time of planting. The main stem is pinched at a height of results in the formation of branches. Only well distributed 4-5 branches on all sides above 60-70cm from ground are allowed to grow.

Multi-stemmed tree: This method is preferred in Maharashtra, where in 3-4 stems are retained at a hill and remaining shoots are removed. But yield has not been found to be affected. This will give a bushy frame work to the plant. Pinched at 1 m height 2 – 3 branches allowed in each stem.

Pruning: Terminal bearing on short spurs. A light pruning during winter is given to shorten previous season growth. Dead, diseased branches and water sprouts also removed.

Intercropping and Intercultivation: Leguminous, vegetables and cereals can be taken during pre-bearing stage. Papaya can be taken as filler plant. Basins should be maintained free from weeds. Deep ploughing should be avoided as it damages the roots.

Mulching is a good idea to conserve the moisture in pomegranate for longer period of time where the problem of water scarcity is observed

- It also helps for the nutrient uptake
- Enhance the growth and yield
- Improve the quality of pomegranate fruits
- Increase the water us efficiency in pomegranate orchard
- It will reduce the growth of weeds

13. **Flowering and fruit set:** To obtain higher fruit yield during a particular period, the pomegranate plants are given a resting period. It is done by bahar treatment

- Most of the commercially grown varieties are free flowering in nature
- So taking the advantage of this habit, fruiting of pomegranate may be regulated as per the need and choice of growers. It is possible to harvest pomegranate under Maharastra and Karnataka conditions from three flowering

Bahar Treatment

- ❖ Bahar treatment means giving rest to the plants by withholding irrigation, root exposure, root pruning etc. Impose moisture stress resulting leaf drop and cessation of growth during the period of unwanted bahars.

- ❖ Later the resumption of normal irrigation and fertigation just before the desire bahar induces new growth and profuse flowering and fruiting. Greater significance in southern central and western India where growth and flowering continuous throughout year.

Table 7: Bahar treatment in pomegranate and their characteristics.

Bahar	Time of flowering/fruiting	Crop regulation treatment	Remarks
Ambe bahar	January - February / June July	Root exposure in October-November Manure applied in December -January Irrigation in January	Incidence of cracking, pest and disease is less. Irrigation requirement is more, yield and quality is better.
Mrig bahar	June-July /October-November	Withholding irrigation during December -April. Manuring, irrigation in May	Irrigation requirement is low but incidence of cracking and black spot disease is more
Hasth bahar	September-October /January- March	Withholding water during August	This bahar is not possible since water cannot be withheld July-August.

As the fruit development takes place during dry months, the fruits of ambe bahar develop an attractive colour and quality suitable for exports. Similarly due to dry weather, the incidences of pest and disease attack are limited. However, ambe bahar can be taken only in areas having assured irrigation facilities.

The flowering and fruiting period of mrig bahar crop coincides with rainy season and the crop is taken without much irrigation. As the fruits develop during the rainy season and mature during winter, the colour and sweetness of the fruit is affected.

The fruits from hasta bahar have very attractive rind with dark coloured arils. Since the availability of the fruits during this season is limited, they fetch high value. Optimum water stress cannot be developed during this period as withholding of irrigation coincides with the rainy season. This leads to poor flowering and thus affects the yield. The choice of flowering/fruiting is regulated taking into consideration the availability of irrigation water, market demand and the pest and disease incidence in a given locality. The tree starts bearing fruits from 3-4th year and continues for about 25 to 30 years. Economic yield is generally obtained from 6th or 7th year onwards.

14. **Harvesting and yield**

Pomegranate fruits become ready for harvesting in 5-7 months after the blossoming. Mature fruits become slightly yellowish & further pink to red. On tapping, the fruits give metallic sound and when pressed they give a “Crunch” sound and flattened during maturity.

15. **Use of Growth Regulators**

Judicious use of growth regulators at various stages could produce high quality pomegranates. GA_3 (20ppm) at flowering stage helps in thinning of excess flowers. Spraying of NAA (10ppm) as soon as the flower drop is observed, 2 to 3 times at weekly intervals, controls unwanted flower drop and increases the fruit set.

16. **Maturity Indices**

- For getting quality fruits, they are harvested at proper stage of maturity.
- The fruit requires 130-150 days after fruit set for proper maturity.
- In summer the fruit colour changes from yellowish to dark red at maturity.
- The fruit is harvested when it gives cracking sound when tapped.
- The calyx at the distal end of the fruit gets closed at the time of maturity
- Properly matured the fruit is easily scratched with finger nails.

17. **Harvesting**

- Being non-climacteric fruit should be picked when fully ripe.
- Harvesting of immature or over-mature fruits affects quality.
- Fruits become ready for picking 120–130 days after fruit set.
- Calyx at the distal end of the fruit gets closed on maturity.
- Ripe fruits give a distinct sound of grains cracking inside when slightly pressed from outside.
- At maturity they turn to yellowish-red and get suppressed on sides.
- Fruit colouris not sure guide to maturity. Plucking is done with hand.

18. **Yield**

The plant starts bearing from the 4th year onwards. A well-developed 8-10 year old tree yields 100-150fruits/tree or 18-20tons/ha. The yield declines gradually after the trees attain 25-30 years of age.

19. **Method and time of harvesting for export**

- Harvest pomegranates either early in the morning or in the evening.
- Use clippers and bags for harvesting.
- Do not pull the fruits.
- Cut the stem and close to the base.
- Do not bruise the base while cutting the fruits. Handle carefully at harvest.
- Do not keep longer stem end, as it can cause damage to other fruits.
- Keep the fruits in plastic crates for emptying the bags.
- Do not keep fruits on the ground.
- Do not keep empty creates in sun but in shade.
- Do not overfill the crates with fruits and keep them in shade and not in the open sun.
- Do not damage calyx while harvesting or while keeping in crates or during field storage.
- Crates and clippers should be washed with water and detergent or wet cloth and dipped in 1% sodium hypochlorite sol.

Quality requirements of importing countries.

- The desirable fruit characters for export purposes are detailed below.
- Smooth cutting at the stem end5
- Dark rose pink colour of fruit.
    - Fruit weight of around 200 – 400 g.
- Round shape of fruit.
- Uniform size and shape of the fruit in pack or box.
- Dark rose pink arils.
- Softness of the seeds.
- Higher sugar contents of about 160B to 170B.
- Freedom from scars, russeting, disease spots, insect injury, and scratches.
- Smooth cutting at the stem end.
- Bracts calyx without any damage and having freshness.
- Pleasant flavour and aroma.

Grading based on Size and Colour

1. Super size – Fruits are free from spots and individual fruit weight is more than 750grams.
2. King size – Fruits are attractive and individual fruit weight is 500-700 grams.
3. Queen size – Fruits are attractive, red and individual fruit weight is 400-500 grams.
4. Prince size – Fruits are attractive, red and individual fruit weight is 300-400 grams.

20. **Processed Products:** Juice**,** Wine**,** Jelly **,** Anardana **and** Rind Powder
21. **Packing:** The graded fruits are wrapped in paper and packed in corrugated fibreboard (CFB) boxes. Brown coloured 3 fold CFB boxes are used for local market while white coloured 5 fold CFB boxes are used for distant markets. Paper shreds are used as padding material.

22. **Storage:** Fruits can be stored at 5°C with 90-95% relative humidity for 2 months. In case of storage beyond two months, temperature should be maintained at 10°C to avoid chilling injury. Pomegranates are very susceptible to water loss resulting in shriveling of the skins. Storing fruits in plastic liners and waxing can reduce water loss, especially under conditions of lower relative humidity.

Cool Chain: Cool chain is essential during the transport of export quality commodity all the way from the farm to the customer. Cool chain helps in maintaining the temperature inside the box at the same low level as in the cold storage.

Anardana

- Anardana is a spice used in Indian cooking to give a sour-sweet taste to dishes. It is made from the dried seeds of pomegranate fruit (*Punica granatum)*.
- The seeds are dried along with the pulp, either by sun-drying or other means of dehydration. They are then ground or sold in whole form.
- The most prized pomegranate for making anardana is a variety called **Daru** which grows wild in the lower Himalayas

The fruits are picked around mid-October, the seeds and pulp are separated by hand, and allowed to dry for 10 to 15 days, turning a reddish-brown

23. Distribution of produce from primary to terminal market

Pomegranates grown in different parts of country are transported to the big cities for marketing. The fruits produced in Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu find market in Mumbai, Nagpur and Kolkata. The important whole sale markets of pomegranate in India are Kolkata, Delhi, Mumbai, Chennai, Bangalore, Nagpur, Pune and Ahmedabad. Pomegranates for these big markets are usually collected at the central places in all pomegranate growing areas. From Mumbai and Kolkata ports the pomegranate is exported to the destination markets.

Some of the major problems confronted in Pomegranate production:

Shot hole borer, Fruit borer, Bacterial blight, Wilt, Fruit cracking, Sun burn and Development of fruit colour.

24. Physiological disorder

- Fruit cracking
- Internal break down

Husk scald

Fruit cracking – It is common in pomegranate and also serious. This disorder is due to the prevalence of high temperature and moisture stress followed by rains cause fruit cracking during fruit development. In the young fruits, it could be due to boron deficiency. While in Mrigbahar (July) grown fruits, it might be due to sudden fluctuation in diurnal temperature. Also prolonged dry spell cause hardening of peel, if this is followed by heavy rainfall or irrigation then the pulp grows fast and results in cracking of pulp. The cracked fruits are also liable to be invaded by certain fungi and bacteria. The fruits loose their market value and become unfit for human consumption.

The cultivars like 'Bedana Bosek' 'Jalore seedless' and 'khog' are comparatively tolerant to cracking.

Control measures:

1. Planting of varieties tolerant to fruit cracking.
1. Early harvesting of fruits immediately after maturity
2. Maintain optimum soil moisture during Mrig bahar fruiting
3. Spray calcium hydroxide on foliage after fruit set.
4. If boron deficiency – spray borax at 0.1 per cent to pl/20g/pl/year.
5. Spray GA_3 at 250ppm in June.
6. Plant windbreak around the pomegranate plantation.

Development of Fruit Colour

- Specially in Ganesh variety,
- High, anthocynin pigment cannot develop
- Because of high temperature
- Aril will become white in colour,
- Which fetches low price in market.

Control manures:

- By spraying of water using sprinklers
- Spraying of potassium nitrate 10g/L of water
- Spraying of MOP @ 2kg /100 L of water
- Spraying of KH2PO4 at 5 to 10g /L of H2O
- Using resistant varietes e.g. Araktha,Mridula

Sun burn:

This is due to improper pruning and can be controlled by proper pruning or covering the fruits by proper bags.

25. Pests and diseases

i. Fruit Borer or Pomegranate Butterfly (*Deudorix isocrates*)

- Adults lay eggs at the time of fruit setting in flowers. Larvae develop inside the fruit and these larvae bore out of the fruits. Black excreta of caterpillars are commonly seen on fruits

Control

- Remove infested fruits and destroy. Spray Phosphamidon (0.03%) or Carbaryl (0.4%) or
- Endosulphan repeat the sprays with Fenvalerate (0.01%). The first spray should be given at the time of fruit setting

ii. Thrips (*Rhipiphorothrips cruentatus/Scirtothrips dorsalis*)

Feed by sucking sap from leaves, flower stalks, petals and result in leaf curl, drying of young shoots and shedding of flowers. On fruits, discolored areas are seen which later show rusty scars

Control

- Affected plant parts should be removed and destroyed on observing the insect infestation.
- Spray chloropyriphos (0.02%) or imidacloprid (0.04%) or deltamethrin (0.15) or dichlorovos (0.05%) as prophylactic or on observing the symptoms.

iii. Shothole Borer (*Xyleborus fornicates/X. perforans*)

- Beetles bore holes in roots and trunks resulting in drying of trees. Their incidence increases in the rainy season.

Control

- When insect symptoms are observed (yellowing and drying of plants) soil drenchingwith chlorpyriphos (0.2%) in and around the affected trees is effective.
- As prophylactic, spray chlorpyriphos (0.2%) and carbaryl (0.2%)

iv. Leaf eating Caterpillar (*Achaea janata*)

- Caterpillars feed voraciously on leaves and adults suck juice from fruits.

Control

- Spray crop with chlorpyriphos (0.1%) as a prophylactic spray or on initiation of insect infestation.

v. Fruit sucking moths (*Othreis ancilla, O.cajecta, O.fullonica, O.materna, Achaea janata)*

- It punchers mature fruits at dusk by inserting proboscis and suck juice. Through feeding punctures, secondary pathogens enter and cause fruit rotting. They lay eggs on weeds.

Control

- Collect and destroy infested fallen fruits.
- Put poison bait containing Malathion 1 ml + 100 g jaggery + 5ml vinegar in small tins during night.
- Generate smoke in orchards during the dusk time.

Disease

i. Bacterial Blight (*Xanthomonas axonopodis PV. Punicae*)

Adopt the following spray schedule

The first spray be given with 1% Bordeaux mixture immediately after pruning Second spray at foliage initiation with Streptocycline (250ppm) + Copper oxychloride (0.25%)
Third spray at 15 days interval with Bordeaux mixture (0.5%)
Fourth spray with Streptocycline (250ppm) + Carbendazim (0.1%)
Under favorable weather conditions of overcast sky and rains and high disease pressure, higher concentrations of Streptocycline (500ppm) should be used. Also, spray interval can be reduced to 8 – 10 days.

ii. Leaf and fruit spots: (Colletotrichum and Sphaceloma spots)

On leaves, the spots are brown-black spots with a light center and purplish-brown borders. On fruits initially, spots are small with dark purplish brown borders with light centers which later enlarge to form larger spots with a light center and dark edge.

Control

- At flower initiation or disease appearance spray the crop with carbendazim (0.1%) or mancozeb (0.25%), or copper oxychloride (0.25%) or Thiophanate methyl (0.15%)

iii. Wilt complex (*Ceratocystis ambriata, Fusarium oxysporum, Rhizoctonia solani and nematodes*)

- Affected plants show yellowing of leaves in some twigs or branches, followed by drooping and drying of leaves. The entire tree dies in few months or a year. When affected tree is cut open lengthwise or cross-section dark grayish-brown discoloration of wood is seen. The disease is more in heavy soil and increases with soil moisture.
- **Control**
- Plant at spacing 4.5 m × 3.0 m in the orchard.
- Plant pomegranate in sandy loam soil with proper drainage.
- Soil drenching with carbendazim (0.2%), or propiconazole (0.15%) or Tridemorph (0.15%) + Chlorpyriphos (0.25%) before planting in diseases prone areas.
- Spray with carbendazim (0.1%) or propiconazole (0.15%) or tridemorph (0.15%) as soon as the first sign of the disease is seen.
- The completely wilted plants should be uprooted and burnt and drench the plant basin as above.

iv. Phytophthora Blight (*Phytophthora nicotianae*)

- Affects seedlings, foliage as well as fruits particularly during the rainy season, when humidity is high. Affected leaves and twigs show typically blighted appearance.
- The fungus also attacks flowers and fruits at all stages and cause fruit rot.

Control

- At disease appearance, spray the crop with metalaxyl 8% + mancozeb 64% (0.25%) or mancozeb (0.25%).

v. Fruit rot (*Cercosporapunicae/ Colletotrichum gloeosporioides*)

- Fruit spot pathogen also results in fruit rots. Pathogens enter through calyx or stem end and result in dark brown depressed spots on fruits.

Control: At flower initiation spray the crop with carbendazim (0.15%) or mancozeb (0.25%) thiophanate methyl (0.15%)

3.7. Production Technology of vegetable crops

1. Tomato (*Solanum lycopersicum* L.)

Tomato is one of the most important vegetable crops. To get good yield, farmers must follow proper production package of practices from field preparation to harvesting.

Climate

- Tomatoes grow best in warm weather.
- Best temperature: 21–24°C in the day and 15–18°C at night.
- Very high (>35°C) or very low (<10°C) temperatures stop fruit growth.
- Tomatoes need 6–8 hours of direct sunlight daily.

Soil

- Best soil: well-drained sandy loam or loam, rich in organic matter.
- Soil pH: 6.0–6.8.
- Waterlogging causes root rot and wilt diseases.

Land Preparation

- Plough the soil deeply (20–25 cm) and make it fine and loose.
- Raised beds are good, especially in wet areas.
- Bed size: 15–20 cm high and 45–60 cm wide, often covered with plastic mulch to conserve moisture and control weeds, 30- 45 cm spacing from bed to bed.

Transplanting

- Seedlings: Raised in nursery or trays with a clean soil mix.
- Age: Ready for transplanting in 4–6 weeks with 4–6 true leaves.
- Spacing:
    - Determinate types: 60–90 cm between rows × 45–60 cm between plants.
    - Indeterminate types: 90–120 cm between rows × 45–60 cm between plants.
- Transplant in the evening or on cloudy days to reduce stress.
- Water seedlings immediately after transplanting.

Water Management

- Tomatoes need regular water, especially during flowering and fruiting.
- Furrow irrigation: Traditional but wastes water.
- Drip irrigation: Best method. It saves 50–70% water, reduces weeds, prevents leaf diseases, and allows fertigation (fertilizer with irrigation).

Nutrient Management

- Basal dose (before planting): 20–25 t/ha FYM + 60:60:60 NPK/ha.
- Top dressing: Add 60–80 kg/ha Nitrogen in parts during flowering and fruiting.

Micronutrients:

- Calcium deficiency causes blossom-end rot.
- Boron and Magnesium are also important. Spray or apply them if deficiency occurs.

Staking & Training

- Staking (supporting plants with sticks/wires) is useful for indeterminate (vining) tomatoes.
- It keeps fruits off the ground, reduces disease, improves air circulation, and makes harvesting easy.

Weed Management

- Remove weeds regularly because they compete for water, nutrients, and light.
- Mulching helps to control weeds.



Harvesting
Tomatoes are picked at different stages depending on how far they must travel, how long they will be stored, and how they will be used.
Immature Green
- Fruit is small, hard, and fully green.
- Seeds are soft and not developed.
- Not good for harvesting.

Mature Green
- Fruit is full-sized and firm, but still green.
- Seeds are hard and well developed.
- Good for long transport and storage.
- Fruits can be ripened later in storage or with ethylene gas.

Turning Stage
- Green color starts fading, yellow patches appear.
- First sign of ripening.
- Suitable for nearby markets if ripening is needed in a few days.

Pink Stage
- About 30–60% of the fruit turns pink or light red.
- Good for medium-distance transport.

Half-Ripe Stage
- Fruit is 60–90% red, still firm.
- Best for local markets.

Red Ripe Stage
- Fruit is fully red, soft, and tasty.
- Used for immediate eating, local sales, or processing.

Overripe Stage
- Fruit becomes very soft and may crack.
- Not good for market.
- Can be used for processing into sauces, ketchup, or puree.

2. Brinjal / Eggplant (*Solanum melongena* L.)

Brinjal (eggplant) is an important warm-season crop. Good harvests come from understanding its specific needs.
Climate: Brinjal loves heat and is more sensitive to cold than tomatoes or peppers. The best temperature is 22-30°C. Growth stops below 17°C. Frost will kill the plants. It needs a long, warm, sunny growing season.
Soil: It grows in well-drained soils but crop yield will be best, when crop raised in the sandy loam to clay loam rich in organic matter. Ideal soil pH is 5.5 to 6.8. It can handle some salt in the soil.

Land Preparation: Like tomatoes, plough deeply and break up the soil to make it fine, level, and free of weeds. Raised beds are very useful, especially in heavy soil. They improve drainage and prevent waterlogging. Beds are usually 15-20 cm high and 45-60 cm wide. 40- 50 micron thickness plastic mulch is often used, 30- 45 cm spacing from bed to bed.

Transplanting:
Nursery Raising: Sow seeds in a protected nursery or trays with sterile mix. Soaking seeds for 12-24 hours before planting helps them sprout. Protect young plants from pests.
Age: Seedlings are ready in 4-6 weeks, when they have 4-5 true leaves.

Spacing: Depends on the variety.
Common spacing: 60-75 cm between rows x 45-60 cm between plants.
Closer spacing (for small varieties): Can be 45-60 cm between rows x 30-45 cm between plants..

Transplant on a cloudy day or in the evening. Water the nursery before moving plants to protect roots. Water immediately after transplanting.

Water Management
Brinjal needs a lot of steady water, especially when flowering and fruiting. Stress can cause flowers and fruit to drop.
Drip Irrigation: The best method. It saves water, sends nutrients to the roots, and keeps leaves dry to prevent disease. Essential with plastic mulch.
Furrow Irrigation: A common method, but avoid too much water.

Nutrient Management
Brinjal is a heavy feeder, especially of potassium. A soil test is important.
Basal Application: Mix well-rotted farmyard manure (20-25 tonnes/ha) and a base fertilizer (e.g., 50:60:50 kg/ha of N: P_2O_5:K_2O) into the soil before planting.
Top-Dressing / Fertigation: Nitrogen and potassium are key for continuous fruiting. Add the rest of the nitrogen (e.g., 50-70 kg/ha) and potassium in 3-4 parts, starting one month after transplanting. Fertigation through drip is most efficient.

Harvesting and Post-Harvest Handling
Pick fruit when it is full-sized, shiny, and glossy, but before the seeds inside get hard and the skin turns dull. This is usually 65-80 days after transplanting, and then weekly for months. Cut the fruit with a sharp knife or shears, leaving a bit of the stem (calyx) attached. This keeps the fruit fresh longer.
Yield: 25-35 tonnes per hectare.

3. Production technology of cole crops

i. Cabbage (*Brassica oleracea var. capitata*)
Climate
- Cabbage grows best in cool, moist climate.
- Optimum temperature: 15–20°C.
- High temperatures cause loose, poor-quality heads.

Soil
- Best soil: well-drained sandy loam to clay loam. Slightly acidic to neutral pH of 6.0 to 6.5. Soil rich in organic matter improves yield.

Nursery Raising and Transplanting
- Seeds are first sown in nursery beds.
- Seed rate: 500 g/ha.
- Seedlings are transplanted after 4–6 weeks, of seedling having 4-5 true leaves, when they are 8–10 cm tall.
- Spacing:
  - Early varieties: 45 between the rows × 30 cm between plants
  - Late varieties: 60 between the rows × 45 cm between plants

Manures and Fertilizers
- FYM: 20–25 t/ha, Fertilizers: 100–120 kg N, 60 kg P_2O_5, 60 kg K_2O/ha.
- Half nitrogen and full P & K are applied at transplanting. Remaining nitrogen is top-dressed in 2–3 splits.

Irrigation
- Requires frequent irrigation as it is a shallow-rooted crop.
- Critical stages: head formation.

Intercultural Practices
- Weeding and hoeing at early stages.
- Earthing up is important to support heads and prevent lodging.

Harvesting
- Harvest when heads are firm, compact, and mature (90–120 days after sowing).

- Delay in harvest causes head splitting.

Yield

- Early varieties: 250–300 q/ha
- Late varieties: 350–500 q/ha

ii. Cauliflower (*Brassica oleracea var. botrytis*)



Climate

- Cauliflower is a cool-season crop.
- Best temperature for curd formation: 15–20°C.
- High temperature causes loose or leafy curds, while very low temperature causes "buttoning" (small curds).

Soil

- Best soil: well-drained sandy loam to clay loam soil with neutral pH of 6.0 to 7. Soil rich in organic matter improves yield.

Nursery Raising and Transplanting

- Seed rate: 500 g/ha.
- Nursery-raised seedlings are transplanted at 4–6 weeks age.
- Spacing:
  - Early varieties: 45 × 30 cm
  - Main season: 60 × 45 cm
  - Late varieties: 60 × 60 cm

Manures and Fertilizers

- FYM: 20–25 t/ha. Fertilizers: 120–150 kg N, 60 kg P_2O_5, 60 kg K_2O/ha.
- Basal dose: Half nitrogen and full P & K applied at planting; Top dressing of remaining nitrogen in splits during growth.

Irrigation

- Needs regular irrigation, as moisture stress reduces curd quality.
- Critical stage: curd initiation and development.

Intercultural Practices

- Weeding and hoeing during early growth.
- Earthing up to support plants.
- Blanching: In some varieties, outer leaves are tied over the curd to protect it from sun and keep it white.

Harvesting

- Curds are harvested when compact, white, and firm.
- Delayed harvesting leads to yellowing and loose curds.

Yield

- Early crop: 150–200 q/ha
- Late crop: 250–300 q/ha

Production technology of Cucurbits

iii. Cucumber (*Cucumis sativus* L.)

Origin & Importance: Cucumber is one of the oldest cultivated vegetables, believed to have originated in India. It is rich in water (96%) and provides minerals and vitamins. Farmers grow it mainly for fresh salad and pickles.

Soil: It prefers well-drained sandy loam soil with good organic matter. Farmers avoid heavy clay soils and waterlogging. Soil pH between 6.0–7.0 is ideal.
Climate: Cucumber grows well in warm and dry climates. The optimum temperature for growth is 25–30°C. Cold and frost damage the crop, while very high temperatures reduce fruit set.
Sowing: Farmers sow seeds directly in the field. They usually sow 2–3 seeds per pit at a spacing of 1.5–2.0 m between rows and 60–90 cm between plants. About 2.5–3.0 kg of seed per hectare is enough.
Transplanting: Seedlings are transplanted after 3–4 weeks, of seedling having 3-4 true leaves.
Manures and Fertilizers: Apply 20–25 tonnes of FYM per hectare during land preparation. Apply 60–80 kg N, 40–50 kg P_2O_5, and 40–60 kg K_2O per hectare and split nitrogen into 2–3 applications to promote continuous growth.
Irrigation: Cucumber is sensitive to moisture stress. Farmers irrigate every 7–10 days in summer. They avoid waterlogging because it causes root rot.
Intercultural Practices: stake or trellis vines to reduce fruit rotting and improve quality. Remove weeds by hoeing and mulching.
Harvesting: harvest fruits when they are tender and green, 50–60 days after sowing. Regular picking encourages new fruiting.
Yield: A good crop yields 120–150 quintals per hectare.

iv. Bottle Gourd (*Lagenaria siceraria*)
Origin & Importance: Bottle gourd is an important summer vegetable grown across India. It is used as a cooked vegetable, in sweets (halwa, kheer), and for making containers and musical instruments from mature dried fruits.

Soil: Sandy loam to clay loam soils rich in organic matter are suitable. Well-drained soils with pH 6.5–7.5 are best.
Climate: It requires warm and humid weather with temperatures of 20–30°C. It cannot tolerate frost.
Sowing: Sow 4–5 kg of seed per hectare directly in pits or ridges. Spacing: 2.5–3.0 m between rows and 1.0 m between plants. Sowing seasons: Summer (Jan–Feb) and rainy season (June–July).
Transplanting: Seedlings are transplanted after 3–4 weeks, of seedling having 3-4 true leaves.
Manures and Fertilizers: FYM: 20–25 tonnes/ha before sowing. Fertilizers: 60:40:40 kg NPK/ha, with nitrogen applied in splits.
Irrigation: Bottle gourd needs frequent irrigation. Farmers irrigate every 4–5 days during flowering and fruiting. Water stress at this stage reduces yield.
Training and Pruning: Farmers grow bottle gourd on bowers or pandals to improve fruit shape, avoid rot, and increase yield.
Harvesting: Tender fruits are harvested 60–70 days after sowing. Harvesting at the right stage ensures continuous fruiting.
Yield: 200–250 quintals/ha under good management.

v. Bitter Gourd (*Momordica charantia*)
Origin & Importance: Bitter gourd, also called karela, is valued for its medicinal properties. It is rich in iron and vitamins and is known for reducing blood sugar levels.
Soil: It grows best in sandy loam soil with good drainage.
Climate: Hot and humid conditions (25–30°C) are ideal. It is highly sensitive to frost.
Sowing: Seed rate: 4–5 kg/ha. Spacing: 2.0–2.5 m × 0.6–1.0 m. soak seeds in water or treat them with GA_3 (100 ppm) to improve germination.
Transplanting: Seedlings are transplanted after 4–6 weeks, of seedling having 3-4 true leaves.
Manures and Fertilizers: FYM: 15–20 tonnes/ha. Fertilizers: 60:40:40 NPK/ha. Nitrogen is applied in 2–3 splits.
Irrigation: Farmers irrigate every 7–8 days in summer. Bitter gourd requires adequate water during fruit set.
Training and Pruning: Growing on trellis/bower improves fruit shape and yield.
Harvesting: Farmers harvest fruits at tender green stage, 55–60 days after sowing. Continuous picking enhances yield.
Yield: A well-managed crop yields 100–120 quintals/ha.

vi. Ridge Gourd (*Luffa acutangula*)

Origin & Importance: Ridge gourd is a popular vegetable in India. Tender fruits are used in curries, sambhar, and chutneys.
Soil: Sandy loam to clay loam soil with rich organic matter is best. Avoid waterlogged and saline soils.
Climate: Ridge gourd grows well in warm climate (25–30°C). It cannot tolerate frost.
Sowing: Seed rate: 3–4 kg/ha. Spacing: 2.0–3.0 m × 1.0 m. sowing seasons: Summer (Jan–Feb) and rainy season (June–July).
Transplanting: Seedlings are transplanted after 4–6 weeks, of seedling having 3-4 true leaves.
Manures and Fertilizers: FYM: 15–20 tonnes/ha. Fertilizers: 50:30:30 NPK/ha with top dressing of nitrogen.
Irrigation: Irrigation every 7–10 days is required, particularly during flowering and fruiting.
Training and Pruning: Growing on pandal ensures straight fruits and reduces disease incidence.
Harvesting: Farmers harvest tender fruits 60–70 days after sowing. Frequent harvesting increases yield.
Yield: 150–180 quintals/ha is common under good care.

3.8. Medicinal and Aromatic Plants

1. Ashwagandha (*Withania somnifera*)

Ashwagandha is a very important medicinal plant grown in India, also known as Winter Cherry in English. Its fruits and seeds are used to treat chest ailments. A paste made from its green berries, leaves, and small twigs is used to treat sores on horses.

Varieties:

- Jawahar Asgandh-20: Yields the highest quantity of dry roots.
- Asgandh WS-90-134: Its roots have high levels of beneficial medicinal compounds (alkaloids and withanine).
- Poshita & Rakshita: High-yielding varieties.

Soil: It grows best in sandy or light red soil that is rich in organic matter and has good drainage. The soil should not be acidic.

Climate: It thrives in a warm climate. It is planted at the end of the rainy season and requires dry weather to develop well. Areas with moderate rainfall (660-750 mm) are ideal.

Propagation:

- From Seeds: Seeds can be sown directly in the field in July. About 10-12 kg of seeds are required per hectare.
- From Seedlings: Seeds can first be sown in a nursery bed. When the seedlings are 6 weeks old, they are transplanted to the main field with a spacing of 60 cm between plants.

Manures and Fertilizers: It is not a heavy feeder. In many areas, it grows well using only the residual nutrients from previous crops. FYM: 15–20 tonnes/ha. Fertilizers: 60:40:40 NPK/ha. Nitrogen is applied in 2–3 splits.

Plant population: After germination, plants are thinned to leave enough space for the others to grow properly (maintaining about 20,000-25,000 plants per hectare). Weeds need to be removed by hand or hoeing every month.

Harvesting: The plant is ready for harvest between January and March when the leaves dry and the berries turn red. The whole plant is uprooted, and the roots are separated, cut into small pieces, and dried. Seeds are also collected from the dried berries.

Yield: One hectare can yield 300-500 kg of dried roots and 50-75 kg of seeds.

2. Periwinkle (*Vinca minor* & *Vinca major*)

Periwinkle is a small plant with attractive purple or white flowers. It has a long history of medicinal use for ailments like diabetes, malaria, and skin diseases. Modern medicine uses it to produce critical cancer drugs, such as vinblastine and vincristine.

Varieties: There are types with purple flowers, white flowers, or white flowers with a purple center. The purple-flowered type is typically cultivated for medicine. New white-flowered varieties like 'Nirmal' and 'Dhawal' yield more biomass.

Soil: It is a hardy plant that can grow in many soil types, except those that are waterlogged or alkaline. Sandy loam soil is ideal.

Climate: It grows well in tropical and subtropical areas and prefers ample rainfall (about 100 cm).

Propagation:

- Seeds: Seeds can be sown directly in the field or started in a nursery first. Seeds have a short viability period, so fresh seeds must be used.
- Stem Cuttings: Propagation from stem cuttings induces earlier flowering, which is beneficial for seed production.

Manures and fertilizers: The application of farmyard manure (FYM) or green manure (like growing and ploughing under legume plants) is highly beneficial. If manure is unavailable, chemical fertilizers can be used (e.g., 20 kg N, 30 kg P_2O_5, and 30 kg K_2O per hectare).

Irrigation: If rainfall is sufficient, additional irrigation is not needed. In dry areas, 4-5 waterings improve plant growth.

Weed Control: Weeds need to be removed twice during the first few months.

Harvesting:

- Roots: Harvested after 12 months.
- Leaves: Can be harvested twice (after 6 and 9 months) before the final harvest.

- Seeds: Collected from mature pods.

Yield: Under irrigation, one hectare can yield about 4 tonnes of leaves, 1.5 tonnes of stems, and 1.5 tonnes of roots.

3. Sarpagandha (*Rauvolfia serpentina*)

This is one of India's most important native medicinal plants. Its dried root is a highly valuable medicine. Traditionally, it was used for snake bites, mental disorders, and skin problems. Modern medicine uses it to treat high blood pressure and as a sedative.

Varieties:

- RS-1: A good-yielding variety with high alkaloid content.
- CIM-Sheel: A high-yielding variety.

Soil: It grows in many soils but prefers clay or clay-loam soil rich in organic matter. The soil should not be alkaline.

Climate: It prefers hot and humid conditions and can be grown in open fields or partial shade.

Propagation:

- From Seeds: This is the primary method, but seeds have low germination rates. Fresh seeds are best. They are first sown in a shaded nursery and later transplanted to the field.
- From Cuttings: Root or stem cuttings can also propagate new plants. This is useful for cloning superior plants.

Manures and fertilizers: A substantial amount of FYM of 25-30 tonnes/ha and fertilizers (e.g., 30 kg N, 60 kg P_2O_5, and 30 kg K_2O per hectare) are required.

Irrigation: The crop requires watering every two weeks in summer and once a month in winter.

Harvesting: Roots are ready after 2-3 years. They are carefully dug out in winter (December) when the medicinal content is highest. The roots are washed, dried until brittle, and stored in a cool, dry place.

Yield: A 2-year-old plantation can yield about 2,200 kg of dried roots per hectare.

4. Isabgol (*Plantago ovata*)

Isabgol known as Blond Psyllium, is a small plant cultivated for its seeds and husk. The husk is highly absorbent and is primarily used as a laxative to treat constipation and diarrhea.

Varieties: Several high-yielding varieties exist, such as Gujarat Isabgol-1 (GI-1), GI-2, and Niharika.

Soil: It is an irrigated crop that grows best on light, well-drained soils. Heavy, waterlogged soil is unsuitable.

Climate: It thrives in cool, dry weather and is sown in winter (November is ideal).

Propagation:

- The land must be prepared to a fine tilth.
- Seeds are very small and light, so they are mixed with sand or fine manure before being broadcast across the field.
- After sowing, a light watering is given to ensure the seeds are not washed away.

Manures and fertilizers: It is not a heavy feeder. A substantial amount of FYM of 10-15 tonnes/ha. A moderate dose of fertilizers 50 kg N, 25 kg P_2O_5, 30 kg K_2O per hectare is sufficient.

Irrigation: It requires careful irrigation. The first watering must be very light. In total, about 6-7 waterings are needed.

Harvesting: The crop matures in 110-130 days (Feb-Mar). The plants turn yellowish, are cut, dried, and then threshed to separate the seeds. The seeds are processed to remove the valuable husk.

Yield: A good variety can yield 800-1000 kg of seeds per hectare.

5. Aloe (*Aloe vera*)

Aloe is a succulent plant (it stores water in its leaves). The thick gel from its leaves is dried to make the medicine "aloe." The fresh gel treats skin burns and wounds, while processed aloe is a potent laxative.

Variety: CIM-Sheetal is a well-defined, good variety for farmers.

Soil: It is a hardy plant that grows in many soils, from sandy to loamy. It cannot tolerate waterlogging.

Climate: It is highly adaptable and can be grown across India in warm, humid, or dry climates. It is typically planted between March and June.

Propagation:

- It is easily propagated from the root suckers (offsets) that grow at its base or from rhizome cuttings.
- Planting: Suckers are planted at a spacing of 60 x 30 cm.

Manures and fertilizers: Its full nutrient requirements are not precisely known, but a substantial amount of FYM of 10-15 tonnes/ha, and a mix of N, P, and K (150 kg/ha) may yield better yield.
Irrigation: It needs 4-5 waterings per year. Water must not be allowed to stagnate around the plant.
Harvesting: Leaves are harvested after 8 months. The plantation provides a good yield from the 2nd to the 5th year, after which it needs replanting.
Yield: About 10,000-12,000 kg of fresh leaves per hectare can be obtained.

6. Coleus (*Coleus forskohlii*)

Coleus is a potential future medicinal crop. Its tuberous roots contain a compound called forskolin, which is being developed into drugs for asthma, glaucoma, heart conditions, and high blood pressure.
Varieties:

- K-8 and CO (Col)-1: Good yield of roots and forskolin.
- Aisiri: Has a very high forskolin content (0.7%).

Soil: It grows well in porous, well-drained soil that is not overly fertile. The red sandy soils of Karnataka are ideal.
Climate: It is a tropical plant found on hills up to 2400 m altitude and prefers high humidity.
Propagation:

- It is best propagated from stem cuttings, as seed propagation is slow and difficult.
- Cuttings are planted on ridges 60 cm apart, with plants spaced 20 cm apart within the row.

Manures and fertilizers: It responds well to farmyard manure of 20-25 t/ha and fertilizers (e.g., 40 kg N, 60 kg P_2O_5, 50 kg K_2O per hectare).
Irrigation: It requires regular watering, especially immediately after planting.
Harvesting: The crop matures in 5-6 months. The roots are dug up, cleaned, cut into pieces, and sun-dried.
Yield: One can harvest 1500-2500 kg of dry roots per hectare.

7. Senna (*Cassia angustifolia*)

Senna is a small shrub. Its leaves and pods contain sennosides, making it a well-known and effective laxative for treating constipation.
Varieties:

- ALFT-2: A late-flowering variety good for leaf production.
- Sona: Suitable for the North Indian plains, with high sennoside content.
- KKM-1: Suitable for multiple harvests (leaf strippings).

Soil: It grows on various soils (red loam, alluvial) but requires good drainage. It is highly sensitive to waterlogging.
Climate: It is a warmth-loving crop that needs bright sunshine. Rainy season sowing is not advisable because the harvest cannot be dried properly.
Propagation:

- Grown from seeds. The seeds have a hard coat, so they are lightly scarified with sand or soaked in water before sowing to improve germination.
- Seeds are sown in lines or on ridges.

Manures and fertilizers: It often utilizes residual nutrients from previous crops. A general recommendation of FYM of 10-15 tonnes/ha, and a mix of is 80 kg N, 40 kg P_2O_5, and 40 kg K_2O per hectare.
Harvesting: Leaves are hand-picked 2-3 times, starting from 50-70 days after sowing. The final harvest includes leaves and pods. The crop must be dried quickly in the shade to maintain its greenish-yellow color and quality. Slow drying turns it black and reduces its value.
Yield: Under good conditions, one hectare can yield 15 quintals (1500 kg) of dry leaves and 7 quintals (700 kg) of pods.

8. Kalmegh (*Andrographis paniculata*)

Kalmegh known as "King of Bitters", it is a bitter-tasting herb. The whole plant is used medicinally for liver problems, to stimulate digestion, and for fever and infections.
Soil: It is a hardy plant that grows in many soils, but sandy loam rich in organic matter is best.

Climate: It grows well in tropical and subtropical regions with good rainfall. The best time to plant is June.
Propagation:

- It is usually grown from seeds, either sown directly or transplanted as seedlings.
- Spacing: A close spacing of 15×15 cm gives the best herb yield.

Manures and fertilizers: It responds well to FYM (25 t/ha) and fertilizers (e.g., 75 kg N, 75 kg P_2O_5, 50 kg K_2O per hectare).
Harvesting: The first harvest is ready 90-120 days after sowing when the plant begins to flower. It is cut, leaving a stump behind. The stump regrows, allowing for 2-3 harvests per year. The harvested plant is dried in the shade.
Yield: About 2-2.5 tonnes of dry herb per hectare can be obtained.

Long Pepper (*Piper longum*),

The unripe spikes (flower heads) of the *Piper longum* plant are used. They contain the compound "piperine" and are used in traditional medicine for respiratory and digestive issues and as a general health tonic.
Soil: It grows well in rich, well-drained loamy soil or limestone soil rich in organic matter.
Climate: It requires a hot, moist climate and is best grown under partial shade (20-25% shade).
Propagation:

- Propagation: It can be grown from seeds, suckers, or stem cuttings. Rooted cuttings in polybags are a common method.
- Planting: Rooted cuttings are planted in pits filled with manure at the beginning of the monsoon.

Manures and fertilizers: It requires heavy manuring with FYM (20 t/ha) and fertilizers (e.g., 50 kg N, 20 kg P_2O_5, 70 kg K_2O per hectare).
Irrigation: It needs weekly watering if grown alone. If grown as an intercrop (e.g., under coconut trees), it utilizes the water provided to the main crop.
Harvesting: Spikes are picked when they are blackish-green and pungent. They are sun-dried for 4-5 days. The roots and thick stems can also be harvested after 18 months, cut into pieces, and dried. This dried root is called "Piplamool."
Yield: In the first year, about 400 kg of dry spikes per hectare can be obtained, increasing to 1000 kg by the third year.

9. Sweet Flag (*Acorus calamus*)

Sweet Flag is an herb whose dried rhizome (underground stem) is used for medicine and flavouring. It treats digestive problems, is believed to improve memory, and its oil is used in perfumes.
Climate: It is a hardy plant that prefers areas with well-distributed rainfall throughout the year.
Propagation:

- Propagation: It is propagated by replanting the tender top portion of the rhizome after harvest; the mature part is sold.
- Planting: The field is prepared like a rice paddy. Rhizome pieces are pressed into the mud in rows.

Manures and fertilizers: It requires green manure, compost, and fertilizers (N, P, K).
Irrigation: The field is kept flooded with about 5-10 cm of water, similar to a rice field.
Harvesting: The crop is ready after a year. The rhizomes are dug up (they can be 60 cm deep), cut into pieces, washed, and sun-dried. They should not be peeled before drying.
Yield & Oil: About 10 tonnes of rhizomes per hectare can be obtained, yielding 1.2-3.5% essential oil.

10. Citronella (*Pelargonium citrosum*)

Citronella is an aromatic grass. When its leaves are steamed, they produce citronella oil, which is used in soaps, perfumes, cosmetics, and as a natural insect repellent.
Varieties: Jorhat-C2, Java-2, Manjusha, and Mandakini are high-yielding varieties. 'Manjari' is a new, superior variety.
Soil: It grows best in sandy loam soil with plenty of organic matter.
Climate: It needs a warm, humid climate with plenty of sunshine and well-distributed rainfall (200-250 cm).
Propagation:

- Propagation: It does not produce viable seeds, so it is propagated by dividing old clumps into "slips" (small pieces with roots).
- Planting: Slips are planted on ridges during the monsoon (May-June).

Manures and fertilizers: It requires FYM and fertilizers like Nitrogen, which is applied in split doses after each harvest.

Harvesting: The first harvest is ready after 9 months. The grass is cut 20-45 cm above the ground. Harvesting is done 3-4 times a year. The grass must be distilled for oil within 24 hours of cutting.

Yield: From the second year, one hectare can yield 20-25 tonnes of grass, giving 200-250 kg of oil.

11. Vetiver (*Chrysopogon zizanioides*)

Vetiver is known as **Khus**, it is a dense, tufted grass. The oil from its roots has a deep, pleasant, and persistent fragrance, making it a prized ingredient in perfumes ("the perfume of the earth"). It is also used in cosmetics and to flavor food and drinks. Vetiver is a perennial grass known for its aromatic roots, extensive uses in agriculture and medicine, and its ability to prevent soil erosion..

Varieties: Dharini, Gulabi, and KS-1 are good varieties known for high oil yield and quality.

Soil: It can grow on almost any soil, but well-drained sandy loam and red soils rich in organic matter are best for oil production.

Climate: It prefers a tropical climate with moderate to high rainfall (1000-2000 mm). It can also be grown with irrigation.

Propagation:

- Propagation: It is grown from "slips" (small divisions from the base of the plant).
- Planting: Slips are planted in rows during the rainy season (June-July).

Manures and fertilizers: It benefits from FYM (10 t/ha) and a moderate dose of fertilizers (N, P, K).

Harvesting: Plants are harvested after 18 months, usually in the dry season (Dec-Feb). The roots are dug up, separated from the leaves, washed, and shade-dried for 1-2 days before distillation. Sun-drying reduces oil yield.

Yield & Oil: Yield can be 3-4 tonnes of roots per hectare. Oil recovery is about 1%. The oil's aroma improves significantly if aged for six months after distillation.

12. Lemongrass (*Cymbopogon citratus*)

Lemongrass is an aromatic grass. Steam distillation of its leaves yields lemongrass oil, which has a lemon-like scent. The oil is used in soaps, perfumes, and cosmetics and is a source for synthesizing Vitamin A. It is a versatile herb known for its culinary uses, aromatic properties, and health benefits, thriving in warm climates with plenty of sunlight.

Varieties: Pragathi, Krishna, and SD-68 are high-yielding varieties with high citral content (the main aromatic compound).

Soil: It grows on a wide variety of soils, from rich loam to poor laterite. Waterlogged soil must be avoided.

Climate: It requires a warm, humid climate with high rainfall (200-250 cm) and plenty of sunshine.

Propagation:

- Propagation: It can be grown from seeds or by dividing clumps (slips). Direct seeding is common.
- Planting: Seedlings are transplanted during the monsoon at a close spacing (30x30 cm).

Manures and fertilizers: It responds very well to Nitrogen fertilizer, applied in split doses after each harvest.

Harvesting: It is a perennial crop. The first cut is made 90 days after planting. Subsequently, it is harvested every 40-60 days. The grass is cut 10 cm above the ground and must be distilled fresh for oil.

Yield: From the second year, one can obtain 350-400 kg of oil per hectare.

13. Palmarosa (*Cymbopogon martinii*)

Palmarosa is an aromatic grass. Its oil has a sweet, rosy scent due to its high geraniol content. The oil is called "East Indian Geranium Oil" and is used in high-grade soaps, perfumes, and cosmetics.

Varieties: Trishna, Tripta, and Haryana-49 (RH-49) are excellent high-yielding varieties.

Soil: It requires well-drained loamy soil. Waterlogging is very harmful.

Climate: It needs a warm tropical climate. Frost will kill the plant.

Propagation:

- Propagation: It is mainly grown from seeds raised in a nursery.
- Planting: Seedlings are transplanted at the beginning of the rainy season. Closer spacing (30x30 cm) gives a higher yield.

Manures and fertilizers: It needs a balanced fertilizer (N, P, K). Foliar sprays with micronutrients like Zinc and Iron can boost growth and yield.

Harvesting: The grass is harvested when it is in full bloom, as the flowers contain the most oil. The whole plant is cut and distilled. A plantation remains productive for about 4 years.

Yield: From the second year, an irrigated crop can yield 220-250 kg of oil per hectare.

Steam Distillation Technique for Extraction of Essential Oils

Steam distillation is the most widely used method for extracting essential oils from aromatic plants. In this technique, steam is passed through the plant material containing volatile oils. The heat and moisture

help in rupturing oil glands, releasing the essential oils, which then evaporate along with the steam. The vapor mixture of steam and oil is condensed by cooling, and the resulting liquid separates into two layers: water and essential oil. Since essential oils are immiscible in water and lighter in density, they can be easily separated. This method is economical, preserves the natural quality of oils, and is suitable for large-scale extraction of oils from flowers, leaves, seeds, and other aromatic plant parts.

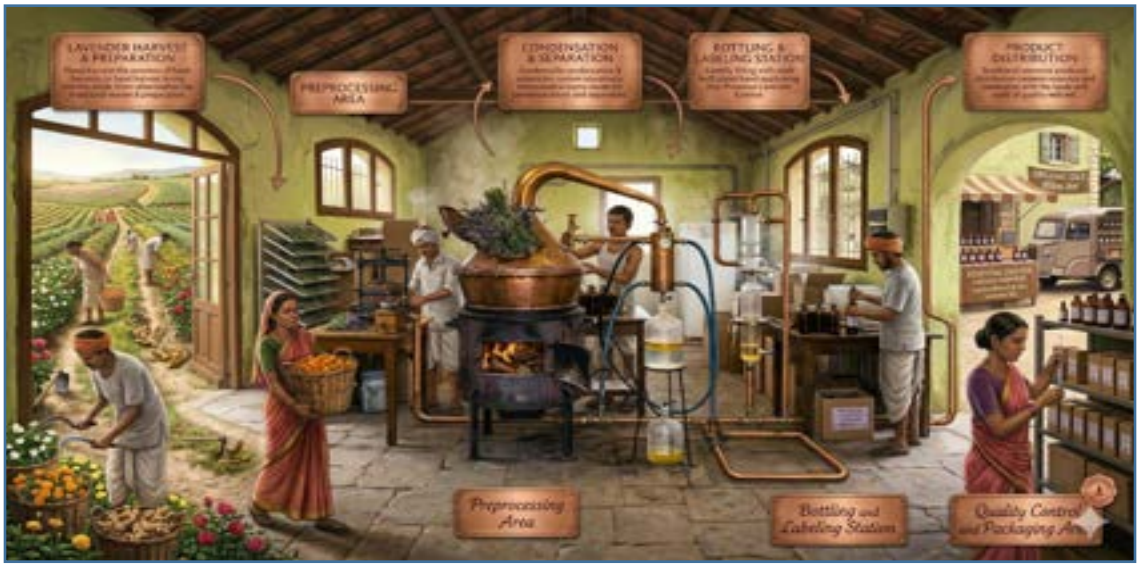


Fig: Steam Distillation Technique for Extraction of Essential Oils

3.9. Floriculture

India is having a long tradition of floriculture however commercial floriculture has assumed importance, only in the recent past. Flowers are associated with mankind from "birth till death" for various purposes during our daily life. The commercial flower crops production involves cultivation of loose flowers (traditional flowers) and Cut flowers (Commercial/Modern flowers), also involves cultivation of foliage crops, ornamentals, etc.

The production technology for different flower crops involves tailored methods focusing on site selection, planting material, precise nutrient management (fertigation), controlled irrigation, weeding, special crop management practices like training, pinching, pruning, staking, etc to achieve optimized yield and quality of flowers, integrated pests & disease management, proper post harvest handling to harness market.

Flower production of certain flowers (especially cut flowers) often involves protected cultivation under polyhouse/net house to create optimum environmental conditions for the crop and to meet the market standards for export.

1. Rose:- (*Rosa spp..*)

Rose also known as "Queen of Flowers" is the most popular among all the flower crops throughout the world and known to be grown before the appearance of man on this earth. Rose is commercial grown both for cut flower and loose flower purpose. Rose is also having industrial applications with the extraction of oil from petals, having edible value (Jam, Gulkhan, etc), rose and its fruits (hips) have got medicinal value also. Various types of Rose are having greater application in garden display also.

Soil:- Rose can be grown in any type of soils but it's found best to grow in medium loamy soils with sufficient organic matter & proper drainage. It grows well in a soil with pH of 6.0 to 7.5, however it can withstand little acidity (5.5). Land with high water table isn't suitable.

Climatic conditions:- Rose is a sun loving plant which needs high light intensity (6000-8000 foot candles) with bright sunshine for whole day (specially forenoon). The optimum day and night temperature requirement is 24–26 º C and 15–17 º C respectively. Rose prefers an optimum Relative humidity (RH) of 60 % is ideal for achieving better growth of plants and for producing best quality flowers. On other hand higher RH leads to incidence of pests and diseases affecting growth & flowering. Under protected cultivation Co2 enrichment is done to level of up to 1000-3000 ppm to get quality flowers with increased stem length reducing incidence of flower abortion.

Protected structure: - Under mild climatic conditions (Bangalore and Pune) roses can be successfully cultivated under naturally ventilated Polyhouse. However, under warm and high temperatures (Hyderabad and Delhi) it needs forced ventilation system (cool-cell pad) to get quality flowers.

Propagation: - Rose is commercially propagated through Budding (T-budding/Shield)

Varieties: - Every year many new cultivars are added to the market. Presently > 45,000 rose varieties are available (differing widely in size, shape, color, fragrance, growth habit, etc) and the success of rose cultivation greatly depends on the proper choice of cultivars based on the location, purpose of growing and the targeted market.

Popular Cut flower Roses: - First red, Grand gala, Tajmahal, Golden strike, Nobless, Confitte, Super star, Golden times, Gladiator, etc

Popular Loose flower Roses: - Mirable, Cherisma, Vanessa, Rubygon, Santan, Kelly, etc.

Season of Planting: - Best season of planting is from June-October

Spacing: - Rose is planted on raised bed method or pit method of planting (45 Cm^3 pits) with a spacing of 75X75 cm (hybrids) or 60X60 cm (varieties) under open condition. Whereas under protected cultivation rose are planted on raised beds with a spacing of 30X15 cm or 40X20 cm with a path spacing of 30-45 cm between beds.

Irrigation (Fertigation):- Adequate soil moisture is required during different stages of plant growth however water logging isn't good for rose. The frequency of irrigation greatly depends on stage of growth, soil texture, climate, etc. In general water rose beds once in a week during winter and twice a week during summer. Drip irrigation is best, fogging, overhead sprinklers are also common.

Rose is a nutrient loving plant. All 16 elements play important role for proper growth and development of plants. Apply organic matter (FYM) at 5-10 kg/plant every year. The recommended dose of fertilizers is 10:10:15 g of NPK/plant twice a year during pruning and 45 days after pruning along with 100 g/plant of micronutrient rose mixture. Fertigation requirement 170 ppm N, 34ppm P, 160ppm K, 120ppm Mg per every watering

Weeding: - Manual weeding & hoeing is effective if done properly and frequently. However, chemical weeding is economical, convenient to eradicate weeds in 1 or 2 applications. Pre-emergent herbicides like Pendimethalin, Oryzalin or Isoxaben found suitable. Post emergent herbicides like Clethodium or Sethoxydim for grassy weeds and 2,4-D for broad leaved weeds management.

Special cultural practices:-

i. (Pruning, Training):- Pruning is an important operation of removal of certain portion of the plant for maintaining floriferousness and flower quality along with vigor of the plants. Training is sometimes confused with pruning, which is concerned with giving definite shape during the initial growth of the plants, while pruning effects the functioning of plants by removing unproductive growth because rose plant bear flowers on a new shoot. It is advisable to conduct pruning twice a year (May-June and October-November). Stop watering plants before one week of pruning.

Types of Pruning: - Based on intensity of pruning 3 types are practiced *Viz.*

a. Light pruning: - Dried & dead branches are trimmed off. Then the cut is given either at the 2nd or 3rd eye bud immediately below the flower bearing stalk.
b. Moderate pruning: - Healthy shoots are pruned back to 45-60 cm from the base.
c. Hard pruning: - Keeping only 3 to 4 shoots of last year growth, complete heading back at about 3 to 4 eyes from the base. This type is practiced for rejuvenation of old bushes/weak plants. Pruning is done by leaving 10-30 from the bud joint.

Within a fortnight after pruning new flush of growth will start and within 45 days of pruning new flowers will be ready for harvesting.

ii. Thinning: - Removal of undesirable shoots

iii. De-suckering:- Removal of suckers from the rootstock (shoots produced below bud union)

iv. Pinching: - Removal of terminal growth to reduce plant height and promote auxiliary growth. Pinching of blind shoots is beneficial to increase flowering.

v. Disbudding: - Removal of undesirable buds

vi. Defoliation: - Process of removal leaves which force plants to produce growth and flowering during desired period

vii. Use of growth regulators: - GA3 @ 250 ppm to increase stalk length, flower size and reduce number of blind shoots

viii. Removal of faded flowers **ix. Bending**

x. Bud capping: - It is practiced under protected cultivation of rose for cut flower purpose to get uniform shape of flowers and for even opening of flowers.

Plant protection: - **Pests-** Red spider mite, thrips, aphids, white flies, caterpillars

Diseases – Powdery mildew, Downy mildew, Die back, Botrytis, Black leaf spot, Verticillium

Harvesting and Yield: - Yield starts 4-5 months after planting, and 45 days after pruning, harvest tight bud stage for long distance, stem length vary from 40-90cm. Flower yield ranges from 100-150 stems under greenhouse. It yields 1.6-2 ton/acre under open cultivation for loose flower purpose.

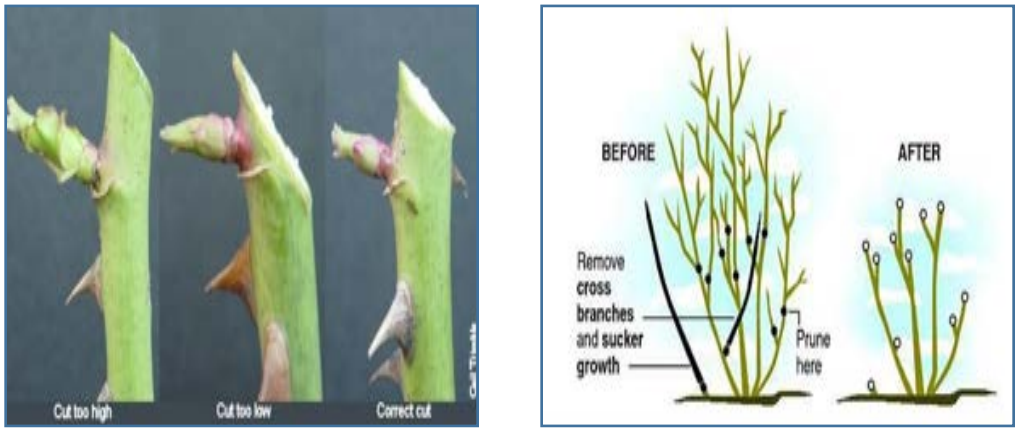


Fig: Where to prune the Rose

2. Chrysanthemum

Chrysanthemum is the most popular flower crop next to rose in world. It is cultivated both for loose flower purpose, cut flower, along with major potted plant. The flowers are available in a wide range of colour. The flower is inflorescence which consists of 2 types of florets like outer ray florets (male) and central disc florets (hermaphrodite).

Soil and Climate: - A well drained Sandy loam soil with a pH range of 6.5 to 7 is found ideal for cultivation of chrysanthemum. It is a shallow and fibrous rooted plant, hence sensitive to water logged conditions leading to incidence of root rot and wilt diseases. The environmental conditions like light and temperature mainly affect the growth, development and flowering of chrysanthemum. Basically it is a short day plant which produces flowers under short day conditions and growth is influenced by long day conditions. It prefers high light intensity. The ideal temperature for vegetative growth is 18.3º C and 13.3-15º C during flower bud initiation.

Propagation: - It is commercially propagated by terminal cuttings. The cuttings treated with NAA @ 250 ppm will give better rooting and establishment after planning.

Varieties: - Chrysanthemum is available in wide range of colours however the most popular and commercially cultivated varieties are white and yellow. The most popular varieties grown includes Scent yellow, Scent white, Muscat white, Marigold/rubber chrysanthemum, Poornima yellow, Poornima white, Chandini (milky white), Aishwarya 1 & 2, Harini white, Suvarna yellow, etc. The varieties should be selected based on the location and market preference.

Soil preparation: - Plough the soil 3-4 times to remove clods and bring the soil to the fine tilth, then add 8-10 ton per acre of FYM at the final ploughing. Add 200 kg of Neem cake and pongemia cake. Enrich the FYM with biofertilizers like Trichoderma, Psudomonas, etc and then applying to the soil increases fertility of soil, also reducing soil borne diseases.

Planting and Spacing: - Planting at a distance of 30X30 cm is ideal which yields maximum. Planting can be done by ridge and furrow method by planting on one side of ridges or on raised beds.

Fertilizers: - Apply NPK @ of 15:60:70 kg per acre during planting. Again 30 days after planting and after pinching apply 15 kg of N. Again after one month of pinching apply 15 kg N.

Fertigation schedule: - Apply 16.8 kg urea, 70 kg SSP and 12.8 kg MOP as basal dose and then 20 days after transplanting follow below mentioned schedule

Days after planting	Urea/week	MAP/week	SOP/week
0-20 days	No fertigation		
21-65 days	1.9 kg	3.1 kg	2.5 kg
66-100 days	2.3 kg	3.7 kg	3 kg
101-180 days	1.2 kg	1.8 kg	1.5 kg

Irrigation: - A day after transplanting drench with water, and initial 10-15 days with pipe is better compared to drip. Later on based on soil moisture & weather apply water at 4-5 days interval.

Special cultural practices:-

i. Pinching: - Removal of terminal portion of the stem to reduce plant height and promote more number of auxiliary branches which is practiced 30 days after transplanting.

ii. Disbudding: - Removal of undesirable immature flower buds during early stage of vegetative growth. It is done either to get large flowers or small flowers in large number.

iii. De-suckering:- Removal of suckers plants to allow better growth, development of main plant

iv. Staking: - To avoid lodging of plants/branches it is advisable to provide staking upto 4-5 ft.

v. Growth regulator spray: - spraying of GA3 @ 1g/10 litre of water at one month after pinching to increase flower yield.

Weed control: Mulching best to follow during summer and even rainy also. Even it cost less 16 K, compared to weed management in traditional method.

Plant protection: Pests: - Thrips, Apids, White flies, Bud borer/hairy catterpillars, mites, Leaf hopper, etc

Diseases: - Collar/Root rot, Yellow mosaic virus, Leaf spot, Rust, Fusarium wilt, botrytis blight, etc

Harvesting and Yield: - The harvesting will start from 3-3.5 months after transplanting and continue further for 45-60 days. It yields about 8-10 ton/acre (loose flowers) and 12-16 lakh cut flower/acre.

3. Marigold

Marigold is an important flower crop among traditional/loose flowers which has gained popularity among growers for its easy cultivation and wider adoptability. Marigold is mainly used for garland making, decorations, flowers with long stem used for vase arrangements, highly suitable for bedding, herbaceous borders in gardens. The flowers and leaf extracts have got medicinal value. Marigold is having industrial application with the extraction of pigment (Xanthophyll) from petals.

Soil and climate:-

Fertile sandy loamy soil, well drained and aerated soils with pH of 6-7.5 is found suitable. It requires a mild climate 18-26 º C for luxurious growth and profuse flowering. If the temperature is too high of about 26-36 º C then the flower quality and yield will be adversely affected ceasing growth of plants.

Planting season: - Marigold can be grown throughout the year. For summer crop transplant during 2d week of February, for rainy season crop transplant during 2 week of June and for winter season crop transplant during 2nd week of September.

Propagation: - It is commercially propagated by seeds and even vegetative propagation by terminal cuttings. Seed rate of 400-600g/acre for African type, 600-800 g/acre (French type). Seedlings will be ready for transplanting in one month after sowing.

Varieties: - There are mainly 2 types of marigold are grown

1. African marigold: - *Tagetes erecta* (Tall marigold [3.3.5 feet] with big sized flowers) produce flowers with lemon yellow to yellow, golden yellow/orange colour.

2. French marigold:- *Tagetes patula* (Dwarf marigold [30-45 cm] with small/medium sized flowers), produce flowers with colour ranging from yellow, orange, shades of crimson, sometimes bicolour (light yellow to maroon blotch), deep crimson edged yellow/golden red.

Important varieties include Pusa basanti gainda, Pusa narangi gainda, Arka shubha, Arka vibha, Arka abhi, arka banu, Arka agni, Arka Bangara, Arka pari, Arka madhu, etc.

Spacing: - African marigold-60X45 cm French marigold- 20X20/30X30 cm

Land preparation: - After deep ploughing for 3-4 times, add 8 ton/acre of FYM at the time of final plough. Prepare ridge and furrows or raised beds for transplanting the seedlings.

Fertilizers: - At the time of planting as basal dose apply 50:30:30 kg of N: P: K /acre. At the time of pinching around 30-45 days after transplanting apply 40 kg of N.

Irrigation: - watering should be done based on soil moisture and weather conditions, once in 4-6 days or twice in a week. Keep the field free from weeds by doing 3-4 manual weeding for whole crop period or apply post emergent herbicide Simazine @ 2 kg a.i/ha. Use of mulching sheets when grown on beds will avoid weeds conserving soil moisture.

Special cultural practices:-

i. Pinching and disbudding: - Removal of terminal shoots at 40 days after transplanting to encourage more number of auxiliary branches, hence to get more number of flowers and yield. Remove all buds which arise till one month or pinching is done.

ii. Foliar application of micronutrients:- Foliar spray with **MgSO4 1.25g** + **ZnSO4 1 g** + **Borax 0.25 g** in **1 liter of water** @ 30 &45 days after transplanting which helps to get better quality and size of flowers till last harvesting increasing overall productivity (**Technology from IIHR).**

Plant protection: - Pests: - Leaf hoppers, Red spider mites, Hairy caterpillar, etc

Diseases: - Damping off, Collar rot, Leaf blight, Botrytis Flower blight, Fusarium wilt, leaf spot, etc.

Harvesting and Yield: - Harvesting starts from 2 months after transplanting and then continue for further 2 & half months. Harvest flowers along with stalk. It yields around 8-10 ton/acre (African type) and 5-6 ton/acre (French type).

4. Jasmine

It is one of the oldest fragrant flower crops having industrial value (essential oil) along with loose flower purpose. Jasmine is one important among flower crop grown commercially in India. There are about 200 species, out of which 40 species are native to India. Important species from commercial cultivation point of view includes

Jasminum auriculatum **(Vasantha mallige):-** varieties Co-1, Mullai, Co-2

J. grandiflorum **(Jajimallige):-** Varieties like Co-1, Co-2, Arka surabhi

J. sambac **(Gundu mallige/Arabian jasmine):-** Varieties include Gundumalli, Double mogra, Iruvatchi, Kasturimalli, Arka aradhana, Madanabanam, Oosimalli, Ramabanam, Single Mogra, Khoya, Mysore gundu mallige, Udupi mallige, Madhuramalli, etc.

J. multiflorum **(Kakada):-** This species produce flowers throughout the year, hence cultivated more even though it is lacking fragrance.

Soil and Climate: - Jasmine require dry humid air for its successful cultivation. It prefers dry warm summer with mild winter with ideal temperature of 20-30 ºC for better growth. Well drained sandy loam soil with pH of 5.5 to 6.5 is found ideal soil for jasmine cultivation.

Planting season: - It is best to plant during the onset of monsoon during June-August.

Propagation and Spacing: - 15-20 cm length of cuttings either from terminal or semi-hardwood portion of the stem is suitable for propagation. Treating the cuttings with IBA improves rooting.

J. auriculatum: - Ideal spacing is 1.5 X 1.5 mt; *J. grandiflorum*: - Ideal spacing is 2X1.5 mt

J. sambac: - Ideal spacing is 1.25X1.25 mt; *J. multiflorum*: - Ideal spacing is 1.2X1.2 mt

Preparation of land, planting and nutrient management: - Deeply plough the land to bring soil to fine tilth. Then open 0.5 mt^3 pits at the recommended spacing. Leave the pits for 1-2 week and then fill the pits with equal proportion of soil and FYM. Apply 200-250 g/pit with Neem cake. Apply 20kg FYM/plant/year or 2-4 kg vermicompost along with recommended dose of NPK. In South India nutrients are applied in 6 split doses, first during January immediately after pruning, then during march, April, May, july, September and November.

Recommended dose of fertilizers based on age of the plants

Nutrients	1-2 year plants	3-5 year plants	>5 year plants
Nitrogen	30 (70 g urea)	60 (140 g urea)	120 (270 g urea)
Phosphorous	60 (375 g SSP)	120 (750 g SSP)	240 (1500 g SSP)
Potassium	60 (100 g MOP)	120 (200 g MOP)	240 (400 g MOP)

- Foliar spraying with ZnSo4 @ 0.25% and MgSo4 @ 0.5% sprayed before flowering increases flower yield as well as quality.

Irrigation: - Maintain good amount of soil moisture for getting good quality flower, yield and growth of plants. Irrigate once in 7-10 days based on soil moisture and weather conditions. Through drip irrigation 2-4litre/plant/day is applied depending on age of plant, weather, and soil type.

Weeding: - Manual weeding is expensive though few inter cultivation/ hoeing can be done do reduce weeds. Application of paraquat/glyphsate @ 2 kg a.i. /ha will control both monocots and broad leaved weeds. Mulching will be economical in controlling weeds along with conserving moisture.

Special cultural practice (Pruning):- The main objective of pruning is to increase yield by increasing number of shoots as pruning will influence growth, flower bud initiation, differentiation finally increasing flower production. Plants are pruned by removing all the past season's shoots including dead and diseased branches. All the leaves are also stripped off. It is advisable to withhold water prior to pruning. Pruning once in a year will rejuvenate the plants with new growth.

The time of pruning differ from species

Species	Ideal time	Ideal height
J. multiflorum	March-April	40-60 cm from the ground
J. sambac, J. auriculatum	November, December-January	40-60 cm
J. grandiflorum		90 cm

Plant protection: - Pests:- Bud borer, Mites (red spider/gall mite/cyclamine mite), Mealy bugs, Gallery worm, Tingid bugs, Scales, Blossom midge, White flies, Nematodes

Diseases: - Leaf blight, Rust, Wilt, Root rot, Mosaic virus, Powdery mildew, etc.

Physiological disorder: - Phyllody

Harvesting and yield: - The plants start yielding in 6 months after planting however it takes 3 years for giving economic yield. In general jasmine yields about 3-4 tons/acre till 12-15 years of age.

5. Tuberose

Tuberose is called as King of flowers and is one of the most important bulbous flower crops which is grown for its fragrant flowers both for loose flower & cut flower along with whole flower stalk. The flowers are also commercially cultivated for extraction of essential oil.

Soil and Climate: - Well drained sandy loam soil with pH of 6.5 to 7.5 is found suitable for cultivation of tuberose. Soil should have good water holding capacity but avoid water logged soil. It prefers warm & humid climatic conditions with ideal temperature of 20-30 ⁰ C. If temperature goes beyond 35 ⁰ C will reduce spike length. It grows well in sunny situation.

Propagation: - Commercially propagated by division of bulbs (tubers). Spindle shaped disease free bulbs with 2-3 cm size should be used for planting. Freshly harvested bulbs will have dormancy, hence should be stored to break dormancy before planting.

Time of planting: - May-July is best for planting tuberose

Varieties: - There are mainly 2 types based on number of whorl as Singles (Mexican single, Shringar, Rajat rekha, Arka prajwal, Arka nirantara, Arka sugandhi), Doubles (Suvasini, Swarna rekha, Vaibhav).

Land preparation & planting: - Plough the land for 2-3 times to bring soil to fine tilth and add 8 ton/acre of FYM at the final ploughing along with 200 kg neem cake. Prepare ridge and furrow at 30 cm spacing and plant the bulbs at 30 cm distance on one side of ridge. Planting can be done on raised beds also at spacing of 30X30 cm. The ideal depth of planting bulbs is 2-4 cm.

Irrigation: - The soil should have optimum moisture during planting and don't irrigate till the bulbs sprout as it would lead to rotting of bulbs. After that irrigate the plants at an interval of 5-7 days and later on increase the frequency of watering to get more number of flowers. During summer irrigate twice a week to increase flower yield and bulb yield to greater extent.

Nutrition: - For singles- 120:60:100 kg NPK/acre and for doubles-200:120:120 kg NPK. Apply half of nitrogen at the time of planting and remaining half of N along with full dose of P & K should be applied 6 weeks after planting. Need foliar spray with **ZnSo4 @ 0.5 % + FeSo4 @ 0.2 % + Boric Acid @ 0.1 %** may also be practiced for getting better growth and yield in tuberose.

Earthing up: - It is done to give support to the plants and also helps the spike to grow erect avoiding lodging of spikes.

Weeding & Mulching: - It is done to conserve moisture and to maintain optimum soil temperature reducing weed population. Hoeing can be done to reduce weeds and provide aeration. Apply preemergent herbicides like Atrazine @ 3 kg a.i. /ha or Gramaxone @ lit/ha which control maximum weeds.

Growth & flowering: - The growth of tuberose bulb take up a characteristic cycle of development which will start with the initiation of growth, then it will undergo vegetative stage during which bublets will grow attaining maximum vegetative growth. Then it enters the reproductive stage with the initiation of flowers and differentiation of floral parts. It will take around 80-95 days to flower after sprouting of bulbs. It flowers profusely during summer and also during rains. In hilly region peak flowering if from may-aug, but in mild climatic conditions it flowers throughout the year.

Plant protection: - Pests: - Thrips, Mealy bugs, Aphids, Nematodes, etc

Diseases:- Fusarium wilt, Stem rot, Leaf spot, Flower blight, Flower bud rot, etc

Harvesting and Yield: - Harvesting starts 3-3.5 months after planting. The flower spikes should be cut at appropriate maturity & at regular interval. For cut flower purpose cut the spike when lower most pair of flower opens. For loose flower purpose harvest when the flower buds are completely developed & harvest early in the morning. It yields about 7-8 tons/acre/year of loose flower and about 1-1.5 lakh spikes. After 2 years the crop yields 6 ton/acre of bulb yield.

Ratoon cropping: - After main cropping season, cut the spikes and apply recommended dose of fertilizers and irrigate the crop to get ratoon crop. From once planted crop, 1-2 ratoon crops can be taken.

6. Crossandra (Fire cracker flower)

It is an important traditional flower crop in southern states commercially grown for loose flower purpose. The flowers are non fragrant with high keeping quality, light in weight, attractive, ideal for garlands.

Soil and Climate: - Fertile red loamy soils with pH of 6-6.7 is ideal. Soil should be well drained rich in organic matter. It can be grown both in tropical and sub tropical climate but it can't tolerate low temperature of < 13 º C. It prefers warm humid climate with average temperature of 20-32 º C.

Propagation: - It is commercially propagated by seeds (2 kg seeds/acre). Seeds will be harvested at 55-60 days after flowering, stored for 6 months treating with 2g captam/kg of seeds. The seedlings will be ready in 50-60 days after sowing for transplanting.

Varieties: - mainly 2 coloured varieties are there like orange, yellow. Important varieties include Arka ambara, Arka Kanaka, Arka chenna, Delhi crossandra, Lakshmi, Abdul kalam, etc.

Land preparation: - Plough land 2-3 times and apply FYM @ 10t/acre at final ploughing.

Planting & spacing: - Seedlings will be planted at 4-6 leaf stage at a distance of 30X50-60 cm with pit system or on raised beds.

Nutrition & Irrigation: - Recommended dose of fertilizer is 25:40:30 kg NPK/acre applied twice at 6 months interval. Immediately after fertilizer application irrigation should be given and during initial growing period irrigate twice a week later once in a week depending on soil moisture. When the plants are about to flower keep the plants wet continuously.

Weeding: - Hand weed along with earthing up is done to avoid weeds. Metachlor can be applied at 1.25 kg/ha to control weeds.

Pruning: - Pruning is done usually after flowering by pruning flowering branches to 2/3rd of their height. During late winter pruning should be done to ½ of their height.

Mulching: - Mulching increases the length of spike and flower yield conserving moisture and controlling weeds.

Pinching: - Removal of terminal growing point of stem. It is practices when the plants are young to encourage more number of auxiliary branches, which also helps to delay flower bud maturity.

Removal of dead spikes: - once seeds are formed on spike and reach adultant stage after complete flowering, these spikes should be removed regularly to keep the plants productive.

Plant protection: - Pests includes Scales, White flies, etc. Important **diseases** are Wilt, Foot & Root rot, Flower blight, Nematodes, etc.

Harvesting and Yield: - Flowers starts producing 2-3 months after transplanting and are produced almost throughout the year with lean production during rainy season. Flowers starts opening from base of the spike, 2 flowers diagonally opposite will open together. Fully opened flowers are to be picked early in the morning by pulling the corolla out of the calyx. Harvesting of flowers is to be done on alternate days. Individual plant takes 15-25 days for complete opening. On an average it yields 2-3.5 ton/acre. The plants remain economical for about 3-4 years.

7. China aster

China aster is one of the most common half hardy annual grown throughout the world for its loose flowers, along with branch as cut flower. It is having landscape value also.

Soil and Climate: - Sunny locations with well drained red loamy soils and pH of 6-7 is ideal. It prefers cool climatic conditions with day temperature of 20-30º C, night temperature of 15-17º C, relative humidity of 50-60%. Bright sunlight is required for growth & profuse flowering.

Planting Season: - Throughout the year under mild climatic conditions. For kharif crop planting to be done during June-July, for rabi during Oct-Nov.

Varieties: - Available in different colours. Important varieties of commercial importance include Kamini, Poornima, Shashank, Violet Cushion, Phule Ganesh White, Phule Ganesh Pink, Phule Ganesh Violet, Phule Ganesh Purple.

Propagation: - Commercially propagated by seeds. Seed rate is 1-1.2 kg/acre. The seedlings will be ready for transplanting in 30-45 days after sowing. Planting should be done on raised beds at spacing of 30X20 cm/30X15cm to get maximum yield and good quality cut flowers, for loose flower purpose plant at distance of 45X20cm/60X20 cm depending on type of soil.

Nutrition: - FYM @ 8t/acre to be applied during final land preparation. The recommended dose of NPK is 180:60:60 kg/ha of which 90:60:60 kg to be applied as basal dose and remaining 90kg of N to be applied as top dressing 40 days after transplanting.

Irrigation:- It's a shallow rooted crop require regular watering at an interval 4-7 days based on soil moisture condition.

Pinching and Earthing up:- Removal of terminal growing tips at 30 days after transplanting to induce more number of lateral shoots and increased yield. It's a 3 months old crop, require 2 earthing up, one during pinching and secondly one month after 1st to help in luxurious growth, vigour of plants preventing lodging of crop.

Weeding: - Hand weeding becomes laborious and uneconomical. Hence application of herbicides like Oryzalin @ 3.75 kg/ha applied 4 days before transplanting gives excellent results. Also Oxadiazon @ 2-3 kg a.i./ha as pre-emergent gives 100% weed control.

Plant Protection:- Pests:- Leaf hopper, Stem borer, Bud borer, Black blister beetle, Semilooper, Potato aphid, Spider mites, Nematodes, etc.

Diseases: - Damping off/collar rot, Wilt, Foot rot/root rot, Alternaria leaf spot, Yellow mosaic virus, etc.

Harvesting and Yield:-

For cut flower: Flowers along with stalks or whole plants are harvested
For loose flower: Individual flowers are harvested with short stems attached
Yield: 7 - 8 t/ha.

8. Dahlia

It is one of the most important bulbous flowering plant. It is having immense popularity due to wide spectrum of colour, size, shapes, forms, profuse flowering, and easy cultivation. It is grown for loose flower purpose, potted plant, and also for exhibition purpose.

Soil and Climate: - Well drained, fertile, porous soil with pH of 6.5 is found ideal. It grows best in open sunny situation but plants should be protected from strong winds. It prefers cool atmosphere free from frost.

Propagation: - Seeds, cuttings, division of tuberous roots. Commercially propagated by terminal cuttings with 7-8cm length, treat the cuttings with IBA.

Varieties: - Wide range of varieties are available differing in number of whorl, type of florets, etc. Important varieties include Basudev, Bikku, Jayanthi Jyothsna, Kenya white, Kenya blue, Kenya yellow, Lord budha, Swami madwananda, Swai Lokeshwarananda, etc.

Land preparation and Planting: - Plough the soil deep to a depth of 40 cm, add 5 kg/m^2 of FYM. Planting is done on raised beds at a spacing of 60X75 cm (Tall varieties) and 30-45cmX50-90cm (Dwarf varieties). Planting is done during September-October (plain), April in Hilly areas.

Manuring: - Recommended dose is 80:60:100kg/ha of NPK. Apply half of N, full P & K as basal dose, remaining half N as top dressing after one month.

Irrigation: - 40cm of top soil should be fully moistened however don't over water which results in soft growth & weak roots increasing more of vegetative growth than flowering.

Special Cultural Practices:-

i. Staking: - It is done immediately plants starts luxurious vegetative growth using jute string which helps plants to grow vertically without lodging.

ii. Pinching: - Removal of terminal growth at 2-3 pair of leaves/at 15 cm height which results in more auxiliary shoots and delay flowering by 15 days. Pinching at 4th node gives best result.

iii. Pruning: - It is done mainly to thinning of shoots, and will keep the bushes open. In case of large decorative type maintain 4-5 main branches, while 8-10 in small flowering type.

iv. Disbudding: - It is done to get larger blooms and for regulation of number of flowers.

Plant protection: - Pests: - Aphids, Leaf hopper, Thrips, Two spotted mites, etc

Diseases: - Powdery mildew, Stem rot, Wilt, Smut, Crown gall, Mosaic virus, Ring spot virus

Harvesting & Yield:- It takes 1&$^{1}/_{2}$ months after planting for harvesting flowers & 3&$^{1}/_{2}$ months for harvesting of tubers. Once the bud appear will take 15-20 days for maturity. Average yield of 8-10 flowers/plant (cut flower), 15-30 flowers/plant (loose flower) is obtained.

9. Gladiolus

Gladiolus popularly known as Sword lily is one of the major cut flower grown under open condition. Its elegant spikes with wide range of colours in various forms, size has won it a place of pride in ornamental garden and as cut flower. It is widely used for flower arrangement, bouquets, bunches, baskets and indoor decorations.

Soil & Climate: - Gladiolus prefers light sandy soils with pH of 6-7 and grows well under sunny situation. After planting of corms growth will be more active at the temperature between 18-25 º C, but growth retards if temperature goes <7-8º C and >30º C. It prefers high light intensity for best flowering.

Propagation: - It is commercially propagated by Corms and Cormels. Corms have dormancy which needs to be broken by storing under low temperature or treating with GA3/Thiourea before planting.

Varieties: - There are some varieties which perform well in all locations and in all the seasons of particular location. So, location specific selection is very important aspect before going for commercial cultivation. There is a wide range of colours in gladiolus varieties. Colour and length of spike play a major role in gladiolus trade. The preferred colours are white, red, orange, pink, yellow and purple. American Beauty, Friendship, Her Majesty, Jester, Nova Lux, Royal Gold, Oscar, Morning Kiss, Day Dream, Priscilla, White Prosperity, Friendship, Rose Supreme, Blue Sky, Peter Pears, Rose Delight, Christian Jane, Sancerre, Yellow Stone, Trader Horn, Apollo, and Jack's Gold are some commercially grown varieties in India.

Land preparation and Planting: - Plough the land thoroughly 15 days before planting and apply FYM 10t/acre. Gladiolus is a shallow rooted crop so plough to a depth of 30 cm. Open ridges and furrows at recommended spacing of 30-45 cm and plant the corms at spacing of 15-25 cm. Planting is also done on raised beds at spacing of 25X20 cm (20X30) between rows-corms. The depth of planting varies from 10-15 cm depending on type of soils.

Planting season: - During Aug to Jan (Plains), Mar to May (Hills)

Fertilizers: - The recommended dose of NPK is 100:60:60kg/ha. Half of N and full P & K to be applied at the time of planting and remaining half of N to be applied during top dressing.

Irrigation: - At the time of planting soil should have sufficient moisture and don't apply till the corm sprouts. Then maintain sufficient moisture in soil, with surface soil dry which helps the roots to penetrate deeply inside soil producing long spikes.

Weed management: - Herbicides like Fluchloralin @ 1kg a.i. /ha, Diuron @ 2.5 kg a.i. /ha, Trifluralin @ 2kg a.i. /ha applied 2 weeks before planting gives maximum results.

Plant protection: - Pests:- Aphids, Thrips, Cut worms, Leaf eating caterpillar, Mealy bugs, Borers, etc

Diseases: - Wilt, Corm rot, Curvularia blight, etc.

Harvesting and Yield: - It takes 2-3 months after planting for flowering. Harvest when 1st 2 bottom florets are fully opened and remaining florets just showing colour. It yields about 1 lakh flower spikes/acre, 1-1.2 lakh plantable corms/acre small cormels of 0.15-1.5 lakh corms

10. Carnation

It is an important cut flower crop grown throughout world. It is a prime cut flower because of its attractive colour, form and shape with long vase. It is also used for extraction of essential oil. Standard types have greater demand for cut flower.

Soil and Climate: - The soil should be well drained, rich sandy loam/sandy soils for successful cultivation. The ideal soil pH is 6-7. It prefers sufficient sunshine with high light intensity especially during winter and

mild climate during summer. The optimum temperature is 15-25º C, ideal RH is 50-60%. The site should be protected from strong winds.

Varieties: - Two types have got commercial importance like Standards (single flower with long stalk) and Sprays (Bunch with small flowers). White and pink coloured are more preferred followed by red, yellow, and bicoloured varieties.

Propagation: - Annual types by Seeds and commercial perpetual types are propagated by terminal stem cuttings (10-15cm length with 4 pair of leaves for standards, 8-10 cm with 4-5 pair of leaves for sprays type).

Land preparation and Planting: - Carnations are grown commercially under greenhouse with sufficient light and proper ventilation. Planting will be done on raised beds with spacing of 15X15 cm (standards), 20X20 cm (sprays). Planting should be done shallow as too deeper planting will cause wilt, stem & root rot.

Irrigation: - 7-8lit/m^2/day through drip.

Fertilizers: - FYM @ 5-10kg/m^2 and NPK of 30:20:10g/ m^2 for Standards, NPK of 40:20:10g/ m^2. Nitrogen should be applied in 2 split doses first during planting and secondly one month after planting.
Fertigation schedule: - 250:80:200:125:400 g of N: P: K: Ca: Mg/ m^2/year

Stage	Fertilizers (g/m^2/week)				
	N	P	K	Ca	Mg
Planting to end of pinching	4.64	1.62	3.62	2.55	0.55
End of pinching to till harvesting	4.69	1.50	5.58	2.72	0.51
During harvesting	4.88	1.50	7.03	3.09	0.50

Pinching: - Pinching is done 4-5 weeks after planting leaving 6 pair of leaves. This pinching will delay flowering by 2-3 weeks. It is done for regulation of flowering and to get quality flowers. Second pinching is done by removing 2-3 laterals out of 4-6 produced after first pinching retaining 4 pair of leaves. Next pinching is done to further delay flowering by removing all the laterals produced retaining 4 pair of leaves.

Disbudding: - Removal of lateral buds and terminal buds in standards and spray type respectively to improve flower size and best quality.

Staking: - Most important special cultural practice of providing support to the plants using galvanized metal wire/nylon rope at least for 4-5 layers for each bed. The net square should be 7.5X7.5cm in the 1st layer with remaining layers of 15X15cm net squares.

Plant protection: - Pests:- Red spider mites, Thrips, Aphids, etc

Diseases: - Fusarium wilt, Stem rot, Leaf spot, Flower blight, Viral diseases, etc

Physiological disorder: - Calyx splitting

Harvesting and Yield:- Harvesting should be done at "Paint brush stage" when petals starts elongating outside the calyx in case of standards and when 2 flowers are opened with remaining flowers showing colour in spray type. Carnation yields about 200-250 flowers/m^2.

11. Orchids

Orchids are considered to be the world's most beautiful of god's creation and the flowers are highly valued for their exquisite flowers with long keeping quality. Orchids are known to grow on trees (Epiphytes), on ground (Terestrial), on rocks (Lithophytes), on decaying matter (Saprophytes). Orchids exhibits 2 types of growing habits based on their vegetative growth style as Monopodials (have single non branching stem which grow upward from one season to other eg:- Vanda, Arachais) and Sympodials (have rhizome which grow horizontally producing new growth, they contain a clump of shoots of different size eg:-Dendrobium, Cattleya, Oncidium, Cymbidium. A single plant produces a series of annual axis in course of time). Commercially grown sympodial orchid varieties are Sonia 17, Singapore white.

Soil and Climate: - The important environmental factors like temperature, light, humidity, aeration, Co_2 concentration, etc play an important role in regulating growth and flowering of orchids. Orchids can be grown

from sea level upto 2000mt. The optimum temperature for most of the orchids lies between 15º C and 26º C, flowering can be regulated by temperature manipulations. The blooming potential is also determined by quality and quantity of light it receives (15000-24000 lux). Orchids prefer high RH of 70%.

Propagation: - For commercial cultivation tissue culture plants are used. Other methods include division of off shoots or Kiekies, back bulbs, cuttings.

Planting media: - Majority of temperate orchids are terrestrials and tropical orchids are epiphytes. The media for orchids should have good drainage as well as good aeration. Water stagnation should be avoided. Different media for epiphytic orchids are osmunda fibre, red wood fibre, perlite, coarse peat moss, gravel, tile pieces, brick pieces, charcoal, coconut husk etc. The media should be a good support for the orchid plants rather than supplying nutrients.

Planting and after care: - If orchids are grown in containers, support should be given using bamboo sticks or any such pegs. Deep planting should be avoided. Some of the orchids like phalaenopsis are highly susceptible to water stagnation and hence they should be hung in a slanting manner so that the water drains off from the leaf axils. Replanting or Repotting is necessary. When the plant becomes crowded and when the media has broken down. During severe summer slight shading is required due to high temperature and light intensity which leads to yellowing and scorching of leaves ultimately affecting flower production.

Nutrient management: - Afertilizer mixture containing major nutrients and minor nutrients is ideal for Foliar application as most of the cultivated varieties are epiphytes and the media used is highly porous. A fertilizer dose containing 1:1:1 proportion of NPK is beneficial during early growth, 3:1:1 mixture may be used for mature plants as pre flowering and 1:2:2 during flowering stage at fortnightly intervals.

Watering: - The quantity of water required by the plants depends on climate, substrate and the age of crop. The irrigation system must be capable of supplying between 5 to 12 liters of water per meter per hour. It is very important to ensure that plants are provided with appropriate drainage.

Plant protection: - Pests:- Slugs & Snails, Mites, Aphids/scales, Caterpillars, Sciaridae (Fungal gnats), etc

Diseases: - Black rot, Soft rot, Anthracnose, etc.

Harvesting and Yield: - The plants start yielding one year after planting and live economically for >6 years. The average yield is about 6 flower spikes/plant/year. The stage of harvest influences the keeping quality. It is better to harvest when 75 per cent of the flowers are opened, retaining 2-3 unopened buds.



Fig: Propagation for Orchid

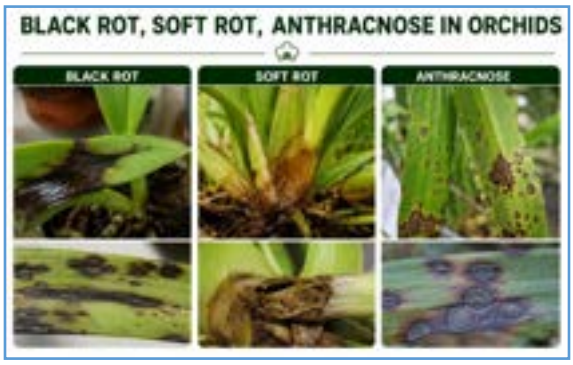


Fig: Diseases

3.10. Plantation Crops

1. Coconut

Climate Requirements

Coconut thrives in humid tropics between 20° N and 20° S latitudes, up to 600 m MSL (1000 m near equator). Optimal growth occurs at 27 ± 5°C with minimal diurnal variation (<7°C). Flowering requires >10°C, whereas <10°C for one month causes nut fall, and >40°C reduces leaf area, dry matter, and yield. Annual rainfall of 1000–2500 mm, 120 hours of monthly sunshine, and 80–90% relative humidity are ideal. RH below 60% restricts transpiration, while near-saturation humidity predisposes palms to diseases.

Soil Requirements

Coconut adapts to diverse soils including sandy, laterite, alluvial, swampy, and saline types. Ideal soils are 1–1.5 m deep, well-drained, fertile, with good organic matter and water holding capacity, and pH 5.0–8.5. Naturally, coconut thrives in sandy coastal belts but has expanded to inland and hilly regions.

Nursery Management

Quality planting material is essential as performance is realized years after planting. Mother palms selected for seed nuts should yield >80 nuts annually under rainfed and >120 nuts under irrigated conditions with copra ≥150 g/nut. Palms with umbrella-shaped crowns, 30+ leaves, strong petioles, and stout bunch stalks are ideal.

Seed Nut Collection: In southwest monsoon areas, December–April; in northeast monsoon areas, July–September. Only 12-month-old, fully mature, undamaged nuts are used.

Sowing: Tall varieties are sown 2–3 months after harvest, dwarfs within 15–30 days. Beds of 40 × 30 cm spacing with 20–25 cm deep trenches are recommended. Leaf mulch promotes germination.

Polybags nursery: Sprouts (8–10 cm) are transplanted in 45 × 60 cm bags with potting mixture (soil: sand: manure 3:1:1 or soil: sand : vermicompost 3:1). Biofertilizers (PGPR, VAM, P-solubilizers) @25 g improve seedling vigor.

Planting and Spacing

In general, one-year-old seedlings are preferred for planting. However, in water-logged areas, 1½ to 2 years old seedlings are found to be suitable. Common planting systems are, Square system: 7.5 × 7.5 m spacing (175 palms/ha) to 8.0 m x 8.0 m (156 palms ha^{-1}); Rectangular system (hedge): 9 × 6.5 m to increase light for intercrops; and Triangular system: More palms per unit area but hampers operations.

Planting pits size vary with soil: 1 × 1 × 1 m in normal soils, 1.5 × 1.5 × 1.2 m in laterite soils, and 0.75 × 0.75 × 0.75 m in coastal sandy soils. These pits will be filled to a height of 60 cm below ground level with a mixture of top soil and FYM or any compost, and at least two layers of coconut husk (with the concave surface facing up) can be arranged at the bottom of the pit before filling up the pit. This will ensure moisture conservation. In waterlogged areas, mounds are used. Salt (2 kg/pit) or husk (25–30/pit) improves laterite soil productivity and moisture retention.

In well-drained soils, seedlings can be transplanted with the onset of south-west monsoon during June or with the onset of north-east monsoon during October-November. In low-lying areas subject to inundation during monsoon periods, it is preferable to plant the seedlings after the cessation of the monsoon.



Fig: Coconut seedling planting

Management of Juvenile Palms

Young palms require shading, irrigation (45 L once in 4 days or 10 L/day via drip), and drainage. Weed removal, collar cleaning, and gradual pit filling are necessary. Basins should expand yearly up to 1.8 m radius by the fourth year. Regular pest and disease monitoring is essential.

Irrigation Management

Irrigation systems followed in general include:

- Flooding: Traditional, water-intensive, inefficient, not recommended.
- Basin irrigation: 200 L/palm every 4 days. Moderate losses via seepage and evaporation.
- Sprinkler/Perforated irrigation: Suitable for intercropping, but costly.
- Drip irrigation: Most efficient, saving 40–60% water. CPCRI studies recommend 32 L/palm/day (66% of pan evaporation). Emitters: 6 (sandy soils), 4 (other soils), discharging 2–3 L/h. Coir pith mulch enhances efficiency.

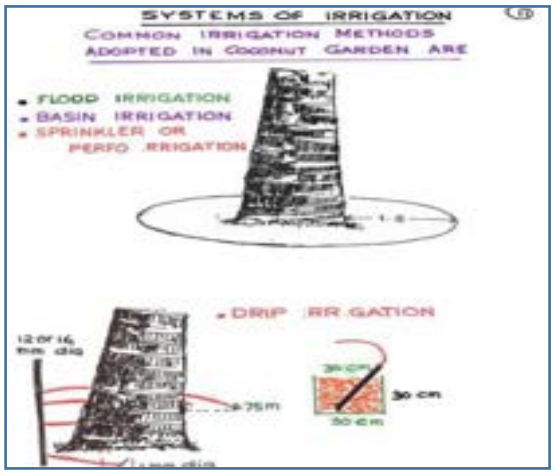


Fig: Drip irrigation in coconut

Fertigation

Application of soluble fertilizers via drip irrigation improves nutrient use efficiency and reduces groundwater pollution. Urea, DAP, phosphoric acid, and MOP are applied in 6 splits. Fertigation with 50% RDF equals 100% RDF by soil application

Nutrient Management

Regular manuring from the first year is crucial for healthy growth, early flowering, and high yield. Soil testing every three years guides fertilizer type and dose. Apply the first dose three months after planting, following ICAR-CPCRI recommendations (Table 1), with one-tenth of the adult palm dose during the first year. In the second year, apply one-third of the adult fertilizer dose, doubling it in the third year; from the fourth year, use the full recommended dose. Fertilizers are applied in two splits: one-third after summer showers around palms within a 1.8 m radius, and two-thirds in August–September with 50 kg green leaf/compost in circular basins (1.8 m radius, 25 cm depth), then covered with soil. For boron deficiency, apply 120 g Borax palm^{-1} in four splits. In acidic or sandy soils, apply 1 kg dolomite/limestone and 0.5 kg magnesium sulphate annually before monsoon rains, incorporating into the basin.

Table 1: General fertilizer recommendation for coconut (g palm^{-1})

Age of coconut palm	May-June			September- October		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
First year	Planting in May-June			50	40	135
Second year	50	40	135	110	80	270
Third year	110	80	270	220	160	540
Fourth year onwards	170	120	400	330	200	800

Chemical Fertilizers

Soil testing (every 2 - 3 years) is recommended. Adult palms require 500 g N, 320 g P_2O_5, and 1200 g K_2O/palm/year in two splits. Green leaf or compost @30 kg/palm enhances fertilizer efficiency. Boron deficiency is common; apply 100 g Borax bimonthly until symptoms disappear. Under irrigation, 4 split doses/year are ideal.

Organic Nutrient Management

The combined use of organic and inorganic fertilizers enhances soil health and palm resilience. Organic practices include manures (green leaf, cattle, goat, poultry), cover crops (*Pueraria, Mimosa, Calopogonium, Vigna*), biofertilizers ('Kera Probio', 'KerAM' @100 g palm^{-1} year^{-1}), Glyricidia alley cropping, and recycling through vermicompost or coir pith compost. Apply 10 kg organic manure per palm six months after planting, increasing annually by 10 kg up to four years, and 50 kg from the fifth year onwards. Organic additions improve soil organic carbon, nutrient availability, uptake efficiency, and overall palm growth while strengthening tolerance to climatic stress.

Weed Management

Diffused sunlight in coconut gardens encourages vigorous weed growth, particularly in monocrop systems, where weeds compete with palms for moisture, nutrients, and light, reducing growth and yield—especially during seedling stage or prolonged dry periods. Mulching with coir pith or coconut leaves in nurseries enhances seedling survival and uniform germination. Weed management options include manual weeding, though laborious, or mechanical cutters, effective but costly and time-consuming in hilly regions. Ploughing twice annually (May–June, September–October) is effective, while chemical weed control is cheaper, less labor-intensive, and useful in high rainfall or sloping areas, where dead weeds act as mulch, conserving moisture and preventing erosion. Cover cropping with Pueraria phaseoloides, Calopogonium mucunoides, or Centrosema pubescens, along with mulching (coconut leaves, husk, coir pith, or plastic), also provides effective weed suppression and soil protection

Coconut-Based Cropping/farming Systems

Studies show that sole coconut palms (7.5 × 7.5 m) utilize only 22.3% of land, 30% air space, and 45–50% solar radiation, highlighting scope for crop diversification. To optimize resources and reduce risks from fluctuating prices, CPCRI developed coconut-based inter/mixed, multi-storied, multi-species systems

integrating crops, livestock, and allied enterprises. Coconut-based mixed farming with fodder grasses (e.g., hybrid Napier, guinea grass) and leguminous crops can support 4–10 dairy animals, with poultry, fishery, and apiculture further enhancing income and soil fertility. Such systems generate FYM, urine, and organic matter, meeting over 75% of nutrient needs. High-Density Multispecies Cropping System (HDMSCS), integrating coconut with banana, pineapple, pepper, clove, and nutmeg, ensures sustainability, maintains coconut yield, and provides higher annual net income while recycling ~25 tonnes of organic biomass for nutrient recycling and reduced fertilizer use.

Soil and Moisture Conservation

Soil moisture in coconut plantations can be conserved through mulching with organic materials like coconut leaves (2–3 layers), husks (250–300 husks basin^{-1}), or coir pith (10 cm thickness, ~50 kg palm^{-1}). Mulching reduces soil temperature, limits evaporation, and improves root growth and soil microbial activity. The ideal time is just before the end of the monsoon, before topsoil dries. Coconut husks may also be buried in layers within trenches (50 × 50 cm) to enhance moisture retention. On mild slopes (15–20%), half-moon bunds reinforced with two pineapple rows prevent runoff, promote infiltration, and provide additional income. On steeper slopes, trenches filled with husks or catch pits (1.5 × 0.5 × 0.5 m) with downstream bunds are recommended. Pineapple helps stabilize bunds and protect soil.

Harvesting

Coconuts mature in 11–12 months. Harvesting frequency varies (6–10 times/year), often monthly in high-yield gardens. Shortage of skilled climbers is a constraint; climbing devices are now popular.

Conclusion

Adopting scientific cultivation practices—drip irrigation, fertigation, soil test-based nutrient management, green manuring, organic recycling, and soil-water conservation—significantly enhances productivity at reduced cost. Coconut-based integrated and high-density multi-species farming systems developed by CPCRI have proven effective in improving income, employment, and sustainability for smallholders.

2. Arecanut

Seedling selection

Arecanut, being perennial and cross-pollinated, requires careful selection of seedlings. Use 12–18-month-old seedlings with at least five leaves and adequate height for transplanting.

Planting and Spacing

The recommended optimum spacing is 2.7 × 2.7 m. For inter/mixed high-value crops, 3.3 × 3.3 m is preferable. Rows should be aligned north–south, with a 35° westward deflection to reduce sun scorch.

Arecanut planting season depends on rainfall intensity and water table conditions. In flood-prone riverbanks or areas with a high water table, September is suitable time for planting and other places May–June is suitable.

Pit size for arecanut plant varies by soil type: 90 x 90x 90 cm in laterite, 75 x 75 x 75 cm in red soils, and 60 x 60x 60 cm in high water table soil. Pits should be half-filled with topsoil and farmyard manure. Seedlings, with intact soil balls, must be placed in centre of the pit and covered up to the collar to prevent aerial root growth.



Fig.Arecanut planting

After care

After planting care is crucial as arecanut stems may break under southwest sun exposure, causing palm death due to lack of secondary growth. Provide shade using banana, red gram, or ivy gourd on borders. Alternatively, cover stems with arecanut/coconut leaves or green shade nets from December to May.

Irrigation management

Arecanut is highly sensitive to drought, and recovery from water stress may take 2–3 years, reducing yield and vigour. In Kerala and Karnataka's humid tropics, irrigation is recommended every 7–8 days (Nov–Dec), every 6 days (Jan–Feb), and every 4–5 days (Mar–May) using basin irrigation @175–200 L palm^{-1}. Drip irrigation offers higher efficiency (90–95%) than conventional (50–60%) or sprinkler systems (70%). Under drip irrigation, 16–30 L palm^{-1} day^{-1} is sufficient depending on evaporation, with 2–3 drippers or microtubes placed opposite or triangularly in the basin.

For proper drainage, provide channels—one per two rows in light soils and one per row in heavy soils, 15–30 cm deeper than planting depth. Clean drains before monsoon and link pits with outlets for smooth water flow.

Integrated Nutrient Management

Application of either organic manures or chemical fertilizers may cause nutrient imbalance in arecanut; hence, integrated nutrient management based on soil and plant analysis is essential. In laterite soils, 100 g N, 40 g P_2O_5, and 140 g K_2O per palm annually, along with 12 kg each of compost and green leaf, are recommended. In heavy soils, 50 g N, 40 g P_2O_5, and 140 g K_2O with green manures are advised. Applications should be made when soil moisture is adequate, avoiding heavy rain or dry spells. For acidic soils (pH <5), dolomite lime may be applied in August–September. Fertilizers are best applied in two splits: half the dose with organics during September–October and the rest in February–March. Organic manures alone cannot meet potassium needs; husks of arecanut, coconut, or cocoa are exceptions. High-yielding palms (>3 kg kernel palm^{-1} year^{-1}) require double doses of N and K for sustained productivity.

Table 2: General guidelines for nutrient recommendation for arecanut (g palm^{-1} year^{-1})

Fertilizer	First year	Second year	Third year onwards
Nutrient			
Nitrogen (N)	33	66	100
Phosphorous (P_2O_5)	13	26	40
Potassium (K_2O)	46	92	140
Fertilizers (Source of Phosphorus is rock phosphate or single super phosphate)			
Urea	72	144	220
Rock phosphate (RP)	65	130	200
Single super phosphate (SSP)	83	167	250
Muriate of Potash (MOP)	77	154	230
Fertilizers (Source of phosphorus is Diammonium Phosphate (DAP))			

Urea	61	121	182
DAP	29	58	87
Muriate of potash	77	154	230

Fertigation

Fertigation in arecanut can save 25–50% fertilizer while ensuring efficient nutrient use. Common fertilizers like urea, DAP, and MOP are 90–100% water-soluble and cost-effective, while liquid fertilizers, though expensive, are suitable for fertigation. Applications should be made from December to May, aligning with flowering and fruit development. Fertilizer doses can be split into 9 or 18 parts, applied every 20 or 10 days. For pre-bearing palms, 50% of the recommended dose via drip is sufficient, while bearing palms require 75%. The fertigation schedule supplies 75:30:105 g N, P_2O_5, and K_2O per palm annually, using 136 g urea, 65 g DAP, and 175 g MOP.

Intercultural operations

Weeding should be done as needed, and collected weeds can be recycled in areca basins. Glyphosate may control weeds in interspaces but not in crop basins. Terracing and contour bunding prevent soil erosion on slopes. In Malnad, intercultural operations loosen soil and restore fertility after monsoon rains, while in Maidan, they conserve moisture and reduce compaction. Cover crops like Mimosa invisa (15 kg/ha), Stylosanthes gracilis (9 kg/ha), Calapogonium mucunoides (11 kg/ha), and Pueraria javanica (11 kg/ha) can be sown in May–June and incorporated in October.

Arecanut based cropping/farming system

The long pre-bearing period, low returns during the initial bearing stage, fluctuations in market prices, unexpected loss due to pests and diseases and natural calamities are the main reasons which make inter-cropping or mixed farming in arecanut plantation essential. Crops like banana, pepper, cocoa, elephant foot yam, citrus, betelvine, pineapple, etc., are suitable for mixed cropping. Other enterprises like dairy is also advisable for achieving higher net income per unit area and unit time.

Table 3: Region-specific cropping models

Region	Cropping Model
Maidan parts of Karnataka	Arecanut+blackpepper+cocoa Arecanut+banana+acid lime
Coastal Karnataka and Kerala	Arecanut+blackpepper+cocoa+banana
North Bengal	Arecanut+blackpepper+banana Arecanut+blackpepper+acid lime
Wynad of Kerala	Arecanut+cardamom
Hilly zone/ M*alnad* region of Karnataka	Arecanut+cardamom Arecanut+blackpepper+cocoa Arecanut+blackpepper+coffee

3. Cocoa

Site selection

Cocoa cultivation requires a soil with 1.5 m soil depth. It is grown mostly in laterite soils, however black and alluvial soils are also suitable.

Cocoa is a shade loving crops hence is desirable to grow cocoa as intercrop in arecant, coconut, oil palm garden as intercrops as they let in more light through their canopy. It can also be grown under temporary shade trees (Tapioca, *Gliricidia*, *Xanthosoma* spp., *Colocasia* spp., Tree cassava or Ceara rubber, pigeon pea, Papaya, Castor etc.) which they are later removed once the cocoa canopy develops.

Planting

Vigorous and healthy seedlings produced from polyclonal seed gardens should be selected for planting.

Spacing: In Arecanut: 2.7 m × 5.4 m

In Coconut: Single row 2.7–3 m, Double row 2.5–2.7 m

In Oil Palm: 2.4 m, 2 m from palm base

For planting, 50 cm x 50 cm x 50 cm pit should be dug aligned north-south with a 35 degree deflection to avoid such scorching and these pits should be filled with top soil+ organic manure and plant the seedling at the center.

If irrigation is available planting can be done any time during the year. However, in low rainfall area planting should be taken up at the onset of monsoon while in high rain fall areas during end of the monsoon planting should be taken up.

Irrigation management:

For healthy growth and development Cocoa required a constant moisture supply. With flood/furrow irrigation system, once in every five days with 175 L per tree or with drip system, 20 L/day need to be applied. In summer, irrigation at weekly interval is recommended to support flowering, fruit set, and pod development.

Nutrient management

Fertilizer should be applied (Table 3) in two splits: April–May and September–October. In the first year, mix fertilizer evenly within 30 cm radius and gradually increase to to 150 cm after the third year to ensure proper soil incorporation and better nutrient absorption.

Table 4: Recommended fertilizer for cocoa

Fertilizer	I year	II year	III year onwards
Nitrogen	33	66	100
Phosphorous	13	26	40
Potash	46	92	140
Urea	72	144	220
Rock phosphate	65	130	200
Muriate of Potash	77	154	230

Fertigation:

Fertigation is advised from December to May at 10–20 day intervals and with this 25 % of the fertilizer can be saved.

Table 5: Application of fertilizers through drip-fertigation

Crop phase	Period	10 days interval				20 days interval			
		No. of doses	Fertilizer per dose			No. of doses	Fertilizer per dose		
			Urea (g)	DAP (g)	MOP (g)		Urea (g)	DAP (g)	MOP (g)
Flowering and fruit set	December-January	6	7.5	3.6	9.7	3	15	7.2	19.4
Cherelle development	February-March	6	7.5	3.6	9.7	3	15	7.2	19.4
Fruit development	April-May	6	7.5	3.6	9.7	3	15	7.2	19.4

Pruining in cocoa

Pruning is essential in cocoa to maintain tree shape, improve flowering, and direct nutrients to pod development, especially when grown as an intercrop. In Karnataka and Kerala, it is usually practiced during August–September.

Formation pruning is recommended to young plants, keeping the first jorquette at about 1.5 m height, from this point four well-spaced fan branches in all directions are ideal for easy movement in the garden, and to carry out other farm operations like harvesting, spraying etc. Regular removal of chupons, trimming, and cutting low branches is necessary.

For middle-aged trees (12–15 years), the ideal canopy spread is 3.8–4.0 m with a height of 2.7 m, retaining 20–30 leaves per pod. Funnel-shaped pruning improves sunlight and ventilation, while top pruning to 4 m eases harvest and removal of diseased pods.

In clonal plants, early pruning ensures a strong framework by retaining a single main stem and removing drooping or inward branches. After three years, secondary pruning develops an umbrella canopy. All pruning should be done carefully to avoid bark damage. Cut surfaces must be swabbed with Bordeaux paste to prevent fungal infection in humid conditions.

4. Oilpalm

Planting material: The seedlings ideal for transplanting are 12 months old healthy seedlings, having 1 to 1.2 meters height, and 12 functional leaves with 20 to 25 cm girth at collar.

Method of planting: Oil palm can be planted in any season, though June–December is ideal. For summer planting, adequate irrigation, mulching, and sowing cover crops like sun hemp help reduce heat stress. The equilateral triangular method at 9 m spacing accommodates about 57 palms per acre (143 per hectare). Pits of 2 × 2 × 2 ft are prepared and enriched with 400 g single super phosphate (or 250 g DAP), 50 g pesticide granules, and a basket of farmyard manure mixed with soil. Seedlings are planted after removing the polybag, ensuring the bole is 25 cm below ground level. The pit is filled firmly with soil, a basin is formed around the plant, and copious irrigation is provided immediately after planting.

Basin management: After planting, form basins around the palm—1 m radius in the first year, 2 m in the second, and 3 m from the third year onward. The basin area, being the active root zone, should be kept weed-free to prevent competition for nutrients and moisture.

Weed management: Palm basins should be kept weed-free to ensure efficient use of nutrients and water. Weeding frequency depends on weed growth, and paraquat (2.5 ml/L water) is commonly used, applied

during the vegetative stage for effective control.

Cover cropping: Cover cropping in oil palm gardens, especially in high rainfall areas, involves growing leguminous creepers. In India, species like *Pueraria phaseoloides*, *Calopogonium mucunoides*, *Centrosema pubescens*, *Mimosa invisa*, and *Mucuna bracteata* are used.

Mulching: Mulching of oil palm basins is essential to conserve moisture as well as to control weeds. Mulching can be done with dried leaves, male flowers, coconut husk, empty bunches etc.

Flowering and Ablation: Oil palm starts flowering 14–18 months after planting, producing separate male and female inflorescences. During the juvenile stage, these should be removed (ablation) using an ablation tool to promote stem girth, vigour, and root development.

Irrigation Management: Adequate irrigation is essential for oil palm, as shortage reduces sex ratio, causes inflorescence abortion, and lowers yield. For palms over 3 years old, provide 100–150 L/day during non-rainy days in the rainy season, 160–170 L/day in winter, 215–265 L/day in summer, and 300–350 L/day in older plantations during peak summer.

Fertilizer management: In oil palm, fertilizers are applied in four split doses annually. The dose per palm is: first year – 870 g urea, 1250 g SSP, 670 g MOP, 125 g $MgSO_4$, 25 g borax; second year – 1740 g urea, 2500 g SSP, 1333 g MOP, 250 g $MgSO_4$, 50 g borax; third year onwards – 2610 g urea, 3750 g SSP, 2000 g MOP, 500 g $MgSO_4$, 100 g borax. Along with the second dose, apply 50–100 kg FYM or 100 kg green manure, plus 5 kg neem cake per palm. Fertilizers should be broadcast 2 ft away from the base in a clean basin, followed by irrigation.

Fertigation: For higher FFB yield, fertigation with NPK @ 600:300:600 g per palm per year at monthly intervals, along with irrigation based on PET, is recommended. This equals 1050 g urea, 652 g DAP, and 1000 g MOP per palm per year (or 60 kg urea, 37 kg DAP, and 57 kg MOP per acre), applied in equal monthly splits.

Inter-cropping: Oil palm, with a three-year juvenile period, supports intercropping with compatible crops such as vegetables, banana, ginger, turmeric, pineapple, chillies, spices, and flowers. In mature plantations, cocoa, long pepper, bush pepper, cut foliage, and ornamentals like red ginger and heliconia can also be grown. Intercrops should not be planted in the palm basin, leaves should not be cut or tied, and ploughing near the base must be avoided to protect roots. For good growth and yield, retain at least 33 green leaves and avoid severe pruning.

Pollination: Oil palm is a highly cross-pollinated crop, mainly assisted by insects, as wind pollination alone is insufficient. The weevil *Elaeidobius kamerunicus* ensures effective pollination and fruit set, and should be released 2.5 years after planting, or after 3 years if palms lack adequate girth and vigour.

Harvesting: Oil palm bunches are ready for harvest when fruits turn yellow-orange, 5–10 fruits drop naturally, and pressing exudes orange oil. Harvest with a chisel in young palms and a sickle on an aluminum pole in older palms, leaving a 5 cm stalk. Fresh fruit bunches should be transported promptly to the collection center without damage.

Module IV: WEED MANAGEMENT

4.1. Importance of Weed Management in Crops and types of Weeds

Weeds are plants that grow where they are not wanted. In other words, any plant that grows in a place where we want to grow another crop or where we want no plant is considered a weed. Weeds are among the most significant and detrimental problems in crop production. They compete with crops for sunlight, water, nutrients, and space, thereby reducing crop growth, yield, and quality. Most crops suffer greater losses from weeds than from insects and diseases, especially when weeds are not removed at the proper time. Weeds cause substantial economic losses in agriculture. On average, they reduce crop yield by 25 to 40 per cent (Fahad et al., 2013).

Crop losses due to weeds can be as low as 18 per cent when weed growth is limited, but in severe cases they can reach 80 per cent. Among all the problems faced by crops, weeds are the most important cause of yield loss. Overall, weeds cause yield losses ranging from 20% to 76% in various crops (Gharde, 2018; Asghar et al., 2024). In India alone, weeds cause an estimated loss of about 10 billion US dollars every year in ten major crops. The percentage of crop yield lost due to weeds in different crops is groundnut, pearl millet, soybean, maize, sorghum, green gram, sesame, mustard, wheat and rice with 35.8%, 27.6%, 31.4%, 25.3%, 25.1%, 30.8%, 23.7%, 21.4%, 18.6% and 13.8% (transplanted rice) and 21.4% (direct seeded rice), respectively (Kaur et al., 2020). Very high yield loss has also been reported in vegetable peas, where weeds cause about 46.82% loss in yield (Gharde et al., 2018).

In animal husbandry, many weeds are unpalatable or harmful, causing injuries, poisoning, or lower-quality fodder. For humans, some weeds cause allergies, skin irritation, or act as poisonous contaminants in food grains. In aquatic ecosystems, invasive weeds like Eichhornia and Hydrilla block water bodies, lower oxygen levels, and disrupt fisheries. Weeds also act as alternate hosts for insect pests, nematodes, and plant diseases, sustaining disease cycles. Weeds can be grouped into three main types: annuals, which complete their life cycle in one season; biennials, which take two seasons; and perennials, which persist for many years through vegetative structures. There are also more specific types, including terrestrial, aquatic, parasitic, and crop-associated weeds. Therefore, proper weed management is crucial in modern farming to obtain good yields and better income for farmers.

Weeds interfere with farm operations, such as irrigation, harvesting, and fertiliser application. Rapidly growing weeds, such as Parthenium hysterophorus, Cyperus rotundus, and Phalaris minor, have become serious problems in Indian agriculture owing to their rapid growth, easy adaptation, and strong competition with crops. Proper management of weeds involves the adoption of diversified cultural, mechanical, chemical, and biological methods to reduce weeds without causing environmental hazards. Integrated Weed Management advocates timely control of weeds, rotation of herbicides season to season, selection of varieties that can compete well with weeds, and the adoption of conservation farming.

1. Classification of Weeds

Out of about 2, 50,000 plant species in the world, approximately 250 are major weeds found in farming and non-farming areas. Approximately 30,000 plant species are considered weeds worldwide

i. Based on Life Span
ii. Based on Ecological Affinities
iii. Based on Soil Type (Edaphic
iv. Based on Place of Occurrence
v. Based on Origin
vi. Based on Cotyledon Number
vii. Based on Soil pH
viii. Based on Morphology
ix. Based on Nature of Stem
x. Based on Specifici

Category	Sub-category	Examples
I. Based on Life Span	**a. Annual Weeds**	
	Monsoon annual	*Commelina benghalensis*
	Winter annual	*Chenopodium album*
	b. Biennials	*Alternanthera echinata, Daucus carota*
	c. Perennials	
	Simple perennials	*Sonchus arvensis*
	Bulbous perennials	*Allium* spp.
	Corm perennials	*Phleum pratense* (Timothy)
	Creeping perennials	
	Rhizome	*Sorghum halepense*
	Stolon	*Cynodon dactylon*
	Roots	*Convolvulus arvensis*
	Tubers	*Cyperus rotundus*
II. Based on Ecological Affinities	a. Wetland weeds	*Ammania baccifera*
	b. Garden land weeds	*Trianthema portulacastrum,*
	c. Dryland weeds	*Tribulus terrestris*
III. Based on Soil Type (Edaphic)	a. Black cotton soils	*Aristolochia bracteata*
	b. Red soils	*Commelina benghalensis*
	c. Sandy/loamy soils	*Leucas aspera*
	d. Laterite soils	*Lantana camara*
IV. Based on Place of Occurrence	a. Croplands	*Phalaris minor* (in wheat)
	b. Pasture lands	*Indigofera enneaphylla*
	c. Waste places	*Gynandropsis pentaphylla, Calotropis gigantea*
	d. Playgrounds/Roadsides	*Alternanthera echinata, Tribulus terrestris*
V. Based on Origin	a. Indigenous	*Acalypha indica*
	b. Introduced/Exotic	*Parthenium hysterophorus, Phalaris minor*
VI. Based on Cotyledon Number	a. Monocots	*Panicum flavidum, Echinochloa colona*
	b. Dicots	*Crotalaria verucosa, Indigofera viscosa*
VII. Based on Soil pH	a. Acidophile	*Rumex acetosella*
	b. Basophile	*Taraxacum* sp.
	c. Neutrophile	*Acalypha indica*
VIII. Based on Morphology	a. Grasses	*Echinochloa colonum, Cynodon dactylon*
	b. Sedges	*Cyperus rotundus*
	c. Broad-leaved weeds	*Flaveria australica*
IX. Based on Nature of Stem	a. Woody weeds	*Lantana camara, Prosopis juliflora*
	b. Semi-woody	*Croton sparsiflorus*
	c. Herbaceous	*Amaranthus viridis*
X. Based on Specificity	a. Poisonous weeds	*Datura fastuosa*
	b. Parasitic weeds	
	Total root parasite	*Orobanche cernua*
	Partial root parasite	*Striga lutea*
	Total stem parasite	*Cuscuta chinensis*
	Partial stem parasite	*Loranthus longiflorus*
	c. Aquatic weeds	
	Submerged weeds	*Utricularia stellaris, Ceratophyllum demersum*
	Emerged weeds	*Nelumbo nucifera, Jussiaea repens*
	Marginal weeds	*Typha, Polygonum, Cephalanthus, Scirpus*
	Floating weeds	*Eichhornia crassipes, Pistia stratiotes, Salvinia*

2. Integrated Weed Management

Integrated Weed Management refers to the planned and coordinated use of multiple weed control methods to manage weeds effectively in the field. It involves the combined application of cultural, mechanical, biological, and chemical approaches. According to Pooniya *et al.* (2012), the primary objective of IWM is to maintain weed populations at levels that do not cause economic damage to crops. Malviya and Singh (2007) further reported that this integrated approach aims to prevent weed reproduction and emergence, promote depletion of the weed seed bank, and minimize crop–weed competition, thereby serving as a key component of sustainable agriculture. **Under such circumstances, effective control of a complex weed flora is best achieved through a logical and integrated combination of several weed management methods (Kumar et al., 2012).** These alternative strategies, which suppress weed growth and reproduction below the economic threshold level, are collectively referred to as ecological approaches to weed management.

i. Cultural Control

Cultural methods help crops compete better with weeds by reducing the chances of weed growth (Singh, 2014). These methods also encourage faster crop growth, allowing crops to cover the field and suppress or smother weeds (Das et al., 2012). It is one of the most widely used methods of weed management. It includes practices such as crop rotation, proper time of sowing or planting, use of cover crops, intercropping, suitable cropping patterns, and appropriate tillage practices. Weed control is further improved by using the correct method and rate of sowing, applying fertilizers in a balanced manner, adopting intercropping and mixed cropping, using weed tolerant crop varieties, and maintaining proper plant spacing (Verma and Singh, 2008). In addition, practices like growing smother crops and carrying out summer ploughing or fallowing help in effective and successful weed control (Dubey, 2014).

a. Crop Rotation

Crop rotation has a significant impact on weed management and is an important cultural practice in agriculture. Its effects on weeds are breaks the weed life cycle, reduces weed dominance, depletes the soil weed seed bank, improves weed suppression through crop competition, facilitates effective herbicide use and controls problematic and perennial weeds. Rotating crops with different growing periods helps break the relationship between crops and weeds. When farmers change the crop every season, the planting and harvesting times also change. Crop rotation involving crops such as wheat, maize, and soybean helps reduce the number of weed seeds in the soil and suppresses the growth of broadleaf weeds. Additionally, parasitic weeds that attack pulse crops such as Striga, Orobanche, and Cuscuta can be effectively managed by rotating pulse crops with cereal crops (Kaur et al., 2015).

b. Optimum time of Sowing

The time of sowing does not involve any direct cost, yet it has a strong influence on crop yield. Early sowing allows crops to establish and grow before weeds, giving the crop a competitive advantage by limiting the sunlight available to weeds. Several studies have shown that sowing rice after the onset of the monsoon results in higher grain yield and reduced weed density (Kumar *et al.,* 2012). Similarly, late sowing of wheat has been found to effectively reduce the infestation of the weed *Phalaris minor* (Das and Yaduraju, 2007).

c. Method of planting

Zero-tillage and FIRB sowing methods resulted in lower weed infestation and higher wheat grain yield (Jat et al., 2013). The broad bed furrow (BBF) method of sowing creates a better environment for crop growth and helps reduce weeds compared to flat-bed and ridge–furrow methods (Jha and Soni, 2013). Planting rice seedlings in puddled soil reduces weed growth more than direct sowing (Hassan et al., 2010). Drum seeding with green manure also reduces weeds better than drum seeding alone or broadcasting (Sangeetha et al., 2009).

d. Intercropping

Growing different crops together, particularly crops such as beans, cucurbits, and sweet potato, helps in rapid field coverage and early canopy development, which effectively suppresses weed growth. Intercropping sugarcane with green gram resulted in the minimum weed infestation and the highest sugarcane yield. Growing cowpea together with pigeon pea resulted in the least number of weeds and the lowest weed dry weight (Singh and Abraham, 2017).

e. Seed rate

Changing the seed rate, especially using a higher seed rate, helped reduce weed population and their dry weight by ensuring enough crop plants grew in the field (Meena et al., 2010). A higher number of crop plants covered the ground well and suppressed weeds effectively (Sharma and Singh, 2011). This also increased the crop's productivity and profit.

f. Seed treatment

Maintaining a good population of healthy plants in the field helps reduce weeds. This can be done by proper land preparation and using methods like seed treatment with growth boosters (such as KCl and GA_3), pre-heating the seeds, or soaking and drying them before sowing. In sorghum, coating seeds with the fungus *Fusarium oxysporum* helps control the parasitic weed *Striga* (Elzein et al., 2006). *Pseudomonas fluorescens*, when used as a seed treatment, functions as a beneficial bacterium that suppresses weed growth while simultaneously protecting crops against seed- and soil-borne diseases. *Imazapyr and pyrithiobac*, when used as a combination seed coating in maize (corn), have been shown to suppress parasitic weeds such as *Striga*, thereby improving crop establishment and increasing grain yield (Kanampiu et al., 2003).

g. Planting pattern

Planting pattern modifies the crop canopy structure and microclimate and, when combined with weed management practices, can greatly influence weed infestation (Dwivedi et al., 2012). Increasing crop density by reducing row spacing and maintaining uniform plant distribution enhances the competitive ability of crops, thereby improving weed suppression (Kewat, 2014 and Singh, 2014). Closer row spacing increases crop competition for limited resources by promoting rapid canopy closure, which suppresses weed seedling growth and helps reduce the soil weed seed bank (Arvadiya et al., 2012).

h. Mechanical method

The mechanical method means removing weeds using different tools and machines. Farmers commonly use hand-operated, power-operated, or animal-drawn harrows and cultivators, as well as manual or power weeders. Tillage and hoeing are also part of this method.

i. Hoeing

It is an important farm activity done while the crop is growing. It means removing weeds from the field using hand hoes or simple machines, mainly from the space between crop rows. Hoeing helps control weeds, especially in the early stage of crop growth, when weeds compete with crops for water, nutrients, and sunlight. Hoeing also loosens the

Soil, which allows air and water to move easily into the soil. It breaks hard soil layers formed after rain or irrigation, helping plant roots grow better. Hoeing is commonly used in row-grown crops like cereals, pulses, oilseeds, and vegetables, and it plays an important role in good weed management. It effectively controls both annual and perennial weeds.

j. Mulching

Mulching is a farming practice in which the soil around plants is covered with materials such as straw, dry leaves, crop waste, plastic sheets, or other organic matter. This covering prevents sunlight from reaching weeds, thereby reducing their growth. Mulching also helps keep moisture in the soil and maintains a proper soil temperature. It protects the soil from erosion and, when organic materials are used, enhances soil fertility and promotes healthy crop growth. Black polythene mulch and newspaper mulch were found to reduce the number of weeds and their dry weight much more than water hyacinth, paddy straw, or wheat straw mulches (Singh, 2014).



Fig: Orgnaic and Inorganic mulching

g. Soil solarization

It is an eco-friendly way to control weeds and soil pests. It uses thin plastic sheets to cover moist soil. These sheets trap the sun's heat, raising soil temperature. The heat kills fungi, nematodes, weed seeds, and young weeds. It controls weeds like *Amaranthus*, *Avena*, *Chenopodium*, *Phalaris*, *Portulaca*, and *Solanum*. Soil solarization kills many weed seeds and young weeds in the top soil, stops the growth of soil germs that help weeds grow, and keeps the soil cleaner for crops without chemicals. It is environmentally safe, reduces the use of chemical weed killers, and helps improve soil health by lowering pest problems.



Fig: Soil Solarization

h. Stale seedbed technique

The stale seedbed technique is very effective in controlling weeds in dry direct-seeded rice (DSR). When light rains occur before the onset of the monsoon or when irrigation is available, it is possible to induce and kill several flushes of weed growth before planting. In this method, weeds are first allowed to germinate, and the emerged seedlings are then destroyed using a non-selective herbicide or shallow cultivation. This practice helps deplete the weed seed bank in the top layer of soil, thereby reducing subsequent weed emergence. It is important not to cultivate deeper than the top 1–2 cm of soil, as this may trigger another flush of weed growth. The stale seedbed technique is particularly useful in managing difficult-to-control weeds such as *Cyperus rotundus*, weedy rice, and volunteer rice seedlings.



Fig: Stale seedbed technique

i. **Biological Control**

Biological control is a method of weed management that involves the use of living organisms to suppress weeds. Major biotic agents include insects, mites, nematodes, plant pathogens, animals, fish, birds, and their toxic products, with insects being one of the most important groups (Tiwari et al., 2013). This method has been used to manage *Parthenium hysterophorus*, a noxious weed commonly found in pulse crops such as chickpea, as well as in sorghum, maize, and fruit crops. Sushilkumar (2009) reported that the insect *Zygogramma bicolorata* is the only successful biological control agent against *Parthenium*. However, this beetle alone is insufficient for complete control, as it multiplies mainly during the rainy season.

j. Chemical Control

Chemical control is an important method of weed management that involves the use of herbicides to kill or suppress weeds without causing injury to the main crop. Weed control in agricultural crops primarily relies on selective and broad-spectrum herbicides applied at appropriate doses and growth stages. The combination of Pendimethalin 30% EC + Imazethapyr 2% EC is a broad-spectrum herbicide effective against most broadleaf weeds as well as certain annual grasses in groundnut (Naik et al., 2025). Flumioxazin 50% SC and Fenoxaprop-P-ethyl 9.3% EC are used to control a wide range of broadleaf and grassy weeds in crops such as soybean, groundnut, sugarcane, tea, cotton, and rice. A specific rice herbicide containing Triafamone 20% WDG and Ethoxysulfuron 10% WDG is used for broad-spectrum control of grasses, sedges, and broadleaf weeds in both transplanted and direct-seeded rice.

Clodinafop Propargyl 15%+Metsulfuron Methyl 1% WP is is a post-emergence herbicide used to control both grassy and broadleaf weeds, particularly *Malva* spp. and *Solanum nigrum*, in cereal crops such as wheat and barley. Proper application of these modern herbicides at recommended dosages and timings plays a crucial role in effective weed management and enhances crop productivity.

Conclusion:

Weeds can cause heavy loss or even complete failure of crops like pulses, cereals, and fruits if they are not controlled early. A single method of weed control is inadequate since different weeds have different habits of growth. Therefore, farmers should use a combination of methods that are simple, low-cost, and effective in maintaining the number of weeds at low levels to increase crop yield. Herbicides kill weeds quickly but should be combined especially with good farming practice since weeds have different growth habits and periods of dormancy. Continual use of the same herbicide leads to the development of resistant weeds. This resistance can be avoided by changing herbicides or using mixtures. The main aim of weed management is to decrease the population of weed seeds in the soil and improve the growth of agricultural crops through reduced emergence of weeds. Weeds you see in the field are only the surface problem but the real problem is the weed seeds stored in the soil.

4.2. A. Classification of Herbicides Based On Chemical Nature-Time and Method of Application. Classes of Herbicides Based on-Selectivity-Spectrum- Translocation-Residual Nature - Soil Sterilant and Fumigants

The word 'herbicide' is originated from Latin words: 'herba' meaning plant, and 'caedere' meaning to kill. Herbicides are chemical substances exclusively designed to kill or inhibit the growth of unwanted plants in crops. Herbicide usage in agriculture began as early as the late 19th century and became widespread from the 1940s onwards, transforming weed management in modern agriculture.

1. Classification of Herbicides

Based on chemical nature: Based on chemical nature, herbicides are primarily grouped into inorganic and organic.

Inorganic herbicides: A compound composed of natural mineral raw materials and does not contain carbon. These are the first chemicals used for weed control. Examples: - Acid types: Arsenic acid, Arsonous acid, Sulphuric acid.

- Inorganic salts: Sodium arsenate, Sodium chlorate, Copper sulphate.

Organic herbicides: Mainly synthesized from organic compounds such as benzene, alcohols, fatty acids, and organic amines. Over 150 herbicides are available and are grouped into 31 chemical classes based on their behaviour in soil, plants, mode of action, etc.

Table 1: Organic herbicides– Based on chemical nature

Sl.No.	Group	Examples
1	Aliphatic acids	Dalapon, TCA, Glyphosate, Methyl bromide, Cacodylic acid, MSMA, DSMA
2	Amides	Alchlor, Butachlor, Propachlor, Metolachlor, Diphenamide, Propanil
3	Benzoics	2,3,6-TBA, Dicamba, Tricamba, Chloramben
4	Bipyridyliums	Paraquat, Diquat
5	Carbamates	Propham, Chlorpropham, Barban, Dichlormate, Asulam
6	Thiocarbamates	Butylate, Diallate, EPTC, Molinate, Triallate, Benthiocarb, Metham
7	Dithiocarbamates	CDEC, Metham
8	Nitriles	Bromoxynil, Ioxynil, Dichlobenil
9	Dinitroanilines	Fluchloralin, Trifluralin, Pendimethalin, Nitralin, Isoproturon
10	Phenols	Dinoseb, DNOC, PCP
11	Phenoxy acids	2,4-D, 2,4,5-T, MCPA, MCPB, 2,4-DB, Dichlorprop
12	Triazines	Atrazine, Simazine, Metribuzin, Ametryn, Terbutryn
13	Ureas	Monuron, Diuron, Linuron, Metoxuron, Isoproturon, Methabenz-thiazuron
14	Uracils	Bromacil, Terbacil, Lenacil
15	Diphenyl ethers	Nitrofen, Oxyfluorfen, Nitrofluorfen
16	Aryloxyphenoxy propionates	Diclofop, Fenoxaprop-p, Quizalofop-p, Haloxyfop-p, Fluazifop-p
17	Cyclohexanediones	Sethoxydim, Clethodim, Tralkoxydim, Cycloxidim

18	Imidazolines	Imazapyr, Imazamethabenz, Imazaquin, Imazamox, Imazethapyr
19	Isoxazolidinones	Clomazone
20	Oxadiazoles	Oxadiazon, Methazole
21	Oxadiazolides	Oxadiazon and Oxadiargyl
22	N-phenylphthalamides	Flumiclorac
23	Phenylpyridazones	Sulfentrazone
24	Phthalamates	Naptalam
25	Pyrazoliums	Difenzoquat, Metflurazone
26	Picolinic acids / Pyridines	Picloram, Dithiopyr, Pyrithiobac, Fluridone, Thiazopyr
27	Quinolines	Quinclorac
28	Sulfonylureas	Bensulfuron, Chlorimuron, Metsulfuron, Sulfosulfuron, Triasulfuron
29	Triazolinones	Sulfentrazone, carfentrazone-ethyl, and azafenidin
30	Cineoles / Pyridates	Cinmethylin
31	Others	Picloram, Pyrazon, Endothal, Oxadiazon, Amitrole, Anilofos

Based on time of application

The timing of herbicide application is critical for its effectiveness and crop safety.

Based on time of application these are grouped in to,

Pre-planting

Applied before sowing or planting of the crop.

May be incorporated into the soil to prevent loss by volatilization or photodecomposition.

Often used to control weeds before crop establishment.

Examples: Fluchloralin, Trifluralin (incorporated), Glufosinate (for stale seedbed technique).

Pre-emergence

Also called as soil treatment herbicides

Applied after sowing but before emergence of crop and weeds.

Create a chemical barrier in the soil to kill germinating weed seeds.

Examples: Pendimethalin, Atrazine, Butachlor

Post-emergence

Also called as foliage treatment herbicides

Applied after both crop and weeds have emerged.

Usually absorbed by foliage; may be selective or non-selective.

Examples: 2, 4-D (selective for broadleaf weeds in cereals), Metsulfuron, Sulfosulfuron, Bispyribac sodium etc.

Early post-emergence

Application of herbicides after a crop has emerged from the soil, while the weeds are still young and vigorously growing.

Applied in slow growing crops like potato and sugarcane.

Applied in 2-3 week after sowing/planting.

Example: spraying of paraquat to control emerged weeds after 10-15 days after planting potato

Based on method of application: Based on this, herbicides are classified into five types.

Soil-applied herbicides

Applied to soil surface or incorporated.

Taken up mainly by germinating seeds or underground plant parts.

Examples: Atrazine, Alachlor, Metolachlor.

Foliar-applied herbicides

Applied directly to leaves and stems.

Absorbed and either translocated or act only on contact points.

Examples: 2-4 D (systmic), Paraquat (contact).

Directed application

Sprayed towards weeds while avoiding contact with crop foliage.

Useful in row crops and orchards.

Example: Directed spray of Glufosinate in sugarcane inter-rows.

Band application

Applied in narrow strips over or along the crop row, leaving inter-row spaces untreated.

Saves herbicide and allows mechanical weeding in untreated areas.

Spot treatment

Applied only to small infested patches, avoiding blanket coverage.

Ideal for treating localized perennial weed patches.

Based on selectivity: Based on this, herbicides are grouped in to,

Selective herbicides

These herbicides kill only specific weed species without harming the crop.

Applicable to pre-planting, pre-emergence and post-emergence stages.

Selectivity depends on:

Herbicide dose

Crop species

Growth stage of the crop

Crop variety

Examples: 2-4 D, Atrazin, Metribuzin

Non-selective herbicides

These herbicides kill all vegetation, including crops and weeds.

Commonly used in:

Non-cropped areas

Industrial sites

Roadsides

Chemical ploughing under zero tillage

Examples: Glufosinate, Paraquat, Diquat, Amitrol etc.

Classification based on spectrum

Narrow-spectrum herbicides

Narrow-spectrum herbicides are effective against a specific group of weeds such as broadleaf weeds (BLWs), grasses, or sedges. These herbicides do not control all types of weeds in a crop field, making them suitable for targeted weed management.

Examples:

2, 4-D: Controls broadleaf weeds (BLWs); sometimes effective against Cyperus spp. (a sedge).

Metsulfuron methyl, Bentazone, Lactofen: Effective mainly against broadleaf weeds.

Diclofop-methyl, Fluazifop-p-butyl, Fenoxaprop-p-ethyl, Clodinafop-propargyl: Selective grass killers, particularly effective against: Phalaris minor, Avena fatua, Lolium spp.

Broad-spectrum herbicides

Broad-spectrum herbicides are capable of controlling a wide range of weed species, including both grasses and broadleaf weeds. However, they do not kill every weed present in the field.

Examples:

Atrazine: Controls most BLWs and some grasses (used in maize and sorghum).

Pendimethalin: Controls most grasses and some BLWs.

Others commonly used in crops:

Isoproturon, Chlorsulfuron, Sulfosulfuron, Alachlor, Butachlor, Metribuzin, Imazethapyr

Non-crop area herbicides - Glufosinate and Paraquat

Based on translocation

Systemic herbicides (Translocated)

Move from the point of entry (leaf or root) to other parts of the plant via xylem and/or phloem.

Effective against perennial weeds.

Example: Glufosinate, 2, 4-D., Atrazine, Simazine etc.

Contact herbicides

Kill only the plant tissue they touch.

No movement within the plant.

Regrowth from underground parts is possible. Example: Paraquat, Diquat.



Fig: Conatct Herbicides

Based on residual nature

Based on this herbicides are classified into non-residual and residual types based on how long they remain active in the soil after application.

Residual herbicides (Persistent)

Herbicides that retain their phytotoxicity in the soil for a period after application, thereby continuing to control weeds after spraying. Remain active in soil for weeks to months, providing extended weed control.

Example: Atrazine, Simazine, Diuron.

Table 2: Persistence of different herbicide in soil

Herbicide	Persistence in soil
Fluzifop-p-butyl	1 week
Bentazone	2 weeks
Glyphosate, Paraquat, 2,4-D, 2,4-DB	1 month
Alachlor	1-2 months
Metolachlor	1-3 months
Diuron	2-3 months

Non-residual herbicides (Non-persistent)

Herbicides that leave no or very minimal residues in the soil and are quickly deactivated upon contact with soil.

They quickly degraded by microbes, sunlight, or chemical processes. Example: Paraquat.

Soil sterilant and fumigants

Soil sterilant and fumigant herbicides are also known as bare ground herbicides, that kills complete vegetation and prevents plant growth for an extended period up to six months or more. They are used in areas where no vegetation is needed, such as industrial sites, road sides, and parking lots. These herbicides are non-selective in nature.

Temporary soil sterilants / fumigants

Provide short-term weed control (15-16 weeks).

Highly volatile compounds preferred for quick action.

Examples: Methyl bromide, Metham, Methyl isocyanate (MIC), Chloropicrin, CS gas, Chlorfenac. Release phosphine gas (like Celphos, Zinc phosphide, Calcium phosphide).

Permanent soil sterilants / fumigants

Volatile herbicides forming heavy vapors that penetrate soil and kill all vegetation.

Used in nursery beds of rice, tobacco, and vegetables.

They have long soil activity and persist for multiple seasons or years.

Examples: Atrazine, Linuron (phenyl urea), Sodium chlorate (at high dose).

Conclusion

The diverse classification of herbicides helps in selecting the appropriate product for specific weed problems under varying agro-ecological conditions. Understanding their characteristics not only improves weed control efficiency but also minimizes crop injury, environmental impact, and herbicide resistance development. A judicious and informed approach to herbicide use ensures sustainable weed management in both cropped and non-cropped areas.

4.2. B. Compatibility of Herbicides with Agro-Chemicals and their Application

In the present agriculture scenario, intensive cultivation of crops to meet the rising demands of food, fiber, and fuel often call for the use of multiple agro- chemicals such as herbicides, insecticides, fungicides, plant growth regulators, micronutrients and fertilizers. Herbicides, in particular, play a crucial role in controlling unwanted weeds, which otherwise compete with crops for light, nutrients, and water, leading to significant yield losses. The synchronized management of insect pests, diseases, and nutritional deficiencies is equally indispensable for achieving optimum crop productivity. This comprehensive approach to crop protection and management has given rise to the practice of mixing different agro-chemicals, commonly in a single spray operation is commonly known as **tank- mixing**. The Physical, **chemical and biological properties** of the mixed substances must be carefully evaluated to avoid undesirable interactions that can lead to reduced efficacy, phytotoxicity, or even crop failure.**Compatibility** refers to the ability of different agro-chemicals to be mixed and applied together without adverse effects on the crop plant or equipment. The compatibility of herbicides and agro-chemicals is also influenced by other factors *viz*, **water quality, pH, temperature, tank mix adjuvants and formulation types** (Eg.EC, SC, WP, WG, etc.).

Herbicide compatibility refers to the ability of an herbicide to be mixed or applied with other agrochemicals (such as insecticides, fungicides, micronutrients, or fertilizers) without causing undesirable physical, chemical, or biological interactions that reduce the effectiveness or safety of any component.

Objectives of combining agrochemicals

- To reduce the number of field operations.
- To save on labour and fuel costs.
- To enhance weed and pest control efficiency.
- To ensure synchronized management of multiple stress factors (weeds, insects, diseases, and nutrient deficiencies).
- To promote integrated pest and weed management (IPWM).

1. Types of compatibility

There are there are three types of compatibilities *viz.*

i. **Physical compatibility-** Ability of two or more agro-chemicals to be mixed without forming lump, precipitates, gels or separation.

ii. **Chemical compatibility-** When the active ingredients of herbicides react chemically with other agro-chemicals leading tophytotoxic effects on crops. Eg. **Sulfonylurea herbicides** + **organophosphate insecticides** → increased crop injury in maize.

iii. **Biological compatibility-** Indicate whether the combined application enhances, reduces, or maintains the biological effectiveness (efficacy) of each component. Eg. **Pendimethalin + Chlorpyrifos**; Used safely in groundnut for weed and termite control without crop injury.

2. Interaction effects of herbicide mixtures

When two or more chemicals accumulate in the plant, they may interact and bring out responses. These responses are classified as additive, synergistic, antagonistic, independent and enhancement effects.

Effect	Description	Example
Synergistic effect	Combined effect is greater than the sum of individual effects, representing a positive interaction.	Combined application of Pendimethalin + Imazethapyr in soybean controls broader weed spectrum for longer period.
Antagonist effect	Combined effect is lesser than expected due to one chemical reducing the activity of another.	Glyphosate + 2, 4-D amine reduced glyphosate uptake in some perennial weeds.
Additive effect	The total effect is equal to the sum of the effects of the components when applied independently.	Atrazine + Metolachlor in maize controls both grasses and broadleaves with no loss in individual efficacy.
Enhancement effect	Combination of an herbicide and a non-toxic adjuvant result in improved efficacy compared to the herbicide alone.	Ammonium sulphate+Glyphosate enhance the uptake and performance of glyphosate.
Independent effect	The total effect is equal to the effect of the most active component when used alone	$A + B = A > B \rightarrow$ The dominant component dictates the overall result.

3. Factors influencing compatibility

- **pH of the spray solution** - Affects chemical stability.
- **Water quality** - Hard water (high Ca^{2+}, Mg^{2+}) may reduce herbicide solubility or activity. Iron and bicarbonates can precipitate some herbicides.
- **Formulation type** - Emulsifiable concentrates (EC), suspension concentrates (SC), wettable powders (WP), soluble liquids (SL), etc., have varying compatibilities.
- **Sequence of mixing** - Incorrect order can cause physical incompatibility.General mixing order: **WP → DF → SC → EC → SL → Adjuvants → Fertilizers**
- **Temperature and humidity** - Affects volatilization and evaporation of volatile components.
- **Time interval between applications** - Simultaneous vs. sequential applications yield different effects.

4. Compatibility with other agro-chemicals

i. Herbicide + herbicide

Often mixed to broaden weed control spectrum or delay resistance. Eg: - Atrazine + Pendimethalin in maize (*additive effect)*.

- Isoproturon + 2, 4-D in wheat (*additive effect)*.

ii. Herbicide + insecticide

In most of the cases herbicide + insecticide combinations are safe at recommended doses. However, certain interactions may alter crop tolerance or enhance phytotoxicity.

Eg: - Phorate increases the phytotoxicity of *monuron* and *diuron* in cotton crop.

- Propanil + carbamate/organophosphate insecticides (as rice seed treatment) increased vegetative injury.
- Metribuzin + phorate reduced soybean yield.
- Propanil + carbofuron increases phytotoxicity in rice

iii. Herbicide + fungicide

It is very rare but possible in disease-prone crops.

Eg: - Mancozeb + 2, 4-D in wheat for disease + weed management

iv. Herbicide + fertilizer

Fertilizer carriers (Urea and ammonium sulfate) sometimes improve herbicide activity and uptake in the targeted species.

Eg: - Atrazine + urea in maize (Urea aids early crop growth after weed removal).

- NH_4NO_3 (0.1%) enhances absorption of isocotyl ester of 2, 4, 5-T.
- $(NH_4)_2SO_4$ (0.5%) + glufosinate against *Imperata cylindrica* is used.
- Amitrole + high P become phytotoxic to groundnut.

v. Herbicide + antidote

This combination generally leads to antagonistic interaction

Eg: - Antidotes, i.e., R 25788 and CDAA + alachlor, EPTC and butylate.

- NA (seed treatment) protects maize seedling from EPTC injury.
- NA coating on oat seeds reduces barban phytotoxicity.
- Activated charcoal is an effective barrier.



Fig: Injury in Maize

vi. . Herbicide+ moisture interaction

- **Dry spells:** Soil-applied herbicides often fail during a dry spell of 10–15 days after application.
- **Pre-emergence losses:** Pre-emergence herbicides may be lost due to photo- decomposition, volatilization, or wind.
- **Leaching:** Excessive moisture may leach herbicides into the seed/root zone leading to crop injury and poor weed control.
- **Foliage wash-off:** Heavy showers can wash herbicides off foliage.

- **Wet weather sensitivity:** Continuous wet weather causes crops to become succulent, increasing herbicide absorption and injury. Eg: Maize becomes susceptible to atrazine under wet and cold conditions due to increased absorption and reduced metabolism.
- Water Quality:
    - Dusty water → reduces paraquat efficacy

Advantages of mixing herbicides with agro-chemicals

- **Cost efficiency** - Saves fuel, labor, and time by combining operations.
- **Broader spectrum of control** — Multiple weed types or pests targeted in a single application.
- **Reduced crop competition** — Early weed and pest control improves crop establishment.
- **Better timing** — Ensures both weed and pest problems are tackled at the optimal stage.

vii. Some common compatible combinations

Herbicide	Compatible with	Crop	Purpose
Atrazine	2,4-D	Maize, Sorghum	Control broadleaf and grassy weeds
Pendimethalin	Chlorpyrifos	Groundnut	Weed + termite control
Butachlor	Carbofuran	Rice	Weed+stem borer/nematode control
Glufosinate	Ammonium sulfate (AMS)	Non-crop Areas	AMS improves glyphosate absorption in hard water
Isoproturon	2,4-D	Wheat	Broadleaf + grassy weed control
Paraquat	Diuron	Orchards	Total vegetation control with residual effect

viii. Some Common Incompatible Combinations

Herbicide	Incompatible With	Reason
Glyphosate	Calcium or magnesium-rich hard water	Forms insoluble salts, reducing efficacy
Glyphosate	Strongly alkaline solutions	Rapid hydrolysis and deactivation
Sulfonylureas	Organophosphate insecticides	Increased crop phytotoxicityin maize
Paraquat	Oil-based sprays	Reduced herbicide absorption and uneven coverage

ix. Guidelines for mixing and application

- ✓ **First check the label** for compatibility instructions.
- ✓ **Do jar test** before field application.
- ✓ **Follow correct mixing order** ie. WALES

rule: **W** — Wettable powders → **A** — Agitate → **L** — Liquid flowables → **E** — Emulsifiable concentrates → **S** – Surfactants/adjuvants last.

- ✓ **Maintain continuous agitation** in tank to avoid settling.
- ✓ **Spray immediately** after mixing.
- ✓ **Use clean water** (avoid muddy or alkaline water).
- ✓ Avoid mixing if **crop safety** or **residue regulations** are uncertain.

Eg: If you are mixing **pendimethalin (EC)** + **carbendazim (WP)** + **insecticide (EC)**:

1. Fill tank halfway with water.
2. Add Carbendazim (WP).
3. Agitate.
4. Add Pendimethalin (EC).
5. Add insecticide (EC).
6. Top up water and add surfactant last.

Conclusion

Tank-mixing of herbicides with other agro-chemicals can improve operational efficiency and crop protection outcomes when done correctly. However, understanding chemical compatibility, physical interactions, and environmental influences is essential to avoid phytotoxicity, reduced efficacy, or equipment damage. Following scientifically validated guidelines and field testing (e.g., jar test) ensures safe and effective use of these mixtures in integrated crop management systems.

4.2. C. New Developments in Herbicides – Micro-Herbicides and Nano-Herbicides

In crop production, weed management has always been a vital element. Weeds compete aggressively for three major resources with crops viz., light, nutrients, water, and space, leading to significant yield losses and deterioration of crop quality. In the recent past, chemical herbicides have become indispensable and widely adopted method for controlling weeds in both agricultural and non-agricultural areas.

The long-term and indiscriminate use of broad-spectrum chemical herbicides has created serious challenges in modern agriculture. Herbicide-resistant weed biotypes have evolved in many parts of the world, with species such as *Amaranthus palmeri*, *Phalaris minor*, and *Echinochloa crusgalli* showing resistance to multiple modes of action. Persistent nature of chemical residues in soil, water bodies, and food products have raised serious concerns on environmental and public health. Further, impact of herbicides on beneficial soil organisms, pollinators, and biodiversity has prompted stricter regulatory frameworks. Hence, these issues have created an urgent need to transition towards eco-friendly, precise, and sustainable weed management solutions. Therefore, research and development in weed science has shifted focus from **"more chemical"** to **"smart chemical and biological"** approaches. A significant outcome of this paradigm shift is the emergence of **micro-herbicides** and **nano-herbicides**. These technologies aim to enhance **weed control efficacy**, reduce **environmental contamination**, and delay the development of **herbicide resistance** in weed populations.

1. Micro-herbicides

The biologically derived weed control agents that employ living microorganisms (fungi, bacteria, viruses) or their metabolites to suppress or kill weeds are called as Micro- herbicides. When derived from fungi, they are often referred to as **mycoherbicides**.

i. Characteristics

Micro-herbicides possess several unique features that distinguish them from conventional chemical herbicides and make them attractive for sustainable weed management:

- **Derived from naturally occurring weed pathogens** – originate from fungi, bacteria, or other Micro organisms that naturally infect and suppress specific weed species.
- **Target-specific action** – affect only the intended weed species or a narrow group of related weeds.
- **Non-persistent and biodegradable** –break down naturally in the environment, leaving no harmful residues in soil, water, or harvested produce.
- **Versatile formulation options** – prepared as viable spores, vegetative cells, or microbial extracts containing active metabolites.
- **Ease of application** – applied with standard agricultural spray equipment, using methods similar to chemical herbicides.

ii. Mode of action

Micro-herbicides suppress weed growth by infecting the target plant and disrupting its normal physiological processes. Common effects include:

- **Tissue necrosis** – The pathogen damages leaf, stem, or root tissues, leading to localized or systemic death of plant parts..

Table 3: Types of Micro-Herbicides with trade name, pathogen and target weed.

Trade Name	Pathogen / microbe	Target weed
DeVine	*Phytophthora palmivora* (First commercial mycoherbicide, USA, 1979; persists 3-4 years)	Strangler vine (*Morrenia odorata*) in citrus orchards
Collego	*Colletotrichum gloeosporioides* f.sp. *aeschynomene*	Northern joint vetch (*Aeschynomene virginica*) in rice and soybean
BioMal	*Colletotrichum gloeosporioides* f.sp. *malvae*	Round-leaved mallow (*Malva pusilla*); registered in Canada
Chontrol	*Chondrostereum purpureum*	Unwanted hardwood trees in forest management
Smolder	*Alternaria destruens*	Dodder (*Cuscuta* spp.); effective against parasitic weeds
Balanomyces	*Stagonospora* sp.	Annual bluegrass in. turf management
Bipolaris	*Bipolaris sorghicola* (applied as suspension of fungal spores)	Johnson grass
Product-F	*Fusarium oxysporum* (host-specific vascular wilt pathogen)	*Orobanche* in sunflower
ABG 5003	*Cercospora rodmanii* (causes leaf spot in weed)	Water hyacinth
VELGO	*Colletotrichum coccoides*	*Abutilon theophrasti* in cotton; broadleaf weed

CASST	*Alternaria cassiae* (causes blight disease)	*Cassia obtusifolia* in cotton, soybean, and groundnut

- **Vascular blockage** – Fungal or bacterial growth within xylem and phloem impedes the transport of water and nutrients, ultimately weakening the plant.
- **Disruption of photosynthesis** – Some micro-herbicides interfere with chlorophyll function or damage photosynthetic tissues, reducing the plant's energy production capacity.
- **Inhibition of seed germination** – Certain pathogens produce metabolites that prevent the germination of weed seeds or kill seedlings soon after emergence

v. Advantages

Micro-herbicides offer several benefits over conventional chemical herbicides, making them an attractive option for sustainable and integrated weed management programs.

They are,

- Safe and secure
- Low risk of resistance development
- Integration potential with other practices
- Minimal chemical load
- Safe for human and animal health.
- Adaptability to organic farming
- Potential for climate-specific adaptation
- Reduced environmental drift risk.

vi. Limitations

Despite their many benefits, micro-herbicides also have certain constraints that can limit their widespread adoption:

- **Environmental sensitivity** – Low humidity or extreme heat may reduce infection rates and overall weed control efficacy.
- **Slower action** – Micro-herbicides often require several days or weeks to show visible effects on the target weeds, which may not be suitable for situations demanding rapid suppression.
- **Shorter shelf life** – Being a biological derivative, they often have reduced storage stability and may require specialized formulations, refrigeration, or protective carriers to maintain viability over time.
- **Regulatory hurdles** – The approval process for biopesticides can be complex and time-consuming and safety assessments that vary across countries.
- **Production and formulation challenges** – Mass production of consistent, viable, and field-effective microbial inoculum can be technically demanding and costly.
- **Variable field performance** – Inconsistent results may occur due to soil type, competing microorganisms, and weather patterns, making performance less predictable than some chemical herbicides.

2. Nano-Herbicides

Nano-herbicides are advanced herbicide formulations developed using **nanotechnology**, in which the active ingredient is **encapsulated, adsorbed, or attached** to nanoparticles typically ranging from **1 to 100 nanometres** in size. These nanoparticles, or **nanocarriers**, act as delivery vehicles that protect the active ingredient, enhance its stability, and enable **controlled release** to the target weed. This approach allows for reduced herbicide doses, increased efficacy, and **site-specific action** while minimising environmental contamination. By combining **precision agriculture principles** with advanced formulation technology, nano-herbicides represent a promising step toward more **sustainable weed control** in modern farming systems.



Fig: Naono Herbicides

i. Characteristics

Nano-herbicides possess several distinct characteristics that set them apart from conventional herbicide formulations:

- **Nano-encapsulation** – The herbicide is enclosed within nanocarriers such as liposomes, polymeric nanoparticles, solid-lipid nanoparticles, or mesoporous silica particles.
- **Controlled release** – The active ingredient can be released gradually over time or triggered by environmental cues such as **pH variation**, **light exposure**, or **enzymatic activity** in the target weed.
- **Target specificity** – Surface modifications on nanocarriers can enable preferential binding or penetration into weed-specific tissues.
- **Improved solubility and stability** – Enhance the solubility of poorly water-soluble herbicides and shields them from photodegradation and volatilisation losses.

ii. Types of Nano herbicides

Nano herbicides represent a pioneering step in weed management, leveraging nanotechnology to improve the precision, efficiency and environmental safety of herbicide delivery. Based on their composition and mode of action, nano herbicides are broadly classified into organic, inorganic, and hybrid types.

iii. Organic Nano herbicides

These are derived from biodegradable organic materials such as natural polymers, proteins, and lipids. They are environmentally friendly and safe for crops and soil biota (Table 4).

Table 4. Different types of organic nano herbicides

Type	Carrier material	Examples	Advantages
Polymeric nanoparticles	Natural or synthetic polymers	Chitosan, PLGA, starch	Controlled release, biocompatible
Lipid-based nanoparticles	Liposomes, solid lipid carriers	Phospholipids, lecithin	Non-toxic, enhances absorption
Protein-based nanoparticles	Biopolymer proteins	Albumin, casein, zein	Natural, degradable, non-toxic
Carbohydrate-based nanoparticles	Polysaccharides	Cellulose, alginate	Renewable, eco-safe

iv. Inorganic Nano herbicides

These are based on metallic or mineral nanoparticles that have inherent antimicrobial or herbicidal properties, or act as carriers (Table 3).

Table 3. Different types of inorganic nano herbicides

Type	Carrier material	Examples	Advantages
Metal nanoparticles	Metals with bioactivity	Silver (Ag), Copper (Cu), ZnO	Antimicrobial, improved efficiency
Silica nanoparticles	Mesoporous silica	SiO_2 nanoparticles	High surface area, stable loading
Clay-based nanocarriers	Layered silicates	Montmorillonite, kaolinite	Slow release, soil-compatible
Carbon-based nanomaterials	Carbon nanostructures	Graphene oxide, CNTs	Strong, enhances mobility in plants

v. Hybrid Nano herbicides

These combine both **organic and inorganic materials** to enhance performance, stability, and targeted delivery (Table 4).

Table 4. Different types of hybrid nano herbicides.

Type	Components	Examples	Advantages
Organic-inorganic nanocomposites	Polymeric + metallic/silica	Chitosan-Ag NP, PLGA-SiO_2	Combines biocompatibility and potency
Lipid-metal hybrids	Liposomes + metal NPs	Lipid-Cu/Zn composites	Improved uptake and toxicity to weeds
Clay-polymer hybrids	Clay + polymer	Alginate-montmorillonite	Better release control and soil stability

Table 5. Examples of types of nano-herbicides

Nano-herbicide	Nanocarrier	Active ingredient	Benefit
Nano-atrazine	Polycaprolactone nanoparticles	Atrazine	Slow release, reduced leaching into groundwater
Nano-pendimethalin	Chitosan nanoparticles	Pendimethalin	Extended persistence in soil, lower application dose
Nano-diuron	Solid lipid nanoparticles	Diuron	Enhanced UV stability and field persistence
Nano-glyphosate	Nanoemulsion	Glyphosate	Improved leaf penetration and rainfastness
Mesoporous silica-based 2,4-D	Mesoporous silica Nanoparticles	2,4-D	Controlled, pH-responsive release

Nano-alachlor	Polymeric nanocapsules	Alachlor	Reduced volatilisation losses and better soil retention

vi. Advantages

- Lower application rates
- Extended weed control period
- Minimised drift and leaching
- Improved uptake and penetration
- Protection from environmental degradation
- Potential for smart delivery systems

vii. Limitations

Despite their promise, nano-herbicides also face certain challenges that must be addressed before large-scale adoption:

- High initial development cost
- Regulatory uncertainty
- Specialised formulation facilities
- Long-term environmental impact
- Potential compatibility issues

viii. Precautions while using Micro- and Nano-Herbicides

Although micro-herbicides and nano-herbicides are generally considered safer and more target-specific than many conventional herbicides, certain **handling, application, and storage precautions** are essential to ensure their effectiveness, environmental safety, and user protection;

a. Storage conditions

vi. Micro-herbicides containing living organisms should be stored under recommended temperature and humidity conditions to maintain viability.

vii. Nano-herbicide formulations should be kept away from direct sunlight and moisture to prevent premature degradation or agglomeration of nanoparticles.

b. Use of Personal Protective Equipment (PPE

- Operators should wear gloves, masks, and protective clothing when handling concentrated formulations to avoid inhalation, skin contact, or accidental ingestion.
- Eye protection is advisable when using spray applications, especially in windy conditions.

c. Avoiding drift and off-target deposition

- Apply under low wind speeds to prevent drift of nano-formulated sprays, which may

have higher penetration potential.

- Use shielded sprayers or directed application methods when working near sensitive crops or habitats.

d. Proper dosage and calibration

- Application of overdosing may harm non-target plants, beneficial microbes, or aquatic life.

e. Environmental considerations

f. Ensure that applications are not carried out before heavy rains, in order to reduce the risk of runoff and unintended spread.

g. Compatibility testing

a. Before tank-mixing with other agro-chemicals (fertilisers, insecticides, fungicides), check compatibility to avoid reduced efficacy or instability in the formulation.

Conclusion:

Micro-herbicides and nano-herbicides represent a significant step forward in the evolution of weed management technologies. By harnessing the specificity and eco-friendliness of biological control agents alongside the precision and controlled-release capabilities of nanotechnology, these innovations address many of the shortcomings of conventional chemical herbicides. They offer the potential for lower application rates, reduced environmental impact, improved target specificity, and compatibility with integrated and precision farming systems**.**

However, their successful adoption depends on overcoming certain challenges, including **formulation stability, environmental sensitivity, production costs, and regulatory approval processes**. Continued research into hybrid systems, smart delivery mechanisms, and climate-resilient formulations will be key to unlocking their full potential.

4.3. Integrated Weed Management (Physical, Chemical, Biological method)

A plant that is growing in an area where it is not wanted. "A weed may be defined as any plant or vegetation that interferes with the objectives of farming or forestry, such as growing crops, grazing animals or cultivating forest plantations.''

The **CRITICAL PERIOD** of weed competition is the specific time duration during a crop's growth when weeds must be controlled to prevent significant yield loss.

S. No.	Crops	Day from sowing	Weeds most problematic
1.	Rice(upland)	Entire period	Barnyard grass, jungle rice, yellow nutsedge
2.	Rice(Lowland)	15 to 45	Barnyard grass, striga, annual sedge
3.	Soybean,	15 to 45	Palmer amaranth, waterhemp, kochia
4.	Sorghum	15 to 45	Barnyard grass, pigweed, johnson grass
5.	Maize	15 to 45	Barnyard grass, bermuda grass, green foxtail
6.	Pearl millet	20 to 40	Barnyard grass, bermuda grass, johnson grass
7.	Wheat	30 to 45	Wild oat, canary grass, field bindweed
8.	Cotton	15 to 60	Barnyard grass, nutsedge, johnson grass
9.	Groundnut	30 to 50	Nutsedge, purslane, perennial sedge
10.	Sugarcane	30 to 120	Bermuda grass, johnson grass, pig weed

1. Objectives of Weed Management

1. Maximize Crop Yields and improve crop quality

2. Enhance Economic Viability
3. Prevent Weed Resistance
4. Reduce Labor Costs
5. Protect Human Health and the Environment
6. Maintain Ecosystem Balance
7. Facilitate Land Use Planning

2. Integrated Weed Management: The use of all suitable weed control methods to keep weed populations below the economic injury level. Methods include cultural practices, use of biological, physical and genetic control agents, and the selective use of herbicides. The principles of IWM are that weed management should not rely on one single form of control.

3. Principles of Weed Management

Effective weed management is built on several key principles:

1) Prevention 2) Eradication 3) Control

i. **Prevention of Weeds**

Weed prevention encompasses a range of proactive measures aimed at stopping the introduction, establishment, and spread of unwanted plant species.

- **Use Certified Clean Seeds***:*

Selecting high-quality, seeds that are free from weed seeds is essential. This practice minimizes the risk of introducing new weed species into the planting area.

- **Utilize well-Decomposed Organic Manure:**

Using well-decomposed manure, as the composted manure kills most off viable seeds.

- **Keep Irrigation Channels Clean:**

Weeds can proliferate in irrigation channels and spread seeds through water movement. Keeping channels clear of debris and invasive plants ensures that water flows freely and does not contribute to weed growth in fields.

- **Implement Quarantine Regulations:**

Adhering to local and regional quarantine regulations helps prevent the movement of potentially infested plants and soil. These regulations are designed to control the spread of invasive species and protect agricultural and natural ecosystems from new threats.

ii. Eradication **of Weeds**

Eradication focuses on the complete elimination of all live weeds and their propagules from a specific area.

- **Manual Removal**: Hand-pulling or digging out weeds, ensuring that all roots and seeds are removed.
- **Mechanical Methods**: Techniques like mulching can suppress weed growth by blocking light and reducing seed germination.
- **Herbicides**: Targeted application of chemical herbicides can effectively kill weeds, although this method must be used judiciously to minimize environmental impact.
- **Promoting Competitive Plant Growth**: Encouraging the growth of desirable plants can help outcompete and suppress weed species.

iii. Control

a) **Physical / Mechanical Methods of Weed Control**

- **Tillage** It involves turning and breaking up the soil using implements such as plough, discs, harrows, cultivators. It uproot weeds, exposing roots to the air, and drying them out, leading to their death. It is effective for annual weeds but may bring new seeds to surface.
- **Hoeing** It is used to cut, chop, or scrape weeds at or just below the soil surface. It is useful in row crops It is effective for controlling annual and biennial weeds. In perennial weeds, hoeing only removes the top portion of the plant, and the underground parts (roots, rhizomes, or tubers) may remain intact, leading to regrowth.
- **Hand Weeding** It is physical pulling of weeds out by hand or using tools such as a khurpi. It is labour intensive but precise and effective for small areas.
- **Digging** It is effective for controlling perennial weeds by removing their underground parts, such as roots, rhizomes, tubers, and stolons, responsible for regeneration.
- **Sickling and Mowing** Cutting the top growth of weeds using a sickle, preventing weeds from setting seeds and depletes the energy reserves in the underground parts by removing the photosynthesizing parts of the plant.
- **Burning** Burning or flame weeding, involves using fire to destroy weeds in situations where mechanical weeding is impractical. Burning is less effective on deep-rooted perennials, as it mainly affects the above-ground parts.
- **Flooding** Flooding involves submerging the land under water for extended periods to kill weeds by depriving them of oxygen. It is effective for weeds that are not adapted to survive in waterlogged conditions.
- **Mulching** It in covers the soil with organic (straw, wood chips, leaves) or synthetic (plastic or landscape fabric) materials. It suppresses weed growth by blocking sunlight, and preventing weed seed germination.
- **Soil Solarization**: Covering the soil with clear plastic for several weeks can trap heat and kill weed seeds and seedlings through high temperatures.



Fig: Physical / Mechanical Methods of Weed Control

b) **Cultural Methods of Weed Control**

Cultural weed control involves using various agricultural practices to create conditions that favor crop growth and suppress weeds, reducing their ability to compete.

- **Optimum Plant Population:** A dense crop stand creates a canopy that shades out weeds and reduces their ability to grow, providing a natural form of weed suppression.
- **Proper Crop Rotation**: Rotating crops prevents the build up of weed species that are adapted to a single crop, reducing the weed seed bank over time.
- **Inter Cropping**: Growing two or more crops together in the same field increases crop diversity and covers

the soil more effectively than a single crop, thus preventing weeds from accessing light and nutrients.

- **Stale Seed Bed**: Weeds are allowed to germinate in a well-prepared field by applying irrigation or waiting for rainfall to encourage weed seed germination before the crop is planted. Emerged weeds are destroyed through shallow tillage or by applying a non-residual herbicide like paraquat.
- **Vigorous, fast-growing Crop Varieties**: These varieties are better competitors against weeds because they establish quickly, outgrowing and shading weeds early in the season.
- **Proper Fertilizer Placement**: Fertilizers should be placed where crop roots can access them most efficiently. This ensures that the crops benefit more from the nutrients, leaving fewer resources for the weeds.
- **Efficient Irrigation Practices**: Timely and efficient irrigation allows crops to establish quickly, giving them an advantage over weeds, which often require similar conditions to germinate.

C) Biological Weed Control

Involves use of living organisms such as insects, herbivorus fish, disease causing organisms, competitive plants to limit their infestation

- **Insects** The larvae of *Cactoblastis cactorum*, a moth bores and feed on the cactus prickly pear (*Opuntia spp.*) contributing its management.
- The larvae of *Crocidosema lantana*, a moth consume flowers and fruits of *Lantana camara* significantly weakening the plant and reducing its reproductive capacity.
- **Herbivorous Fish:** Fish like Tilapia control algal blooms in aquatic environments. They feed on algae, helping to maintain water quality and ecosystem health.
- **Common Carp:** Uproot submerged aquatic weeds in search of food.
- **Snails:** Certain snail species feed on submerged aquatic weeds. Snails grazing limits the spread of invasive aquatic vegetation, promoting a balanced ecosystem.



Fig: Biological Weed Control

- **Bio-Herbicides/Myco-Herbicides**: It involve the application of plant pathogens, typically fungi that are expected to target and kill specific weeds. The process includes:

- **Culturing Native Pathogens**: Native fungal pathogens are cultured artificially and sprayed on target weeds like post-emergence herbicides. This method allows localized control of weeds prevalent in crop areas
- **Fungal Pathogens**: Bacteria and viruses usually require natural openings or vectors to penetrate host plants effectively whereas fungal spores or their fermentation products when sprayed directly initiate infection and damage the target weeds. That is the reason fungi are often preferred over bacterial or viral pathogens for bio-herbicide applications. Fungi are often preferred over bacterial or viral pathogens for bio-herbicide applications.

- **Allelopathic Crops**: Some plants release chemicals that inhibit the growth of neighboring plants, thus helping to control weeds.

D) Chemical Control Methods

Chemical Herbicides also commonly known as Weedicides can be classified based on several attributes.

- **Based on Mode of Action**

Type	Particulars	E.g.
Contact herbicides	• It has limited mobility. • They do not translocate within the plant • It kills only the exposed tissue.	Paraquat, diquat, propanil, oxyfluorfen
Systemic / translocated herbicides	• It is absorbed by the plant and move from the application site to other parts of the plant • It affects the entire plant.	Atrazine, pendimethalin, glyphosate, metribuzin

*Atrazine is partially systemic, mostly pre-emergence and selective, making it versatile in weed control

- **Based on Time of Application**

Type	Particulars	E.g.
Pre-plant incorporation (PPI):	• Herbicide is applied and incorporated into the soil usually one day before crop sowing, to prevent volatilization loss. • It is suitable for herbicides with high vapor pressure.	Fluchloralin, trifluralin, EPTC
Pre-emergence	• Herbicides are applied after sowing of crop (within 1–2 days) but before crop and weed emergence. • It acts on weeds before they start growing.	Atrazine pendimethalin, alachlor, butachlor
Post-emergence	• Herbicide if applied after both crop and weed emergence, generally 15–30 days after sowing. • It targets weeds without harming the crop.	Isoproturon, sulfosulfuron, metsulfuron

- **Based on Selectivity**

Type	Particulars	E.g.
Selective herbicides	• It is designed to target specific groups of weeds without harming the crops.	Most pre and post-emergence herbicides used in field crops.
Non-selective herbicides	• It kill any plant species they come in contact with regardless of whether they are crops or weeds.	Paraquat, diquat

- **Based on Spectrum of Weed Control**

Type	Particulars	E.g.

Narrow spectrum herbicides	• It targets specific groups of weeds without affecting other plants, allowing for more precise weed management.	Metsulfuron-methyl.
Broad spectrum herbicides	• It is effective against a wide range of weed species viz. grasses, broad leaved plants and sedges in a single application, reducing the need for multiple herbicides	Atrazine, Pendimethalin, Imazethapyr

- **Based On-site of Application**

Type	Particulars	E.g.
Soil applied /Soil active herbicide	• It is applied directly to the soil • It targets germinating weeds preventing emergence by acting on weed seeds and seedlings present in the soil.	Fluchloralin, Trifluralin. Pendimethalin Alachlor.
Foliar applied herbicide	• It is sprayed on the foliage of plants or non-crop weeds to control their growth. • It is absorbed through the leaves, leading to death of plants.	Isoproturon, Sulfosulfuron, Paraquat Glyphosate

How Chemical Control leads to Resistance

Every weed population contains a small number of naturally resistant individuals due to genetic diversity. Frequent application of a single herbicide is the most significant factor for permanent evolutionary change in weeds leading to a population that is no longer effectively controlled by that herbicide. Susceptible weeds are killed, while the resistant individuals survive and set seed passing genes to their offspring, Using herbicides as the sole weed control strategy, without incorporating other practices like cultivation, cover crops, or crop rotation, increases the resistance risk.

Advantages of Integrated Weed Management (Iwm)

- Prevents Resistance in Weeds to Herbicides
- Reduced risk of herbicide residue in soil or plant:
- Environmental safety:
- Increase in crop yield per unit area, crop production and crop quality.
- Suitable for High Cropping Intensity.

Emerging Technologies - AI-based Weed recognition and its Management

Artificial intelligence uses computer vision and machine learning to identify weeds in real-time, enabling automated and targeted removal with reduced herbicide use and labour. Ground-based robots with AI cameras navigate fields to identify and remove weeds. The AI is trained to differentiate between crops and various weed species based on their visual characteristics. Drones can map weed-infested areas and either apply targeted treatments or guide ground-based robots. The technology supports precision agriculture through methods like spot-spraying of herbicides only to the weed or using physical methods like lasers or mechanical weeding to destroy the weed. Some mobile apps use AI to identify plants from a photo, which can be used by farmers for on-the-spot identification. It enables targeted removal of weeds, decreases reliance on chemical sprays which improves crop health, yield and leads to environmental benefits like less soil and groundwater contamination.



Fig: AI-based Weed recognition and its Management

Conclusion - By adopting an IWM strategy, producers can reduce reliance on chemical pesticides, minimize environmental harm, and achieve more sustainable and cost-effective weed control.

Module V: INTEGRATED PEST MANAGEMENT (IPM)

5.1. A. Importance of Pest and Disease Control in Agriculture

Integrated Pest and Disease Management (IPDM) is a smart and safe way to manage pests and diseases. It uses a mix of different methods such as cultural, mechanical, biological and chemical measures of pest and diseases management in a planned and balanced way. The main aim is to keep pest and disease levels below the economical threshold level without harming nature.

In IPDM, farmers first monitor their fields regularly and identify the pest or disease correctly. Then they take suitable control measures that include, field sanitation, clean cultivation, summer ploughing, timely sowing, use of healthy seeds, sowing resistant varieties, crop rotation and use of bio pesticides and natural enemies of pests. Chemical measures are used only when needed and in the right amount. By following IPDM, farmers can protect their crops, reduce costs, improve soil health and get better yields safely and sustainably. This chapter explains how IPDM methods are used in fields to manage major pests and diseases effectively. (Zhou *et al*., 2024; Tratwal *et al.*, 2025).

1. Importance of pest and disease management

Pest and disease management plays a key role in protecting crops and improving farmers' income. Insects, fungi, bacteria, and viruses can cause serious damage to crops which leads to **10–40% yield loss** every year. If farmers do not manage these problems in time, they may lose a large part of their harvest. Proper pest and disease control helps farmers grow healthy crops, reduce input costs, and earn better profits.

Using safe and balanced methods like Integrated Pest and Disease Management (IPDM) also protects the environment and human health. In Haryana, adoption of IPM in paddy fields reduced production costs and increased profits by about **20–30%** (Singh *et al.*, 2004). In Maharashtra, farmers using IPM in paddy gained about **19.84% higher yield** and reduced cost by **₹7,375.89 per hectare** (Nemade *et al.*, 2024). In Tamil Nadu, IPM in brinjal improved yield and income while reducing pesticide use (Kiruthika, 2013).

Pest and disease management also supports social and cultural well-being. It reduces health risks from pesticide exposure and encourages the use of traditional farming practices like crop rotation, timely sowing, and natural pest control. These practices not only protect crops but also preserve farmers' traditional knowledge and local biodiversity. Overall, effective pest and disease management strengthens the economy, safeguards the environment, and supports sustainable farming.

2. Diseases and their diagnosis

The abnormal growth and symptoms expression by plants due to infection of pathogens is called disease. Plant diseases affect the normal growth and health of crops. They are caused by different organisms such as fungi, bacteria, viruses, nematodes, and phytoplasmas (Annexure – I & II). Sometimes, poor soil, bad weather, or lack of nutrients can also make plants sick. Common symptoms of plant diseases include yellowing of leaves, wilting, spots, rotting, stunted growth, and drying of plants. To manage these problems properly, it is very important to **diagnose** the disease correctly.

Plant diseases are diagnosed by observing symptoms in the field and by testing samples in the laboratory also. In the field the pattern of infection, type of spots, and affected plant parts, their color and often visible symptoms are observed for deciding the diseases. In the laboratory microscopes and other tools are used to identify the disease-causing organism. Quick and correct diagnosis helps select the right control measures. Accurate diagnosis not only saves crops and reduces losses but also avoids unnecessary use of chemicals, protecting the environment and human health (**Kumar *et al.*, 2023; Gupta & Sharma, 2024).**

3. **Pests and their diagnosis:** The insects which damage the crops and influence the economical returns are considered as pests (Annexure III & IV). Different insect pests damage different parts of the plants. The first step in assessment of pest damage in field crops is to **regularly observe the crop**. Fields should be visited at least once a week and observed carefully at leaves, stems, flowers, and pods. Insects, eggs, larvae, and any signs of feeding or damage or even movement of insects should be observed. Simple tools like yellow sticky traps and pheromone traps help in detecting early pest activity such as whiteflies, aphids, or pod borers.



Fig: Cotton aphids



Fig: Stem borer in sugarcane



Fig: Brown Plant Hopper in Paddy

The next step is to **identify the type of pest and nature of damage.** Chewing insects like caterpillars and beetles eat leaves and bore into pods and fruits. Sucking pests like aphids, thrips, and whiteflies suck the plant sap, which causes curling, yellowing, and drying of leaves. Boring pests like stem borers and fruit borers make holes in stems, pods, or fruits and damage internal tissues. Correct identification helps in choosing the right management method.

After identifying the pest, **damage level is estimated** by counting the number of insects per plant, per leaf, or per square meter. This helps to know whether the pest level is serious enough to cause economic loss. Limits of **Economic Threshold Levels (ETL)** can be refereed. For example, in pigeonpea, control should begin when 1–2 larvae of pod borer are seen per plant. In cotton, spraying is needed when 8–10 whiteflies per leaf are found.

In short, successful pest management depends on a simple five-step process: **observe, identify, count, compare with threshold, and act accordingly.** Following this approach helps control pests in time, reduce unnecessary chemical use, save costs, and protect the environment while maintaining healthy and profitable crops (Dhaliwal *et al.*, 2015; Kumar *et al.*, 2023).

4. **Principles of disease management:** The disease management in crops is very important to harvest the good returns. As Plant diseases reduce crop growth, yield, and quality. To manage them, some basic rules should be followed. The main aim is to stop diseases before they spread and to protect the plants from damage.

   i. **Avoid the disease**: Many crop diseases may be stopped by avoiding the cause. Use of clean and healthy seeds and fields that did not have disease before are best to avoid the disease. Early sowing or crop rotation also helps to escape diseases. For example, early sowing of pigeonpea can help avoid sterility mosaic disease.
   ii. **Stop the entry of the disease**: The diseases entry should be prevented by avoiding entry of disease-causing organisms into new fields or areas. This is called exclusion. It includes using certified seeds, inspecting fields regularly, and following quarantine rules. For example, not bringing infected planting material helps stop the spread of banana bunchy top virus.
   iii. **Destroy the disease source**: The source of infection should be destroyed by removing and burning infected plants, cleaning crop residues, and ploughing the field after harvest. Removing weeds and alternate host plants also helps reduce the chance of new infections.
   iv. **Protect healthy plants**: Farmers can protect their crops before diseases attack. They can treat seeds with fungicides or bio-control agents like Trichoderma. Spraying suitable fungicides or using organic sprays before infection helps keep plants safe. For example, seed treatment protects seedlings from root rot and damping-off.
   v. **Use resistant varieties**: The best way to manage many diseases is to grow resistant or tolerant varieties. Scientists develop such varieties through breeding. These varieties can fight off or reduce the effect of the disease. For example, pigeonpea variety Maruti resists wilt, and some wheat varieties resist rust diseases.
   vi. **Cure the diseased plants**: Sometimes, farmers can cure or reduce disease after it appears. They can use hot water treatment, chemical dips, or tissue culture methods. For example, hot water treatment of sugarcane setts removes smut spores, and tissue culture helps produce virus-free banana and potato plants.
   vii. **Combine all methods**: The best approach is Integrated Disease Management (IDM). It means using many safe and suitable methods together, like clean seeds, crop rotation, resistant varieties, bio-control, and safe chemical use. This reduces disease, saves money, and protects the environment.

5. **Principles of pest management:** Pests damage crops and reduce yield, quality, and farmers' income. To manage pests effectively, one should follow a few basic principles. The main goal is to keep pest numbers below the level that causes economic loss, using safe and sustainable methods.

   i. **Prevention or avoidance: P**ests incidences can be prevented by choosing the right crop variety, sowing at the right time and keeping the field clean. Crop rotation, timely weeding, and proper spacing help reduce pest attack. For example, early sowing of cotton helps avoid pink bollworm.
   ii. **Monitoring and early detection: R**egular checking of fields for pest symptoms like holes, leaf damage, or eggs should be done. Using traps and light traps helps detect pest activity early. Early detection allows timely control before serious damage occurs.
   iii. **Cultural methods:** Simple farm practices can be followed to reduce pest buildup. Deep ploughing in summer destroys pest stages in the soil. Removing crop residues and weeds removes breeding places. Intercropping and balanced fertilizer use also reduces pest attacks naturally.
   iv. **Mechanical and physical control:** Practices like removing pests by handpicking, using traps or destroying infected parts are very effective. Using barriers, light traps and sticky traps are safe physical methods. Flooding or drying the field also kills some soil pests.
   v. **Biological control:** Use of natural enemies like ladybird beetles, Trichogramma, and spiders help in control of pests. These friendly insects eat or kill harmful pests. Applying bio-pesticides such as *Bacillus thuringiensis* (Bt) or neem-based products is also safe for the environment.
   vi. **Chemical control:** When pest infestation becomes severe, pesticides can be used carefully. Right chemical should be choosen with correct dose and proper spraying time. Overuse or wrong use of chemicals can harm beneficial insects, soil, and human health, so it must be done only when needed.
   vii. **Resistant varieties:** Growing pest-resistant crop varieties reduces the need for chemicals. For example, Bt cotton resists bollworms, and some paddy varieties resist stem borers and leaf folders.

viii. **Integrated Pest Management (IPM):** The best method is to combine all safe practices cultural, biological, mechanical, and need-based chemical control. IPM helps reduce pest problems, protect the environment, and save money while maintaining good yields.

6. Integrated Disease and Pest Management (IDPM)

Integrated Disease and Pest Management (IDPM) is is a smart and eco-friendly way to protect crops from both pests and diseases. In this method, farmers can use many safe and suitable practices together instead of depending only on chemicals. It starts by using clean and healthy seeds, resistant varieties and proper crop rotation to prevent problems (**Kumar *et al.*, 2023**). Regular field monitoring helps detect early signs of pest or disease attack. Use of biological methods like releasing friendly insects such as ladybird beetles or using bio-control agents like *Trichoderma* to keep harmful organisms under control are some of the best examples (**Ramesh *et al.*, 2024**). Mechanical methods like removing infected plants or setting up traps also help reduce damage. Only when pest or disease levels become high, farmers use pesticides or fungicides carefully and in the right dose **(Dhaliwal *et al.*, 2015**). By combining these practices, IDPM reduces crop loss, saves money, protects soil and water, and keeps the environment and people safe. It helps farmers grow healthy crops in a sustainable way **(Gupta & Sharma, 2024).**

5.1. B. Harmful and Beneficial insects.

5.1. C. Important species of pollinators, weed killers and scavengers and their importance in agriculture. Predators and Parasitoids

i. Harmful and Beneficial Insects in Agriculture

Harmful insects are those that damage crops, stored grains or useful plants. They feed on leaves, stems, roots, flowers, and fruits, reducing both yield and quality. Some insects like stem borers, fruit borers, aphids, whiteflies and jassids suck plant sap or bore into plant parts, making them weak and diseased (Dhaliwal *et al.*, 2015). Others, like termites and cutworms damage roots and seedlings. These insects also spread plant diseases caused by viruses, bacteria, or fungi. For example, whiteflies spread yellow mosaic disease in pulses, and aphids spread leaf curl in chili and mustard (Kumar *et al.*, 2022). If not controlled on time, harmful insects can cause heavy economic loss to farmers.

Farmers can identify insects by watching their shape, color, and the kind of work they do on plants. Correct identification helps farmers know which insects to control and which to protect. Harmful insects make holes, curl leaves, suck sap, or bore into stems and fruits. Beneficial insects eat harmful ones or visit flowers for nectar, some help in recycling of farm waste in to productive fertilizers like earth worms (**Singh & Kaur, 2023**).

Beneficial Insects, on the other hand, help farmers by controlling harmful pests or by improving crop production (Annexure - V). Predators like ladybird beetles, lacewings, and spiders eat aphids and other small pests (**Singh & Kaur, 2023**). Parasitoids such as *Trichogramma* lay their eggs inside pest eggs and stop them from hatching (**Gupta *et al.*, 2024**). Honeybees, butterflies, and other pollinators help in fruit and seed formation, increasing yield and quality. Some insects, like silkworms and bees, also give useful products such as silk, honey, and wax. By protecting and encouraging beneficial insects, farmers can reduce the use of chemicals, save money, and promote natural and healthy farming.

There are mainly three types of beneficial insects—predators, parasitoids, and pollinators. Predators like ladybird beetles, lacewings, and spiders eat harmful insects such as aphids, jassids, and whiteflies. Parasitoids such as *Trichogramma* and *Bracon* lay their eggs inside or on pest eggs and larvae, killing them before they grow (**Sharma *et al.*, 2022**). Pollinators like honeybees, butterflies, and bumblebees help plants in forming fruits and seeds by carrying pollen from one flower to another. Some beneficial insects, like silkworms and bees, also give useful products such as silk, honey, and wax. By conserving and encouraging

these helpful insects through eco-friendly farming, farmers can reduce pest attacks, get better yields, and maintain soil and environmental health in a sustainable way.

ii. Predators and Parasitoid insects

Predator and parasitoid insects are very useful in agriculture as they help control harmful pests naturally (Table 1). Predators like ladybird beetles feed on aphids, mealybugs, and scale insects (**Singh & Kaur, 2023**). Green lacewing larvae eat small pests such as whiteflies and thrips. Spiders also catch and eat many flying insects in the field. Parasitoids like *Trichogramma* wasps lay their eggs inside pest eggs, destroying them before they hatch (**Sharma *et al.*, 2022**). Braconid and Ichneumonid wasps attack caterpillars and other pest larvae. These natural enemies reduce pest populations, protect crops, and decrease the need for chemical pesticides, making farming more eco-friendly (**Gupta *et al.*, 2024**).

iii. Pollinating Insects:

Pollinating insects play a very important role in crop production (Table 2). They transfer pollen from one flower to another and help plants produce fruits and seeds (**Klein *et al.*, 2023**). Honey bees are the main pollinators for crops like sunflower, mustard, and fruit trees. Bumble bees help in pollinating tomato and brinjal, while butterflies and moths visit flowers and aid in pollination. Flies, beetles, and wasps also help pollinate many crops and wild plants. These insects increase crop yield, improve fruit quality, and maintain biodiversity in nature (**Singh & Sharma, 2024).**

Table 1: Predator and parasitoid insects useful in crop pest management

Sl. No.	Type	Insect Name	Target Pest	Use / Role in Agriculture
1	**Predator**	*Coccinella septempunctata* (Ladybird beetle)	Aphids, Mealybugs, Scale insects	Feeds on soft-bodied pests and protects crops
2	**Predator**	*Chrysoperla carnea* (Green lacewing)	Aphids, Whiteflies, Thrips	Larvae feed on sucking pests and reduce their population
3	**Predator**	Spiders	Many flying insects	Trap and eat insect pests in crop fields
4	**Predator**	*Orius insidiosus* (Minute pirate bug)	Thrips, Aphids, Mites	Kills small pests on leaves and flowers
5	**Parasitoid**	*Trichogramma chilonis* (Egg parasitoid wasp)	Eggs of borers and caterpillars	Parasitizes pest eggs, preventing hatching
6	**Parasitoid**	*Bracon hebetor* (Braconid wasp)	Caterpillars of Helicoverpa, Spodoptera	Lays eggs inside larvae, killing them
7	**Parasitoid**	*Campoletis chlorideae* (Ichneumonid wasp)	Caterpillars of bollworms	Controls major lepidopteran pests in pulses and cotton

Table 2: Important beneficial insects helping in pollination in crops

Sl. No.	Insect	Examples of Crops Pollinated
1	**Honey bee**	Sunflower, Mustard, Cotton, Apple, Mango
2	**Bumble bee**	Tomato, Brinjal (Eggplant), Clover
3	**Butterfly**	Jasmine, Marigold, Hibiscus, Citrus fruits
4	**Moth**	Jasmine, Yucca, Night-blooming flowers
5	**Beetle**	Custard apple, Sugar apple, Water lily

6	**Fly (Hover fly, House fly)**	Onion, Carrot, Coriander
7	**Wasp**	Fig, Guava, Some wild flowers

vii. **Weed Killer Insects:**

Some insects are very useful in controlling harmful weeds in agriculture (Table 3). They feed on weed plants and help reduce their growth naturally. The leaf beetle *Zygogramma bicolorata* feeds on Parthenium, while weevils *Neochetina eichhorniae* and *N. bruchi* control water hyacinth (**Julien & Griffiths, 2023**). The moth *Cactoblastis cactorum* destroys prickly pear cactus, and the weevil *Cyrtobagous salviniae* checks the spread of Salvinia. The lace bug *Teleonemia scrupulosa* reduces Lantana growth, and the beetle *Agasicles hygrophila* controls alligator weed (**Patel *et al.*, 2022**). These insects act as natural weed killers and reduce the need for chemical herbicides.

viii. **Scavenger Insects:**

Scavenger insects feed on dead and decaying plant and animal matter. They play an important role in keeping the environment clean and improving soil health Table 4). Common scavenger insects include dung beetles, carrion beetles, and certain flies (**Nichols *et al.*, 2023**). Dung beetles bury animal dung in the soil, which increases soil fertility and aeration. Carrion beetles and flies help decompose dead animals and return nutrients to the soil (**Holter *et al.*, 2022**). By breaking down organic waste, scavenger insects recycle nutrients, improve soil structure, and reduce the spread of diseases, making them very beneficial for sustainable agriculture.

Table 3: Weed killer insects useful in weed control

Sl. No.	Insect Name	Target Weed	Remarks / Use
1	*Zygogramma bicolorata* (Leaf beetle)	*Parthenium hysterophorus* (Congress grass)	Feeds on leaves and flowers, effectively controls Parthenium weed
2	*Neochetina eichhorniae* (Weevil)	*Eichhornia crassipes* (Water hyacinth)	Damages leaves and petioles, reducing growth and spread of water hyacinth
3	*Neochetina bruchi* (Weevil)	*Eichhornia crassipes* (Water hyacinth)	Works along with *N. eichhorniae* for better control
4	*Cactoblastis cactorum* (Cactus moth)	*Opuntia spp.* (Prickly pear cactus)	Larvae feed inside cactus pads, destroying the plant
5	*Cyrtobagous salviniae* (Weevil)	*Salvinia molesta* (Water fern)	Feeds on leaves and buds, controls the floating weed *Salvinia*
6	*Teleonemia scrupulosa* (Lace bug)	*Lantana camara*	Sucks sap from leaves and reduces plant growth
7	*Agasicles hygrophila* (Leaf beetle)	*Alternanthera philoxeroides* (Alligator weed)	Feeds on leaves and suppresses the weed effectively

Table 4: Scavenger insects useful in agriculture

Sl. No.	Insect Name	Type	Main Activity	Benefit in Agriculture
1	*Scarabaeus* spp. (Dung beetle)	Beetle	Feeds on and buries animal dung	Improves soil fertility, aeration, and nutrient recycling
2	*Aphodius* spp. (Dung beetle)	Beetle	Breaks down dung and organic matter	Enhances soil structure and reduces pest breeding sites
3	*Necrophila* spp. (Carrion beetle)	Beetle	Feeds on dead animals	Helps in decomposition and nutrient recycling

4	*Sarcophaga* spp. (Flesh fly)	Fly	Feeds and breeds on decaying animal matter	Aids in quick decomposition of organic waste
5	*Musca domestica* (House fly)	Fly	Feeds on decaying materials	Helps in organic matter breakdown (though also a minor pest)
6	*Dermestes* spp. (Hide beetle)	Beetle	Feeds on dry animal remains	Assists in cleaning carcasses and recycling nutrients

vi. Pathogenic Microbes

These including fungi, bacteria, viruses, and nematodes—pose serious threats to crop plants, leading to reduced yields, poor quality and sometimes complete crop failure. Fungal pathogens like *Fusarium oxysporum*, studied by **Ekwomadu (2023),** cause vascular wilt in crops such as tomato, banana, and chickpea, severely affecting production. Bacterial pathogens, including *Xanthomonas axonopodis* pv. *manihotis*, are responsible for bacterial blight in cassava, as described by **Mwangi (2023)** and can spread rapidly through contaminated tools, seeds, and water. Viral pathogens, which cause mosaic and yellowing symptoms, are transmitted by insect vectors, mechanical injury, or infected seeds, making their management challenging. These pathogens are further spread due to global trade, climate change and intensive monoculture farming. Understanding the life cycles of these microbes and implementing integrated disease management strategies, including crop rotation, resistant varieties, and biological control, is essential for maintaining crop health and ensuring food security.

vii. Beneficial Microbes

Beneficial microbes play a vital role in improving soil health and crop productivity. They help in nutrient cycling, disease control, and plant growth promotion (Table 5). Nitrogen-fixing bacteria like *Rhizobium* and *Azotobacter* convert atmospheric nitrogen into a usable form for plants (**Bhattacharyya & Jha, 2012**). Phosphate-solubilizing bacteria and mycorrhizal fungi make nutrients more available to roots. Blue-green algae such as *Anabaena* and *Nostoc* enrich the soil in paddy fields by fixing nitrogen. Microbes like *Trichoderma* and *Pseudomonas fluorescens* protect crops from harmful pathogens and promote healthy root growth (**Verma *et al.*, 2023**). Decomposer microbes break down organic waste into humus, improving soil structure and fertility. Overall, beneficial microbes reduce the need for chemical fertilizers and pesticides, making farming more sustainable and eco-friendly.



Fig: Beneficial insects



Fig: Harmful insect

Table 5: Important beneficial microbes helping in crop cultivation

Sl. No.	Type of Microbe	Name/Example	Role in Agriculture
1	**Nitrogen-fixing bacteria**	*Rhizobium*, *Azotobacter*, *Azospirillum*	Fix nitrogen from the air and make it available to plants, improving soil fertility
2	**Phosphate-solubilizing bacteria**	*Bacillus*, *Pseudomonas*	Convert insoluble phosphate into soluble form for plant uptake
3	**Mycorrhizal fungi**	*Glomus*, *Gigaspora*	Help roots absorb more water and nutrients, especially phosphorus
4	**Blue-green algae (Cyanobacteria)**	*Anabaena*, *Nostoc*	Fix atmospheric nitrogen in paddy fields
5	**Plant growth–promoting bacteria**	*Bacillus subtilis*, *Pseudomonas fluorescens*	Produce growth hormones and protect roots from diseases
6	**Decomposer microbes**	*Trichoderma*, *Aspergillus*, *Penicillium*	Break down organic matter into nutrients, improving soil health
7	**Biocontrol fungi and bacteria**	*Trichoderma harzianum*, *Pseudomonas fluorescens*	Suppress plant pathogens and reduce the need for chemical pesticides
8	**Biofertilizer combinations**	*Azolla–Anabaena*, *Rhizobium–Legume symbiosis*	Increase nutrient availability and crop yield naturally

Conclusion

Pests and diseases can cause serious damage to crops and reduce farmers' income if not managed properly. Controlling them is essential to protect yields, maintain crop quality and ensure food security. Farmers can use different methods such as cultural, mechanical, biological and chemical measures to manage pests and diseases effectively. Integrated Pest and Disease Management (IPDM) combines these methods in a balanced way to reduce crop loss, save money and protect the environment. Beneficial insects like predators, parasitoids, pollinators, and scavengers naturally control pests, improve pollination and recycle nutrients. Similarly, beneficial microbes improve soil health, provide nutrients and protect plants from harmful pathogens. By using IPDM and promoting helpful insects and microbes, farmers can grow healthy crops, reduce chemical use, improve soil and environmental health and practice sustainable agriculture. Overall, proper pest and disease management ensures better yields, higher profits and safer farming.

Annexure I: List of some important diseases and their causal agents in major field crops

Crop	Disease	Causal Organism
Paddy (Rice)	Blast	*Magnaporthe oryzae*
	Bacterial Leaf Blight (BLB)	*Xanthomonas oryzae* pv. *oryzae*
	Sheath Blight	*Rhizoctonia solani*
	False Smut	*Ustilaginoidea virens*
	Brown Spot	*Bipolaris oryzae*
Cotton	Bacterial Blight	*Xanthomonas citri* subsp. *Malvacearum*
	Grey Mildew	*Ramularia areola*
	Alternaria Leaf Spot	*Alternaria macrospora*

	Fusarium Wilt	*Fusarium oxysporum* f. sp. *Vasinfectum*
	Root Rot	*Rhizoctonia bataticola*
Pigeonpea	Fusarium Wilt	*Fusarium udum*
	Sterility Mosaic Disease (SMD)	Pigeonpea sterility mosaic virus (transmitted by *Aceria cajani*)
	Phytophthora Blight	*Phytophthora cajani*
	Alternaria Leaf Spot	*Alternaria alternata*
	Cercospora Leaf Spot	*Cercospora indica*
Wheat	Leaf Rust	*Puccinia triticina*
	Stem Rust	*Puccinia graminis* f. sp. *tritici*
	Stripe (Yellow) Rust	*Puccinia striiformis* f. sp. *tritici*
	Powdery Mildew	*Blumeria graminis* f. sp. *tritici*
	Karnal Bunt	*Tilletia indica*
	Loose Smut	*Ustilago tritici*
	Leaf Blight	*Bipolaris sorokiniana*
Sugarcane	Red Rot	*Colletotrichum falcatum*
	Smut	*Sporisorium scitamineum*
	Ratoon Stunting Disease (RSD)	*Leifsonia xyli* subsp. *xyli*
	Wilt	*Fusarium moniliforme*
	Leaf Spot	*Helminthosporium sacchari*
Mungbean (Green Gram)	Yellow Mosaic Disease (YMD)	Mungbean yellow mosaic virus (transmitted by whitefly)
	Cercospora Leaf Spot (CLS)	*Cercospora canescens*
	Powdery Mildew	*Erysiphe polygoni*
	Anthracnose	*Colletotrichum truncatum*
	Web Blight	*Rhizoctonia solani*
Urdbean (Black Gram)	Yellow Mosaic Disease (YMD)	Urdbean yellow mosaic virus (transmitted by whitefly)
	Cercospora Leaf Spot	*Cercospora canescens*
	Anthracnose	*Colletotrichum truncatum*
	Powdery Mildew	*Erysiphe polygoni*
	Web Blight	*Rhizoctonia solani*
Mustard /Rapeseed	Alternaria Blight	*Alternaria brassicae*
	White Rust	*Albugo candida*
	Downy Mildew	*Peronospora parasitica*
	Sclerotinia Stem Rot	*Sclerotinia sclerotiorum*
	Powdery Mildew	*Erysiphe cruciferarum*
Chickpea	Fusarium Wilt	*Fusarium oxysporum* f. sp. *ciceris*
	Dry Root Rot	*Rhizoctonia bataticola*
	Ascochyta Blight	*Ascochyta rabiei*
	Botrytis Grey Mold (BGM)	*Botrytis cinerea*
	Collar Rot	*Sclerotium rolfsii*

Annexure II: List of some important diseases and their causal agents in major fruits and vegetable crops

Crop	Disease	Causal Organism
Mango	Powdery Mildew	*Oidium mangiferae*
	Anthracnose	*Colletotrichum gloeosporioides*
	Bacterial Canker	*Xanthomonas campestris pv. mangiferaeindicae*
	Sooty Mould	Associated with honeydew from hoppers (fungal complex)
Banana	Panama Wilt	*Fusarium oxysporum f. sp. cubense*
	Sigatoka Leaf Spot / Yellow Sigatoka	*Mycosphaerella musicola*
	Bunchy Top	Banana bunchy top virus (BBTV)
	Banana Mosaic	Cucumber mosaic virus (CMV)
Papaya	Papaya Ring Spot	Papaya ring spot virus (PRSV)
	Powdery Mildew	*Oidium caricae*
	Anthracnose	*Colletotrichum gloeosporioides*
	Root Rot	*Pythium aphanidermatum*, *Phytophthora palmivora*
Guava	Wilt	*Fusarium oxysporum f. sp. psidii*
	Anthracnose	*Colletotrichum gloeosporioides*
	Fruit Canker	*Pestalotia psidii*
	Algal Leaf Spot	*Cephaleuros virescens*
Citrus (Orange, Lemon, etc.)	Canker	*Xanthomonas axonopodis pv. citri*
	Greening / Huanglongbing	*Candidatus Liberibacter asiaticus*
	Gummosis	*Phytophthora spp.*
	Tristeza	Citrus tristeza virus (CTV)
Grapes	Downy Mildew	*Plasmopara viticola*
	Powdery Mildew	*Uncinula necator*
	Anthracnose	*Elsinoë ampelina*
	Bacterial Blight	*Xanthomonas campestris pv. viticola*
Tomato	Early Blight	*Alternaria solani*
	Late Blight	*Phytophthora infestans*
	Bacterial Wilt	*Ralstonia solanacearum*
	Leaf Curl	Tomato leaf curl virus (ToLCV)
	Mosaic	Tomato mosaic virus (ToMV)
Brinjal (Eggplant)	Phomopsis Blight	*Phomopsis vexans*
	Wilt	*Fusarium oxysporum f. sp. melongenae*
	Collar Rot	*Sclerotium rolfsii*
	Little Leaf	Phytoplasma (vector: *Hishimonus phycitis*)
Chilli / Capsicum	Anthracnose / Fruit Rot	*Colletotrichum capsici*
	Leaf Spot	*Cercospora capsici*
	Dieback	*Colletotrichum gloeosporioides*
	Leaf Curl	Chilli leaf curl virus (ChiLCV)
	Damping Off	*Pythium spp.*, *Rhizoctonia solani*
Okra (Bhindi)	Yellow Vein Mosaic	Okra yellow vein mosaic virus (OYVMV)
	Fusarium Wilt	*Fusarium oxysporum f. sp. vasinfectum*
	Powdery Mildew	*Erysiphe cichoracearum*
	Cercospora Leaf Spot	*Cercospora abelmoschi*

Cabbage and Cauliflower	Black Rot	*Xanthomonas campestris pv. campestris*
	Downy Mildew	*Peronospora parasitica*
	Alternaria Leaf Spot	*Alternaria brassicae*, *A. brassicicola*
	Club Root	*Plasmodiophora brassicae*
Potato	Late Blight	*Phytophthora infestans*
	Early Blight	*Alternaria solani*
	Black Scurf	*Rhizoctonia solani*
	Common Scab	*Streptomyces scabies*
Onion and Garlic	Purple Blotch	*Alternaria porri*
	Downy Mildew	*Peronospora destructor*
	Stemphylium Blight	*Stemphylium vesicarium*
	Basal Rot	*Fusarium oxysporum f. sp. cepae*
Cucurbits (Bitter gourd, Melon, Pumpkin, etc.)	Downy Mildew	*Pseudoperonospora cubensis*
	Powdery Mildew	*Erysiphe cichoracearum*, *Sphaerotheca fuliginea*
	Anthracnose	*Colletotrichum lagenarium*
	Mosaic	Cucumber mosaic virus (CMV), Watermelon mosaic virus (WMV)
	Fusarium Wilt	*Fusarium oxysporum f. sp. niveum*

Annexure III: List of some important pests in major field crops

Crop	Major Pests	Scientific Name
Paddy (Rice)	Rice Stem Borer	*Scirpophaga incertulas*
	Brown Planthopper (BPH)	*Nilaparvata lugens*
	Green Leafhopper	*Nephotettix virescens*
	Rice Leaf Folder	*Cnaphalocrocis medinalis*
	Gall Midge	*Orseolia oryzae*
	Rice Hispa	*Dicladispa armigera*
	Gundhi Bug (Rice Bug)	*Leptocorisa acuta*
Cotton	Pink Bollworm	*Pectinophora gossypiella*
	Spotted Bollworm	*Earias vittella*
	American Bollworm	*Helicoverpa armigera*
	Whitefly	*Bemisia tabaci*
	Aphid	*Aphis gossypii*
	Jassid (Leafhopper)	*Amrasca biguttula biguttula*
	Thrips	*Thrips tabaci*
Pigeonpea	Pod Borer	*Helicoverpa armigera*
	Pod Fly	*Melanagromyza obtusa*
	Maruca Pod Borer (Webber)	*Maruca vitrata*
	Tur Plume Moth	*Exelastis atomosa*
	Leaf Webber	*Grapholita critica*
	Leaf Hopper	*Empoasca kerri*
Wheat	Termite	*Odontotermes obesus*
	Aphid	*Sitobion avenae*
	Armyworm	*Mythimna separata*
	Pink Stem Borer	*Sesamia inferens*
	Shoot Fly	*Atherigona naqvii*
	Brown Wheat Mite	*Petrobia latens*
Sugarcane	Early Shoot Borer	*Chilo infuscatellus*
	Internode Borer	*Chilo sacchariphagus indicus*
	Top Borer	*Scirpophaga excerptalis*

	Root Borer	*Emmalocera depressella*
	White Grub	*Holotrichia serrata*
	Pyrilla (Sugarcane Planthopper)	*Pyrilla perpusilla*
	Scale Insect	*Melanaspis glomerata*
Mungbean (Green Gram)	Whitefly	*Bemisia tabaci*
	Thrips	*Thrips palmi*
	Aphid	*Aphis craccivora*
	Pod Borer	*Helicoverpa armigera*
	Maruca Pod Webber	*Maruca vitrata*
	Leaf Miner	*Aproaerema modicella*
	Leaf Hopper	*Empoasca kerri*
Urdbean (Black Gram)	Whitefly	*Bemisia tabaci*
	Aphid	*Aphis craccivora*
	Thrips	*Thrips palmi*
	Pod Borer	*Helicoverpa armigera*
	Maruca Pod Webber	*Maruca vitrata*
	Leaf Webber	*Grapholita critica*
Rapeseed/Mustard	Mustard Aphid	*Lipaphis erysimi*
	Painted Bug	*Bagrada hilaris*
	Sawfly	*Athalia lugens proxima*
	Leaf Miner	*Chromatomyia horticola*
	Diamondback Moth	*Plutella xylostella*
Chickpea	Gram Pod Borer	*Helicoverpa armigera*
	Cutworm	*Agrotis ipsilon*
	Termite	*Odontotermes obesus*
	Aphid	*Aphis craccivora*
	Leaf Miner	*Aproaerema modicella*
	Thrips	*Thrips tabaci*

Annexure IV: List of some important Pests in major Fruits and Vegetable crops

Crop	Major Pests	Scientific Name
Mango	Mango Hopper	*Idioscopus clypealis*, *I. niveosparsus*
	Fruit Fly	*Bactrocera dorsalis*, *B. correcta*
	Stem Borer	*Batocera rufomaculata*
	Mealybug	*Drosicha mangiferae*
	Shoot Gall Psylla	*Apsylla cistellata*
Guava	Fruit Fly	*Bactrocera correcta*, *B. zonata*
	Bark Eating Caterpillar	*Indarbela tetraonis*
	Mealybug	*Ferrisia virgata*
	Thrips	*Scirtothrips dorsalis*
Banana	Banana Rhizome Weevil	*Cosmopolites sordidus*
	Pseudostem Borer	*Odoiporus longicollis*
	Aphid (vector of Banana Bunchy Top Virus)	*Pentalonia nigronervosa*
	Banana Leaf Roller	*Erionota torus*
Citrus (Lemon, Orange, etc.)	Citrus Leaf Miner	*Phyllocnistis citrella*
	Citrus Blackfly	*Aleurocanthus woglumi*
	Citrus Psylla	*Diaphorina citri*
	Fruit Sucking Moth	*Achaea janata*
	Aphid	*Toxoptera citricida*
Papaya	Papaya Mealybug	*Paracoccus marginatus*

	Fruit Fly	*Bactrocera dorsalis*
	Red Spider Mite	*Tetranychus cinnabarinus*
	Aphid	*Aphis gossypii*
Grapes	Thrips	*Rhipiphorothrips cruentatus*, *Scirtothrips dorsalis*
	Flea Beetle	*Scelodonta strigicollis*
	Mealybug	*Maconellicoccus hirsutus*
	Leaf Roller	*Sylepta lunalis*
Tomato	Fruit Borer	*Helicoverpa armigera*
	Whitefly (vector of Tomato Leaf Curl Virus)	*Bemisia tabaci*
	Aphid	*Aphis gossypii*, *Myzus persicae*
	Leaf Miner	*Liriomyza trifolii*
	Thrips	*Thrips tabaci*
Brinjal (Eggplant)	Shoot and Fruit Borer	*Leucinodes orbonalis*
	Aphid	*Aphis gossypii*
	Jassid (Leafhopper)	*Amrasca biguttula biguttula*
	Whitefly	*Bemisia tabaci*
	Epilachna Beetle	*Henosepilachna vigintioctopunctata*
Chilli / Capsicum	Thrips	*Thrips palmi*
	Mite	*Polyphagotarsonemus latus*
	Fruit Borer	*Helicoverpa armigera*
	Aphid	*Aphis gossypii*
	Whitefly	*Bemisia tabaci*
Okra (Bhindi)	Fruit and Shoot Borer	*Earias vittella*, *E. insulana*
	Jassid (Leafhopper)	*Amrasca biguttula biguttula*
	Whitefly	*Bemisia tabaci*
	Aphid	*Aphis gossypii*
	Red Spider Mite	*Tetranychus urticae*
Cabbage and Cauliflower	Diamondback Moth	*Plutella xylostella*
	Cabbage Butterfly	*Pieris brassicae*
	Leaf Webber	*Crocidolomia binotalis*
	Aphid	*Brevicoryne brassicae*
	Cutworm	*Agrotis ipsilon*
Potato	Potato Tuber Moth	*Phthorimaea operculella*
	Aphid	*Myzus persicae*, *Aphis gossypii*
	Whitefly	*Bemisia tabaci*
	Cutworm	*Agrotis ipsilon*
Onion and Garlic	Thrips	*Thrips tabaci*
	Leaf Miner	*Liriomyza chinensis*
	Cutworm	*Spodoptera litura*
Cucurbits (Bitter gourd, Melon, Pumpkin, etc.)	Fruit Fly	*Bactrocera cucurbitae*
	Red Pumpkin Beetle	*Aulacophora foveicollis*
	Aphid	*Aphis gossypii*
	Whitefly	*Bemisia tabaci*

	Epilachna Beetle	*Henosepilachna vigintioctopunctata*

Annexure V: List of Beneficial Insects in agriculture

Type of Beneficial Insect	Example(s)	Role in Farming	Pests/Crops They Help With
Predators	Ladybird beetle (*Coccinella septempunctata*)	Eat soft-bodied insects like aphids and jassids	Cotton, pulses, vegetables
	Green lacewing (*Chrysoperla carnea*)	Feed on eggs and larvae of many crop pests	Paddy, pulses, vegetables
	Spiders	Catch and eat many flying and crawling insects	All field crops
	Dragonflies & damselflies	Eat mosquitoes and flying pests	Paddy fields and orchards
Parasitoids	*Trichogramma chilonis*	Lays eggs inside pest eggs and kills larvae before hatching	Cotton bollworm, sugarcane borers
	Bracon hebetor	Parasitizes larvae of caterpillars	Pulses, cotton, maize
	Aphidius colemani	Controls aphids naturally	Vegetables, mustard
Pollinators	Honeybee (*Apis mellifera*)	Helps in pollination and increases yield	Sunflower, mustard, fruits, vegetables
	Bumblebee (*Bombus spp.*)	Pollinates flowers and improves fruit set	Tomato, strawberry, and other fruits
	Butterflies	Transfer pollen while feeding on nectar	Flower and fruit crops
Producers	Silkworm (*Bombyx mori*)	Produces silk used in textiles	Mulberry
	Honeybee (*Apis spp.*)	Produces honey and wax	All flowering crops
Decomposers	Dung beetles, termites	Break down organic matter and improve soil health	All crops (indirect benefit)

5.2. A. Insect and Disease Symptoms and Difference among symptoms of Insect, Disease, Nutritional deficiencies and Physiological disorders

Plants are living systems constantly interacting with their environment. While they can adapt to certain stresses, various biotic (living) and abiotic (non-living) factors can cause visible changes in plant appearance and function. These visible changes are called symptoms — the plant's reaction to a cause of stress.Correct diagnosis of symptoms is critical in agriculture, horticulture, and forestry because:

- Misdiagnosis can lead to wrong control measures.
- Early detection allows timely intervention.
- Differentiating between insect damage, diseases, nutrient deficiencies, and physiological disorders ensures cost-effective management.

1. Symptoms Caused by Insects and Mites

Insects and mites damage plants by chewing, piercing-sucking, rasping, mining, or boring. They may inject toxins or transmit pathogens. Look for signs such as live insects, eggs, cast skins, webbing, and frass.

i. Chewing Damage: Leaf margins notched, holes between veins, complete defoliation in severe cases. Culprits include caterpillars (Lepidoptera), grasshoppers (Orthoptera), and beetles (Coleoptera).

ii. Piercing-Sucking Damage: Stippling, silvering, curling, yellowing, stunting; sticky honeydew and sooty mould. Aphids, whiteflies, thrips, and leafhoppers are typical.

iii. Mining & Boring: Sinuous mines within leaves; entrance/exit holes in stems/fruits with sawdust-like frass. Leaf miners, stem/fruit borers (e.g., brinjal shoot borer).

iv. Galls & Abnormal Growth: Swollen tissues formed by gall midges/wasps; distorted leaves or shoots.

2. Symptoms Caused by Diseases

Plant diseases are caused by pathogens like fungi, bacteria, viruses, phytoplasmas, and nematodes. Diseases are caused by fungi, bacteria, viruses, phytoplasmas, and nematodes. Accurate diagnosis depends on symptom type, host, environmental conditions, and the presence of signs.

i. Spots & Blotches: Discrete necrotic lesions; fungal spots often have concentric rings; bacterial lesions are water-soaked and angular.

ii. Blight: Rapid death of large areas of tissue, often following spots under conducive weather. **Wilt:** Loss of turgidity due to vascular blockage (e.g., Fusarium, Ralstonia).

iii. Mildews: Powdery (superficial white) vs. downy (underside downy growth under high humidity).

iv. Rusts & Smuts: Rust pustules release powdery spores; smuts form sooty spore masses in grains. **Viral Syndromes:** Mosaic/mottling, leaf curl, vein clearing, stunting—often systemic and distributed throughout the plant.

3. Nutritional Deficiency Symptoms

Nutrient problems are typically field-wide when soil-related, or localized when due to root damage or uneven fertigation. Remember: symptom location depends on nutrient mobility in the phloem.

Table 1: Quick guide to nutrient deficiency diagnosis

Nutrient	Mobility	Key Field Symptom	Typical Crops/Notes

Nitrogen (N)	Mobile	General chlorosis of older leaves, overall stunting	Cereals, vegetables; low protein
Phosphorus (P)	Mobile	Purpling, delayed maturity	Cool soils accentuate symptoms
Potassium (K)	Mobile	Marginal scorch in older leaves, lodging	Fruits quality, disease tolerance
Magnesium (Mg)	Mobile	Interveinal chlorosis on older leaves	Citrus, grapes
Sulfur (S)	Immobile	Uniform yellowing of young leaves	Looks like N deficiency but on young leaves
Iron (Fe)	Immobile	Interveinal chlorosis on youngest leaves	High pH soils, calcareous
Zinc (Zn)	Immobile	Short internodes, little leaf, interveinal chlorosis	Citrus, rice
Boron (B)	Immobile	Death of growing points, brittle leaves, cracked fruit	Fruits, oilseeds
Calcium (Ca)	Immobile	Tip burn, blossom end rot	Tomato, cabbage, apple

4. Physiological Disorders

Physiological disorders arise from temperature extremes, moisture stress, oxygen deprivation, salinity, chemical injury, and mechanical damage. No pathogen or insect is involved, and signs are absent. Symptoms often relate to recent weather or cultural practices.

- Sunscald and heat can cause bleached fruit patches and bark injury.
- Frost/freezing leads to water-soaked tissues that later blacken.
- Drought causes leaf scorch, marginal necrosis, blossom drop, fruit cracking post-rehydration.
- Waterlogging leads to root hypoxia, chlorosis, and wilting despite wet soil.
- Herbicide drift causes leaf cupping, strapping, or interveinal chlorosis in downwind areas.
- Salinity induces marginal burn and stunting, often in low-lying or poorly drained spots.

Table 2: Differentiating the Four Categories

Feature	Insect/Mite	Disease	Nutrient Deficiency	Physiological Disorder
Primary cause	Arthropods feeding	Fungi/Bacteria/Virus/ Nematode	Insufficient/imbalanced nutrient	Environment/chemicals
Key signs	Insects, frass, webbing, eggs	Spores, mycelium, ooze, nematodes	None	None
Symptom pattern	Irregular, holes, mined areas	Spots/blights/wilts, systemic patterns	Uniform by age of leaves	Linked to weather/field position
Field distribution	Patchy foci	Patchy or spreading foci	Uniform where soil-related	Uniform or tied to microclimate
Onset	Often sudden/seasonal flushes	Depends on environment; may be rapid	Gradual, chronic	Often sudden after event
Progression	Feeding continues unless controlled	Spreads plant-to-plant under conducive conditions	Persists until corrected	May cease when stress removed
Tests	Beat tray, sticky cards, sweep net	Microscopy, culturing, PCR/ELISA	Soil/leaf analysis	Weather/management records

5. Crop-wise Case Examples

Rice

- Insect: Brown planthopper—hopperburn, sooty mould on honeydew, insects cluster at base.
- Disease: Blast—diamond-shaped lesions; sheath blight—elliptical lesions near waterline.
- Nutrient: N deficiency—pale older leaves; K deficiency—weak straw.
- Physiological: Iron toxicity in lowland—bronzing.

Cotton

- Insect: Bollworms—bored squares/bolls with frass.
- Disease: Bacterial blight—angular leaf spots, black arm on petioles.
- Nutrient: Zn deficiency—little leaf; B deficiency—aborted squares.
- Physiological: Herbicide drift—leaf cupping/strapping.

Citrus

- Insect: Leaf miner—serpentine mines on flush leaves.
- Disease: Canker—raised corky lesions with yellow halo.
- Nutrient: Mg deficiency—interveinal chlorosis on older leaves; Fe deficiency—young leaves.
- Physiological: Fruit splitting after irregular irrigation.

Tomato

- Insect: Whiteflies—honeydew, leaf curl (and virus transmission).
- Disease: Early blight—target spots; Late blight—water-soaked lesions under cool, wet conditions.
- Nutrient: Calcium deficiency—blossom end rot.
- Physiological: Sunscald on exposed fruit.

Mango

- Insect: Hopper—sooty mould on inflorescences.
- Disease: Anthracnose—black lesions on panicles and fruit.
- Nutrient: Zn deficiency—rosetting; B deficiency—poor fruit set.
- Physiological: Spongy tissue disorder in fruit.

Conclusion

Effective plant health management depends on accurate symptom identification. Misinterpreting a virus symptom as a nutrient deficiency can cause crop loss. Field observation, history, and lab analysis ensure correct measures.

5.2. B. Mouth Parts

1. Chewing (Biting) Type

- **Structure:**
    - **Mandibles**: Strong, toothed jaws for cutting and crushing.
    - **Maxillae**: Assist in holding and manipulating food.
    - **Labrum (upper lip)** and **Labium (lower lip)**: Enclose mouthparts.
    - **Hypopharynx**: Tongue-like organ.
- **Function:** Bite and grind solid food.
- **Examples:** Grasshoppers, beetles, caterpillars.
- **Damage symptoms:** Holes in leaves, skeletonization, cut stems.

2. Piercing–Sucking Type

- **Structure:**
  - Mouthparts form a **long beak/rostrum**.
  - Mandibles & maxillae become **stylets** for piercing tissues.
  - Labium forms a sheath around stylets.
- **Function:** Suck plant sap or animal blood.
- **Examples:** Aphids, mosquitoes, leafhoppers, stink bugs.
- **Damage symptoms:** Leaf curling, yellowing, honeydew secretion.

3. Sponging Type

- **Structure:**
  - Proboscis with **labella** that have sponge-like channels.
- **Function:** Lap up liquid food; saliva liquefies solids first.
- **Examples:** Houseflies.
- **Damage symptoms:** Contamination of food, spread of diseases.

4. Siphoning Type

- **Structure:**
  - Coiled **proboscis** formed by elongated maxillae.
- **Function:** Suck nectar from flowers without piercing tissue.
- **Examples:** Butterflies, moths.
- **Damage symptoms:** Usually harmless to plants (except some moth larvae).

5. Chewing–Lapping Type

- **Structure:**
  - Chewing mandibles + tongue-like structure for lapping liquids.
- **Function:** Collect nectar/pollen while chewing wax or manipulating solid food.
- **Examples:** Honeybees, bumblebees.
- **Damage symptoms:** Beneficial for pollination.

6. Rasping–Sucking Type

- **Structure:**
  - Short, sharp mandibles scrape plant surfaces.
  - Maxillae suck up the exuding sap.
- **Function:** Rasp tissue and suck sap.
- **Examples:** Thrips.
- **Damage symptoms:** Silvery patches, distorted leaves, scars on fruits.

7. Cutting–Sponging Type

- **Structure:**

- Sharp mandibles/cutting organs + sponging mouthparts.

- **Function:** Cut through skin and sponge up blood/fluids.
- **Examples:** Horseflies.
- **Damage symptoms:** Painful bites, blood loss in livestock.

Summary Table

Type	Feeding Mode	Key Examples	Plant/Animal Effect
Chewing	Biting & grinding	Grasshopper	Holes in leaves
Piercing–Sucking	Sap/blood sucking	Aphid, mosquito	Curling, yellowing
Sponging	Lapping liquids	Housefly	Food contamination
Siphoning	Nectar sucking	Butterfly	Pollination
Chewing–Lapping	Chew solids + lap liquids	Honeybee	Pollination
Rasping–Sucking	Scrape & suck	Thrips	Silvery patches
Cutting–Sponging	Cut & lap fluids	Horsefly	Painful bites

5.2. C. Types of Larvae and Pupae – Differences between Nymph and Larva

Insects exhibit diverse developmental stages, which can broadly be classified into ametabolous, hemimetabolous, and holometabolous types of metamorphosis. The larval stage is a juvenile form in complete metamorphosis (holometabolous), while the nymph occurs in incomplete metamorphosis (hemimetabolous). This chapter describes the main types of larvae and pupae, and highlights the differences between nymphs and larvae.

1. Types of Larvae

Larvae are the immature, feeding stages of insects that undergo complete metamorphosis. They differ in body form, presence of legs, and degree of development.

- Polypod larvae: Have well-developed thoracic legs and abdominal prolegs; cylindrical body. Found in Lepidoptera (caterpillars).
- Oligopod larvae: Have well-developed thoracic legs but no abdominal prolegs; found in Coleoptera and Neuroptera.
- Apodous larvae: Legless; body soft and worm-like; common in Diptera (maggots) and some Hymenoptera.
- Campodeiform larvae: Elongated, flattened, with long legs; active predators; found in Neuroptera and some Coleoptera.
- Eruciform larvae: Cylindrical with a distinct head; have both thoracic legs and abdominal prolegs; typical caterpillar form.
- Scarabaeiform larvae: C-shaped, thick-bodied, sluggish; found in Scarabaeidae beetles (white grubs).

2. Types of Pupae

The pupal stage is a non-feeding, quiescent phase in holometabolous insects, during which larval tissues reorganize into adult structures.

- Obtect pupae: Appendages glued to the body by a hardened cuticle; found in butterflies and moths.
- Exarate pupae: Free appendages not glued to the body; found in beetles and lacewings.
- Coarctate pupae: Enclosed within the hardened cuticle of the last larval instar (puparium); typical in higher flies (Cyclorrhaphous Diptera).

3. Differences between Nymph and Larva

Feature	Nymph	Larva
• Metamorphosis type	• Incomplete (hemimetabolous)	• Complete (holometabolous)
• Wings in immature stage	• Wing buds present externally	• No wings or wing buds
• Resemblance to adult	• Resembles adult but smaller	• Looks completely different from adult
• Feeding habits	• Same as adult	• Often different from adult
• Habitat	• Usually same as adult	• May differ from adult
• Development	• Gradual change to adult	• Dramatic transformation during pupation

5.3. A. Integrated Pest Management (IPM)

5.3. B. Concepts and Principles of IPM – Economic Threshold Level (ETL) – Economic Injury Level (EIL) and General Equilibrium Position (GEP)

Integrated Pest Management (IPM) is a holistic approach to pest control that combines various strategies to manage pests effectively while minimizing environmental impact and economic costs. It involves the integration of cultural, biological, chemical, and mechanical control methods to prevent and control pests in a coordinated and sustainable manner. The significance of IPM extends beyond conventional pest control, playing a pivotal role in sustainable agriculture. By reducing reliance on chemical pesticides, IPM promotes environmental health, preserves beneficial organisms, and minimizes the development of pesticide resistance.

IPM allows farmers to manage diseases, insects, weeds and other pests in a cost-effective and environmentally friendly way

1. Importance of IPM

The demands of growing population require farmers to produce more crops on existing farm land. To increase yields requires continuous improvement of agricultural technologies to minimize crop losses. The challenge is to do this while protecting the environment; IPM is a big part of the solution. It is being adopted by the farmers for long-term, sustainable agriculture that achieves adequate, safe and quality food production improves farmer livelihoods and conserves non-renewable resources.

2. Benefits of IPM

IPM provides multiple benefits for society and the environment

I. Environmental Benefits:

ii. Reduced Chemical Usage:

- Minimized Environmental Impact: IPM's focus on targeted and selective pesticide use reduces overall chemical usage, minimizing negative effects on soil, water, and non-target organisms.
- Less Residual Pollution: Lower pesticide residues in the environment contribute to healthier ecosystems, benefiting biodiversity and overall ecological balance.

iii. Preservation of Beneficial Organisms:

- Ecosystem Balance: By sparing beneficial insects and organisms, IPM maintains a diverse and balanced ecosystem, allowing natural predators to control pest populations.
- Pollinator Protection: Reduced pesticide exposure preserves pollinators critical to crop production, ensuring continued pollination services.

B. Economic Benefits:

iv. Cost Savings:

- Targeted pesticide applications and the integration of multiple control methods decrease the need for expensive chemical treatments, leading to cost savings, improving crop yields, contributing to higher profitability for farmers.

v. Long-Term Sustainability:

- Resilient Agricultural Systems: IPM's focus on sustainable practices fosters resilient farming systems that are less vulnerable to pest outbreaks and enhance ecosystem health.

vi. Reduced potential for problems of pest resistance or resurgence.

vii. Increased consumer confidence in the safety and quality of food and fiber products.

3. Limitations:

- Requires more time to understand and implement than traditional pest management,
- May initially be more expensive
- Sometimes the bio-agents may become crop pests.
- It cannot be used for all pests

- It can be hard to determine when to use sprays,
- It doesn't work with all environments

4. IPM Components:

IPM requires competence in three areas: prevention and planning, monitoring and intervention.

i. Prevention and Planning

Many aspects of crop management are designed to prevent initial outbreaks of insects, diseases or weeds. Practical strategies (outlined below) can be combined and optimized for an IPM program.

- **Field selection**

- Growing crops in locations where they are best suited to climate, soil and topography provides them with optimal conditions from the start.

- **Variety selection**

- Selecting and cultivating crop varieties with inherent resistance to pests is a proactive measure in IPM. This reduces the susceptibility of crops to certain pests, minimizing the likelihood of infestations and offering a sustainable and genetic-based approach to pest management.

- **Cultural practices**

- **Crop rotation**: Crop rotation is most effective practice against pests that have a narrow host range and dispersal capacity. Hence if a non-host crop is grown after a host crop, it reduces the pest population e.g. cereals followed by pulses.
- **Ploughing the field**: Deep ploughing in the field exposes the hidden pupae or egg stages of insects and thus get killed.
- **Earthing up**: Sugarcane early shoot borer, potato tuber moth can be controlled by timely earthing up of the field. This prevents insects to lay their eggs.
- **Destruction of crop residues**: Pupae of insect remains inside the crop residue and can be controlled by destroying it.
- **Adjusting the time of sowing**: Early sowing in jowar escapes the shoot fly attack while early planting in rice reduces gall midge damage.
- **Intercropping**: sowing of different crops in alternate rows or in mixed like maize with a legume such as cowpea to help improve soil fertility and reduce weeds, sowing of flax in chickpea reduces wilt disease.
- **Trap cropping**: Two crops of same family can be grown together and after attack of pest minor crop is removed which is trap crop.
- **Resistant varieties**: Sowing crop varieties which are resistant to particular pest can be grown to avoid crop damage.
- **Balanced use of fertilizer**: Higher doses of nitrogenous fertilizers increases pest attack while potash fertilizers make plant more resistant.

ii. Monitoring and Identification

In the intricacy of Integrated Pest Management (IPM), effective monitoring and accurate identification of pest populations play a crucial role. This proactive approach allows for early detection of potential issues, enabling **timely** interventions and reducing the risk of widespread infestations. Automated systems based on **AI** have been developed to identify and monitor flies using e-trapping devices.

- **Economic Injury Level (EIL):** the pest density at which the cost of damage equals the cost of control.
- **Economic Threshold (ET or action threshold):** a lower pest level at which you should act to prevent population from reaching the EIL.

The emphasis is on management, not eradication. IPM holds that wiping out an entire pest population is often impossible, and the attempt can be expensive and unsafe. IPM programmes first work to establish acceptable pest levels, called thresholds levels, and apply controls if those thresholds are crossed. These thresholds are pest and site specific. Advanced modeling techniques and data analytics contribute to more accurate threshold determinations, optimizing resource allocation.

Intervention: Reducing economically damaging pests to acceptable levels may involve cultural, physical, biological and chemical control measures individually or in combination.

1. Cultural Control

Cultural control involves modifying farming practices to make the environment less favorable for pests. These methods are often low-cost and highly effective.

Key Cultural Practices

- **Crop Rotation**: Rotating crops (e.g., corn → soybean → wheat) disrupts pest life cycles and reduces soil-borne diseases.
- **Intercropping and Polyculture**: Growing multiple crops together (e.g., maize and beans) can confuse pests and attract beneficial insects.
- **Sanitation:** Removing diseased plants, crop residues, and weeds eliminates pest breeding sites.
- **Timing of Planting and Harvesting**: Early or late planting can help avoid peak pest activity (e.g., planting rice before the arrival of stem borers).
- **Resistant Varieties**: Using pest-resistant or tolerant crop varieties (e.g., Bt cotton, disease-resistant tomatoes) reduces pest damage.
- **Soil and Water Management**: Healthy plants are more resistant to pests. Proper irrigation, fertilization, and soil health practices support plant vigor.
- **Trap Cropping**: Planting a sacrificial crop (e.g., mustard around cabbage) to lure pests away from the main crop.

2. Biological Control

Biological control harnesses nature's own mechanisms to keep pest populations in check, promoting a balanced ecosystem without relying heavily on synthetic chemicals.

Predators and Parasitoids:

- In Nature's Army: Beneficial insects like ladybugs and parasitic wasps act as natural predators, preying on pest species.
- Precision Warfare: Predatory insects target specific pests, preventing outbreaks without harming non-target organisms.
- Ecosystem Harmony: Encouraging these natural allies helps maintain ecological balance and reduces the need for chemical interventions.

Example of predators

- Lady bird beetle: This insect feeds on aphids.
- *Chrysoperla carnea*: The larvae of this insect feed on all soft bodied insects like aphids, jassids, white flies, mealy bug, etc.
- *Cryptolaemus montrouzieri*: This insect feeds on mealy bugs on grapes.

Example of parasites

- Egg parasite: *Trichogramma chilonis* parasitizes eggs of *Helicoverpa armigera.*
- Larval parasite: *Bracon hebetor* parasitizes larvae of *H.armigera*.
- Pupal parasite: *Trichospilus pupivora* parasitizes pupae of coconut leaf eating caterpillar.
- Adult parasite: *Epiricania melanoleuca* parasitizes adults of sugarcane leaf hopper.
- Egg larval parasite: *Chelonus blackburni* parasitizes eggs of lepidopteron pests and comes out at larval stage by killing the pest.

Pathogens:

- Microbial Warriors: Certain pathogens, like fungi and bacteria, can be harnessed to infect and control pest populations.
- Species-Specific: Biopesticides derived from these natural pathogens are often species-specific, minimizing collateral damage.

- Environmental Safety: Unlike broad-spectrum chemical pesticides, microbial control agents are environmentally friendly, posing minimal risk to non-target organisms.

Example of pathogens

Bacteria: *Bacillus thuringiensis* develops disease in many lepidopterous pests. *B.papillae* develops disease in coleopterous pests.

Virus: Though there are many reports of entomopathogenic viruses, Nuclear Polyhedrosis Virus (NPV) and Granulosis Virus (GV) are commonly used in specific lepidopteron pest control.

Fungus: *Beauveria bassiana* is used for control of lepidopterous pests. *Metarrhizum anisoplae* develops green muscardine disease in root grubs and beetles. *Verticillium lecanii* develops disease in lepidopterous pests.

3. Mechanical and Physical Control

The physical aspects of pest control involve direct interventions to hinder pest access, reproduction, or movement, providing an alternative to chemical measures.

- **Targeted Capture:** Traps attract and capture specific pests, reducing their numbers without affecting non-target species.
- **Hands-On Approach:** Physically removing pests by hand or using tools is a direct and targeted method.
- **Community Engagement**: In some cases, involving local communities in manual pest removal can contribute to sustainable and localized pest control efforts.

4. Chemical control

Chemical crop are often the most cost-effective way of controlling infestations as part of an IPM strategy. Judicious use of chemicals is recommended in case of IPM when required. It is best to rely on chemical pesticides as a last resort in IPM.

Implementation of IPM

Integrated Pest Management (IPM) implementation requires a systematic approach encompassing planning, adaptation, and strategic decision-making for effective pest management while minimizing environmental impact.

5. Planning and Decision-Making

i. Risk Assessment: Assessing potential risks involves evaluating factors such as pest presence, crop susceptibility, and environmental conditions. Utilizing historical data and forecasting models helps in anticipating pest outbreaks and planning preemptive measures.

Developing an IPM Plan:

- Tailored Strategies: Creating a comprehensive IPM plan involves integrating various control methods specific to the crop, region, and pest dynamics.
- Timeline and Protocols: Establishing protocols for monitoring, thresholds for action, and response strategies ensures a structured and efficient approach.
- Continuous Evaluation: Regular review and adjustment of the plan based on monitoring results and feedback contribute to its effectiveness.

ii. Adoption and Adaptation

Farmer Training and Education:

- Knowledge Dissemination
- Capacity Building
- Behavioral Change: Farmer education fosters a mindset shift towards sustainable practices, promoting long-term adoption of IPM principles.

Challenges and Criticisms

1. Resistance Management: (i) Pest Adaptation and (ii) Need for Rotation

2. Integration with Conventional Practices:

- Mindset and Education: Resistance to change from traditional pest control methods to IPM practices can hinder widespread adoption.
- Transition Challenges:IPM may require initial investments, education, and adaptation, posing challenges to farmers accustomed to conventional practices.
- .

In **conclusion**, Integrated Pest Management (IPM) emerges as a comprehensive and environmentally responsible framework for pest control within agriculture. Continued research, innovation, and an unwavering commitment to evolving strategies will fortify our agricultural systems, ensuring sustainable and prosperous farming landscapes for generations to come.

How to start IPM on your farm

- **Map your fields & crops.** Note rotations, susceptible areas and irrigation.
- **Identify priority pests** for each crop (talk to local extension specialists).
- **Set up a simple scouting plan** and pick sampling methods.
- **Install a few traps** (pheromone or sticky) for key pests.
- **Collect baseline data** for one season — pest levels, natural enemies, yield.
- **Find local thresholds** (extension bulletins)
- **Adopt cultural practices** (rotation, sanitation, resistant varieties).
- **Plan a spray decision tree** what to do at each threshold (conserve beneficials).
- **Train workers** on scouting, PPE, and label reading.
- **Review & adapt** after each season; keep records and consult local IPM centers.

5.4. A. Storage pests and their Management

Stored grain pests are insects, mites, rodents, and microorganisms that attack food grains and other agricultural products during storage. These pests cause both quantitative and qualitative losses, including reduction in weight, nutritional value, germination ability, and market value. (Chakaraborty, 2012**)**

The Objective of Storage

- To maintain the quality of stored products after harvest and up to end use.

1. Sources of Storage Problem

Most storage problem arises from:

- Low quality seed placed in storage
- Seed being carried over for too long
- Seed stored in poor ventilated, hot or damp warehouse.

An increase in storage temperature leads to a higher respiration rate. As nutrients are consumed during respiration, it results in a loss of both weight and quality of the store produce.

Table 1: Major Storage Insect Pests and Rodent with Their Damage Symptoms

Insect pest	Scientific Name	Hosts and type of insect pest	Damage Symptoms
Rice weevil	*Sitophilus oryzae*	Rice, wheat, maize and primary internal feeder	Circular holes in grains, larvae feed inside, hollowed kernels
Lesser Grain Borer	*Rhyzopertha dominica*	Wheat, Maize, Millets, barley and primary internal feeder	Both adult and larvae damage grain, producing fine powder
Khapra Beetle	*Trogoderma granarium*	Wheat, Jowar, Rice, Pulses and primary external feeder	Larval feeding, , severe weight loss
Pulse Beetle	*Callosobruchus chinensis*	Pulses (gram, lentil) and primary internal feeder	Lays eggs on seeds; larvae bore inside and eat cotyledon
Rust Red Flour Beetle	T*ribolium castaneum*	Flour,broken grains, milled grains, dry fruits, corn flakes and secondary pest	Infests damaged grains, flour; causes bad odour and mould growth
Rice Moth	*Corcyra cephalonica*	Stored grains , other food and secondary pest	Larvae spin webbing and contaminate grain with frass
Rodents (Rat & Mice)	*Rattus rattus, Mus musculus*	Store food products and structural components	Gnawed grains and bags, urine smell, droppings, nesting material

(Chatterjee and Chakraborty, 2022)

2. Some Other Minor Stored Grain Insect Pests-

- Angoumois Grain Moth, Saw toothed Beetle, Ground nut Bruchid, Drug store beetle, Tamarin Beetle, Cigarette Beetle
- Book lice or Grain Mites-Mostly soft bodies pest feed on fungi & create problem of mold related deterioration of the grain

3. Effect of Temperature and Humidity on Storage Pests

- Most storage pests die at temperatures of below **5°C and above 45°C.**
- The optimum temperatures for the development of most pests lies mainly between **25 and 32°C**.
- At temperatures below **14°C and above 42°C** development generally does not take place
- The optimum relative humidity for most species is around 70°/o, with a minimum **of 25 - 40% and a maximum of 80 - 100%.**
- Very few species can survive in extremely **dry conditions,** such as-
- Saw toothed beetle **down to 10% R.H**.,
- Khapra beetle and Rust Red flour Beetle **down to 3% R.H**.

4. Management of Stored Grain Pests:

An IPM Approach commonly accepted key components:

- Storage hygiene
- **Cleaning and disinfecting the storage system (**Sanitation and Exclusion, Loading, Aeration, Inspection &Monitoring)
  - **Mechanical Control**
  - **Non Chemical Control**
  - **Chemical Control**

Storage Hygiene (Simple, Effective, Cheap)

- Keep storage areas clean.
- Clean storage rooms thoroughly after they are emptied
- Inspect storage room regularly to ensure they are vermin proof.
- Inspect the stored seeds once a week for any signs of insect infestation.

Cleaning and Disinfecting the Storage System –

- Clean storage containers, structures, equipment and bags thoroughly to prevent contamination of newly stored grain
- Treatment with amorphus silica/diatomeous earth once or twice a as a slurry ($6g/m^2$) or dust ($2g/m^2$)

Sanitation and Exclusion

- Begin with a clean secure storage structure and dry grain (Maintain moisture content <12 %)
- Clean out all old grain including from cracks, crevices, false floors and walls. Don't forget to empty any augers or conveyors of any leftover grain.
- Repair holes in roofs or walls, and patch all cracked and broken concrete

Loading and Aeration. Do not over fill bins the leveled grain surface should at least a few inches below lip of the bin

Cooling and Aeration

- Effectively slows insect activity by lowering temperature of store grains -
- It is dependent on cooler outside air availability, temperature of the stored crop, and presence of fans for air circulation.
- In summer months heating of surface layer can be reduced by mixing of Amorphus Silica(1kg/ton.) into the top 30cm of grain
- Panting the roof in northwestern side of the storage facility white can reduce surface heating
- It can also be used in combination with protectant chemical such as IGR (Diatomeus earth, *Bacillus thuringiensis*, Spinosad).

Inspection and Monitoring

- Pre-planned, regular & periodic
- During monsoon months- 15 days interval
- Sample should be drawn systematically with new modern device(Probe trap, Instrument by CIPHET)
- **Mechanical Destruction (Use of Entoleter)**
- High rpm (3000-4000 rpm) will kill insects and mites
- Milling and other processing equipment can mechanically destroy insect Pests

Non Chemical Control

Excessive moisture in stored foods is the major cause for fungal disease such as molds. Hence periodic drying of stored food in the hot sun is essential.

- Treatment of Gunny bags before Storing, treat the gunny bags with 10% Neem Kernel solution.

Use of Plant Products– Neem seed powder, Sweet Flag rhizome (Dried powder), and turmeric powder can be mixed at the rate of 1-2% volume of the grain. These provide effective control against store grain pest for up to 9 Months.

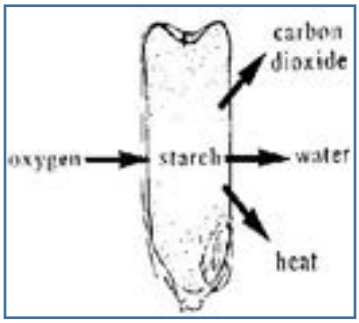
- While storing rice and pulses in metal containers, the addition of two red chilies, dried Neem leaves and a handful of Vitex leaves provides protection against storage pests
- Coconut oil, mustard oil, sesame oil at 15 ml per kg; Kao-line Powder 15 to 20 gm per kg; Dry clay/ Neem powder (10-15 gm/ kg); or Turmeric powder 30 gm/ kg can be applied to grains to prevent infestation by storage pests

Chemical Control

- Surface spraying with safe insecticides (e.g., Deltamethrin, Spinosad) around storage structures.
- Fumigation with Aluminum Phosphide under expert supervision.
- Rodenticides like Zinc Phosphide and Bromadiolone for rodent control.

Conclusion

Proper storage hygiene, drying, and monitoring are keys to preventing storage losses. Integrating cultural, biological and chemical, methods ensures effective and safe pest management.



Nutritional Changes during Storage



Rice weevil with grain



Khapra Beetle (grub) in Grain



Larva of Rice Moth



Probe trap for Monitoring

5.4. B. Rodents- Important major rodent sps. - Nature of damage- management - Rodenticides – zinc phosphide, aluminium phosphide, bromodilone; Fumigants - aluminium phosphide

Rats are among the largest and most fascinating groups of mammals. Since they belong to the class Mammalia and order Rodentia, they are commonly referred to as rodents. Out of over 100 species of rodents reported from India, only a limited number are regarded as pests in agriculture and storage. They form a very diverse group of mammals, including porcupines, squirrels, rats, gerbils, mice, mole rats, etc. (Babbar et,al; 2019).

Why Are Rats Important?

Rats are considered important due to their varied impact on human food systems and health. Globally, they pose a constant and widespread challenge to grain storage and preservation. Because of their voracious appetite, ability to contaminate food, and tendency to cause structural damage, these furry and highly adaptable animals can quickly infest grain silos, warehouses, and other storage facilities, resulting in significant losses.

Rodent Pest Species Found In India

1. Common Species Rat: (Both House & Field) i) Brown rat or Norway rat (*Rattus norvegicus*) ii) Larger bandicoot rat (*Bandicota indica)* 2. Field Rat i) Lesser bandicoot rat (*Bandicota bengalensis)* ii). Indian gerbil (*Tatera indica*) iii) Short tail bandicoot rat (Nesokia *indica*) iv) Soft furred field rat (*Rattus meltada) v*) Indian field mouse (*Mus booduga)* 3. House Rat: i) House rat, roof rat or black rat (*Rattus rattus*) ii) House mouse (*Mus musculus)* - (Prasad, 1999)

Signs of Rodent Infestation

i) Damage symptoms ii) Droppings iii) Runs and tracks iv) Live burrows and nests v) Footprints and trail marks along runways or paths vi). Urine stains and faeces

Damage Symptoms of Rodents

Rodents cause millions of dollars in damage to field crops, stored grain, and farm equipment each year. In addition to economic losses, they are major carriers of more than 60 diseases that can be transmitted to humans, companion animals, and livestock.

Common symptoms of rodent damage include

- Gnawing marks - evident on wooden structures, sacks, plastic containers, and stored materials (from Latin rodere = to gnaw; dent = teeth), often accompanied by droppings and urine stains.
- Cut crop stems at the base - especially in cereals like rice and wheat, leading to lodging and yield loss.
- Seedling damage -uprooting or cutting in nurseries and early growth stages of crops.
- Burrows and tunnels - found in field bunds, storage godowns, walls, and near irrigation channels, weakening structural integrity.

Rodent Management

A combination of physical, cultural, biological, and chemical control methods, tailored to the specific situation, can effectively manage rodent populations in stored grains. This integrated approach helps minimize the risk of resistance and environmental impact.

Cultural Control

Weed Control - Controlling weeds in the field and along bunds and dykes helps reduces the rat population
Clearance of Bush or Swamps- Clearing bushes and swamps near the rice fields helps reduce rodents by removing their shelter and food sources.
Synchronized Planting- Planting of crops at the same time in large areas helps reduce rodent attack.
Monoculture System- Reduction of alternative food sources for rodents can be achieved by encouraging monoculture.
Water level-Maintaining the water level in rice fields may prevent rodent damage.
Deep Ploughing- Deep ploughing breaks rodent burrows and forces them to move away.
Harvesting Time- Early harvesting saves grains from shattering and leaves some on the ground, which rodents may later eat.
Reduction of size and trimming of field bunds- Trimming and reducing field bunds during land preparation helps remove all live and old rodent burrows**.**
Mechanical Control

Use different traps such as snap taps, glue boards, live trap, trap barrier system, multi captured or wonder trap, ultra sound device etc. (Pic.1) to control rodent infestation.

Biological Control

A number of predators such as cats, dogs, snakes, owls, birds of prey (e.g., eagles), and mongooses (Pic.2), as well as parasites (viruses, bacteria, and protozoans), pathogens (helminths and arthropods), and reproductive inhibitors, contribute to the natural regulation of rodent populations. Keeping cats in houses also helps control the rat population.

Chemical Control

The use of rodenticides is the most common approach to control rodents in agricultural, rural and urban environments. The efficacy of a control programme depends upon the selection of an appropriate compound, its formulation and the method and timing of application.

I) Acute Poison – Given in a single dose it can kill a rat with one application. Repeated exposure may make rats bait-shy, so pre-baiting (bait without poison) is needed. Examples: sodium fluoroacetate, zinc phosphide, strychnine chloride, thallium sulphate.

a) Zinc Phosphide (single-dose poison) – Most commonly used rodenticide in India.

Mode of Action: After ingestion, it releases phosphine gas (PH_3) in the stomach, causing respiratory and cardiac failure.

Use: Pulverized, dull black powder is mixed with bait (e.g., grains). Rodents die within hours.

b) Aluminium Phosphide (Rodenticide)

Mode of Action: Releases phosphine gas on contact with moisture or air. This gas is a powerful respiratory poison against rodents.

Use: Tablets or pellets are placed in rodent burrows and in sealed structures like godowns or warehouses to trap the gas inside.

II) Chronic Rodenticides – Multiple dosages of blood anticoagulants are used for chronic poisoning. These include indandiones (Pivol, Rodione, and Valone) and hydroxycoumarins (Warfarin, Fumarin,and Racumin-First generation anticoagulation). Bromadiolone (Second-generation anticoagulant)

Mode of Action: Inhibits blood clotting, leading to internal bleeding and death within 3–5 days

Use: Mixed with baits such as grains or wax blocks for effective indoor and outdoor rodent control.

III) Fumigation (Aluminium Phosphide) – In cases of high infestation in sealed storage facilities, fumigation with specialist gaseous pesticides may be required.

Use: Rat tunnels are fumigated with aluminium phosphide (two 0.6 g tablets or half a tablet per burrow), and the holes are sealed with wet earth.

Mode of Action: Rats in the burrows are killed by phosphine gas released from the tablets upon contact with moisture.

Some Indigenous Technical Knowledge (ITK) for Rat Control

1. Erukku (*Calotropis gigantea*) and Notchi (*Vitex negundo*) are planted densely around fields as a living fence to deter rats.
2. Channampoo (*Cycas circinalis*) flowers are chopped into small pieces and placed throughout paddy fields; their unpleasant odour repels rats.
3. Poles fixed in the field are tied with pieces of palmyra (*Borassus flabellifer*) leaves. The rustling sound of the leaves scares away rodents.
4. Owl perches are installed near rat holes to encourage natural predation by owls.
5. Soaked rice is used as bait, as it attracts more rats.
6. Fresh cow dung is applied to both the fields and bunds to reduce rat infestation.

Conclusion

Rodent populations can be kept under threshold levels through effective management strategies. All the management tools, i.e. deep ploughing, trapping, proper application of baits and finally need based application of chemicals should be employed in a unified programme with community approaches for getting better results.



Woonder Trap



Sherman trap



Trap barrier system



Snakes



Dogs

5.5. Introduction to Conventional Pesticides for Pest Management -Botanical Insecticides- Plant derived Insecticides - Plant derived insecticides - neem based products - different commercial formulations containing azadirachtin, neem seed kernel extract, neem cake and their uses – nicotine, rotenone, plumbagin and pyrethrum – source – properties and uses

Conventional pest management relies heavily on synthetic chemical pesticides, which, although effective, often lead to issues such as pest resistance, environmental contamination, and harm to non-target organisms. Over time, these drawbacks have highlighted the need for more sustainable and eco-friendly approaches. In this context, botanical insecticides have gained prominence as natural alternatives, offering pest control with minimal ecological disruption.

Botanical Insecticides:

Botanical insecticides are pest control substances derived from plants or plant parts such as seeds, leaves, bark, or roots. Many plants naturally produce certain chemical compounds to protect themselves from insects and herbivores. These are called secondary metabolites (like alkaloids, terpenoids, and phenolics).

These natural compounds act as repellents, antifeedants, growth inhibitors, or toxins to insects. Scientists have identified and extracted such substances from plants and developed them into botanical insecticides that can be used to manage agricultural and household pests. Because they come from natural sources, botanical insecticides are generally biodegradable, less toxic to humans and animals and environmentally friendly, making them valuable tools in integrated pest management (IPM) programs.

Table 1. List of Major plants used to prepare botanical insecticides

S.no.	Plant Name	Scientific name and Family	Part Used for Extraction
1.	Neem	*Azadirachta indica* Meliaceae	Leaves,Seed Kernel, Bark
2.	Tobacco	*Nicotiana tobaccum* & *N. rustica*. Solanaceae	Leaves
3.	Chrysanthemum	*Chrysanthemum cinerariaefolium* Asteraceae	Dry flowers
4.	Derris	*Derris elliptica* & *D.lonchocarpus* Fabaceae	Roots
5.	Plumbago	*Plumbago zeylanica* Plumbaginaceae	Roots
6.	Pongamia	*Pongamia pinnata* Fabacaceae	Leaves
7.	Custard apple	*Annona squamosa* Annonaceae	Seeds, leaves
8.	Tropical lily	*Schoenocaulon officinale* Liliaceae	Seeds
9.	Ryania	*Ryania speciosa* Salicaceae	Stem

i. Neem:

It is a perennial tree distributed throughout India. Neem seed extract and oil have various biological compounds, including Azadirachtin, salannin, nimbin, epinimbin and nimbidin. These biological compounds present in neem have insecticidal, insect repellent, ovicidal, and antifeedant properties. They can also act as growth regulators.

Various neem-based insecticidal formulations can be developed and effectively incorporated into IPM programmes for the eco-friendly control of insect pests.

Preparation of Neem Seed Kernel Extract (NSKE 5%): Weigh 50 g of powdered neem seed kernels and soak them in 1 litre of water for about 8 hours. Stir the contents occasionally. After soaking, thoroughly squeeze the material to ensure maximum release of azadirachtin into the solution. Filter the extract through a muslin cloth and make up the volume to one litre with water. To improve adherence on plant surfaces, add 1 ml of a sticking agent such as Teepol, Triton, Sandovit or 2% soap solution before spraying.

Preparation of Neem Oil: Ripe neem fruits are collected to extract the pulp from them, and the seeds are dried in the shade. The dried seeds are then shelled, and the kernels are ground into a coarse powder. The oil is extracted either by cold pressing or solvent extraction, with cold pressing being preferred as it preserves the natural compounds. The extracted oil is filtered through a clean cloth to remove impurities. For spraying, about 30 ml of neem oil is mixed with one litre of water and a few drops of mild soap or emulsifier to help it blend well.

Neem Cake: It is a by-product obtained after extracting oil from neem seeds. The remaining solid residue after extracting neem oil from the seeds is known as neem cake.

The table given below presents a list of neem-based commercial insecticidal products that have been registered under the Central Insecticides Board and Registration Committee (CIB&RC), India.

Table 2. Neem-Based Products Registered In India

Product Name / Type	Active Ingredient (AI)
Neem Oil (Azadirachtin 0.03% min.)	Azadirachtin
Neem Oil (Azadirachtin 0.15% min.)	Azadirachtin
Neem Oil (Azadirachtin 0.30% min.)	Azadirachtin
Neem Seed Kernel Extract (NSKE 5%)	Botanical extract
Neem Oil (Pure Neem Oil 10000 ppm Azadirachtin)	Azadirachtin
Neem Oil (Azadirachtin 300 ppm, 1500 ppm, 3000 ppm, 10000 ppm)	Azadirachtin

ii. **Tobacco:**

Tobacco (*Nicotiana tabacum* and *N. rustica*) is a well-known botanical pesticide used for managing a wide range of insect pests. The main insecticidal compound in tobacco is nicotine(ranging from 2-14%), a natural alkaloid that acts as a neurotoxin affecting the nervous system of insects. Because of its fast action, tobacco-based preparations are particularly effective against sucking pests like aphids, whiteflies, thrips and leafhoppers. Some of the commonly used nicotine-based formulations are described below.

Tobacco Decoction: About 1 kg of dried tobacco leaves is soaked in 10 litres of water for 24 hours. The mixture is boiled for about 30 minutes, cooled, and filtered through cloth. Before spraying, it is diluted to 10 litres with water and a small amount of soap solution (1%) is added for better spread.

Nicotine Sulphate Formulation: Commercially available as 40% Nicotine Sulphate, this is a registered botanical insecticide under CIB&RC, India. It is diluted at 1–2 ml per litre of water and sprayed against pests.

Note:

Tobacco-based pesticides should be handled carefully, as nicotine is toxic to humans and animals. Protective gloves and masks are recommended during preparation and spraying.

iii. Chrysanthemum:

Chrysanthemum (*Chrysanthemum cinerariifolium*) is an important plant known for producing natural insecticidal compounds called pyrethrins. These compounds are concentrated mainly in the flower heads and act as contact insecticides, targeting the nervous system of insects. Pyrethrins cause rapid knockdown and

paralysis of pests by interfering with the transmission of nerve impulses, making them highly effective against a wide range of insects such as mosquitoes, flies, aphids, thrips, and beetles.

Common Formulations of Pyrethrins:

Pyrethrum Extract: Obtained by solvent extraction of dried chrysanthemum flowers. It is often mixed with water or light oils and used as a spray.
Pyrethrum Dust or Powder: Finely ground dried flowers are used directly as dust formulations for controlling household and field pests.

In commercial formulations, Piperonyl Butoxide (PBO) is added as a synergist to enhance the insecticidal activity and persistence of pyrethrins.

Note: They act quickly and degrade rapidly in sunlight, making them environmentally safer than many synthetic insecticides.

iv. Derris species:

Rotenone is a natural insecticidal compound derived mainly from the roots of certain tropical leguminous plants such as *Derris elliptica* and *Lonchocarpus utilis*. It has been traditionally used for controlling a variety of insect pests like aphids, beetles, caterpillars, leafhoppers and mites in agriculture and horticulture.
Rotenone acts as a respiratory inhibitor, leading to paralysis and death of the insect. Because of this, it is effective as a stomach and contact poison.

Common Formulations:

Rotenone Dust: Prepared by mixing powdered derris root with an inert carrier like clay or talc for direct application on crops.
Commercial Products: Derris powder, Cube powder, or Rotenone extract, with typical concentrations ranging from 0.5% to 5%.
Note: It is toxic to fish and aquatic organisms, so it should not be used near water bodies.

v. Plumbago:

Plumbagin is a natural naphthoquinone compound extracted primarily from the roots of *Plumbago zeylanica.* It is well known for its insecticidal, antifungal, and antimicrobial properties, making it an important botanical compound in eco-friendly pest management practices. Plumbagin acts as a contact and feeding deterrent. It disrupts normal physiological and biochemical functions in insects, which damages cell membranes and vital enzymes. It also interferes with insect growth and development, affecting moulting and reproduction. Studies have shown that plumbagin is effective against a range of pests, including mosquito larvae (*Aedes and Culex* spp.), stored grain insects (*Sitophilus oryzae and Tribolium castaneum*), aphids, and leaf-eating caterpillars. Extraction is typically done using organic solvents like ethanol or methanol to obtain crude plumbagin extract.

vi. Pongamia:

Pongamia (*Pongamia pinnata*), also known as *Karanja* or *Indian Beech*, is a leguminous tree. Its seeds and oil are rich in natural compounds with insecticidal, antifungal, and antibacterial properties, making it an important botanical pesticide in sustainable pest management. Karanjin is the primary bioactive ingredient in Pongamia oil, which possesses strong insecticidal and repellent properties. Karanjin acts as an insect growth regulator (IGR) and feeding deterrent.
Pongamia formulations are effective against various agricultural pests, including aphids, whiteflies, thrips,

jassids, leafhoppers, caterpillars, and mealybugs. It is also used to control storage pests and mosquito larvae. Oil is extracted from dried seeds by cold pressing or solvent extraction.

Standard Formulations and Uses:

Karanja Oil Spray: Mix 2–5% Pongamia oil with an emulsifier (like soap solution) and water for foliar spraying on crops.

Seed Extracts: Crushed seeds are soaked in water overnight, filtered, and used as a botanical spray.

Note: Many registered formulations combine Pongamia oil with neem oil or azadirachtin for broader pest control under IPM programs.

vii. Custard Apple:

Custard apple (*Annona squamosa*), also known as *Sitaphal* or *Sugar Apple*, is a tropical fruit-bearing tree whose seeds, leaves, and bark contain potent natural compounds with insecticidal and pesticidal properties. The main bioactive compounds responsible for insecticidal activity are acetogenins, alkaloids (including anonaine and liriodenine) and essential oils. Among them, annonacin, squamocin, and bullatacin are the most potent compounds. These compounds interfere with insect metabolism and have both contact and stomach toxicity. Custard apple extracts have shown potent activity against a variety of pests, including mosquito larvae, aphids, whiteflies, mealybugs, caterpillars, and storage grain insects. It is also effective against head lice and houseflies in domestic pest control.

Common Formulations and Uses:

Seed Extract: Grind 50-100 g of dried custard apple seeds into powder. Soak in 1 litre of water overnight, then filter and spray on crops. Add a few drops of soap solution for better adherence.
Powder Form: Seed or leaf powder can be mixed with grain or soil to control storage and soil-dwelling pests.

Essential oils as Botanical Insecticides:

Essential oils play a vital and increasingly recognized role in eco-friendly pest management due to their diverse bioactive properties and natural origin. Derived as mixtures of volatile secondary metabolites from aromatic plants, particularly those belonging to families such as Lamiaceae, Myrtaceae, Asteraceae, Rutaceae, Apiaceae, and Lauraceae, they possess a complex array of compounds that act synergistically to deter, repel, or kill insect pests. Their modes of action are multifaceted, including ovicidal, larvicidal, antifeedant, repellent, and neurotoxic effects that disrupt insect feeding, reproduction, and development. For instance, citrus oils rich in limonene and linalool function as nerve toxins and contact poisons, while citronella oil from *Cymbopogon nardus* (Lemon grass) is a well-known mosquito repellent. Similarly, essential oils from *Eucalyptus globulus* exhibit larvicidal activity against houseflies, and those from *Mentha* species show strong effects against stored grain pests like the cowpea weevil and red flour beetle. Their rapid biodegradability ensures minimal environmental persistence, making them safe for humans, animals, and non-target organisms.

Limitations for the use of botanicals in Pest management:

Variability in composition: The concentration of active compounds varies with plant species, growth stage, geography and extraction method, leading to inconsistent efficacy.
Short residual activity: Botanicals degrade rapidly under sunlight, heat, and microbial action, requiring frequent reapplication.
Limited shelf life and stability: Many formulations are unstable over time, reducing their commercial viability and field effectiveness.

Slow action: Most botanicals act gradually rather than providing an immediate "knockdown" effect like synthetic insecticides.
Narrow spectrum of activity: They may be effective only against specific pests, making broad-scale pest management difficult.
Formulation challenges: Difficulty in developing stable, user-friendly, and cost-effective formulations that ensure consistent delivery of active ingredients.
Regulatory and registration issues: Many botanical pesticides are not registered or standardized under official pest control regulations.
Lack of awareness and extension support: Farmers often lack knowledge about the proper preparation, application, and dosage of botanical products.
Compatibility issues: Some botanicals may not be compatible with other pest management tools or may degrade when mixed with synthetic chemicals.

Current Scope of Botanicals in Pest Management:

Botanical pesticides have gained renewed attention as viable alternatives to synthetic chemicals due to growing concerns about pesticide resistance, residue hazards, and environmental toxicity. Currently, botanicals such as neem (*Azadirachta indica*), pyrethrum (*Chrysanthemum cinerariifolium*), rotenone, essential oils, and plant extracts (e.g., Pongamia, Annona) are being explored for commercial pest control. Their biodegradability, target specificity, and multi-mode of action make them particularly useful in sustainable agriculture. Recent advances in formulation technology, such as nanoemulsions, microencapsulation, and oil-based carriers, are improving their stability, persistence, and efficacy. Global trends show increasing adoption in organic farming, greenhouse cultivation, stored-grain protection, and urban pest control sectors. Moreover, supportive regulatory frameworks in some countries (e.g., under the U.S. EPA's Biopesticides and Pollution Prevention Division) have enhanced their commercial potential. In developing countries like India, institutions such as ICAR and CIBRC are promoting botanical-based biopesticides under IPM programs.

Incorporation of Botanicals into IPM:

To integrate botanicals effectively into Integrated Pest Management (IPM), a strategic and science-based approach is needed:

Use as first line of defense: Employ botanicals for early pest suppression, repelling or deterring pests before populations build up.
Combination with biological control: Botanicals are compatible with many natural enemies (parasitoids, predators, entomopathogens) and can be used alongside them for synergistic effects.
Rotation with synthetic insecticides: Alternating botanicals with chemical insecticides helps delay resistance development in pest populations.
Use in traps, lures, and repellents: Essential oils and plant volatiles can be incorporated in monitoring traps and push–pull systems.
Seed and soil treatments: Neem and pongamia-based formulations can protect seedlings from early pest attack while improving soil health.
Incorporation in stored-product pest management: Volatile oils (e.g., eucalyptus, citronella, clove) serve as fumigants or repellents against storage pests.
Standardization and formulation development: Development of stable formulations (e.g., nanoformulations) and regulatory standardization will enhance consistency and farmer confidence.
Farmer awareness and training: Extension programs should promote correct preparation, dosage, and timing for effective botanical use within IPM modules.

Summary:

Botanicals represent a bridge between traditional plant-based pest control and modern eco-technological solutions. When integrated systematically within IPM, they can reduce pesticide dependency, conserve biodiversity, and maintain agricultural sustainability. The future scope lies in research-driven formulation improvement, commercialization, policy support, and farmer-level education to ensure their practical success.

Module VI: ORGANIC AND NATURAL FARMING

6. 1.A. Organic Cultivation: Principles, Practices and Ecological Implications

Agriculture has been the foundation of human civilization for thousands of years. In India, farming has undergone major transformations over time. Before 1960s, traditional methods based on farmyard manure, crop residues and natural cycles were common. Green revolution introduced high-yielding varieties, chemical fertilizers and pesticides which increased food production dramatically from 50.8 million tonnes in 1950-51 to more than 354 million tonnes in 2024-25 (DES, 2025). This success changed India from a food importer to a food exporter.

However, heavy reliance on chemicals also created challenges. Continuous use of fertilizers reduced soil organic carbon, pesticides polluted water and monoculture practices decreased biodiversity. Farmers also became dependent on external inputs, which increased costs and sometimes led to health and environmental problems (Ravisankar *et al*., 2021).

Organic cultivation has emerged as a sustainable alternative. It avoids synthetic chemicals and instead depends on natural processes for soil fertility and pest management. The goal is not only to produce food but to protect the environment, conserve biodiversity, and ensure human health (IFOAM, 2020).

Principles of Organic Cultivation

Organic farming is based on four fundamental principles given by the International Federation of Organic Agriculture Movements (IFOAM). These principles are the philosophical backbone of organic agriculture.

Principle of Health

Organic farming seeks to sustain and enhance the health of soil, plants, animals and human. Soil is considered as a living system that must be protected. Healthy soil leads to healthy crops, which in turn provide safe food for human and animals. By avoiding toxic pesticides and synthetic fertilizers, organic cultivation reduces the risk of harmful residues in food and supports overall well-being (IFOAM, 2020). For instance, studies show that crops grown under organic systems have higher levels of antioxidants and micronutrients compared to conventional crops (Khurana *et al*., 2022).

Principle of Ecology

Organic farming should be rooted in ecological systems and cycles. Instead of disturbing natural balances, farmers work with them. Practices such as crop rotation, composting and biological pest control mimic natural processes that maintain fertility and manage pests (FAO, 2021). Use of legumes in crop rotation to fix atmospheric nitrogen naturally through root colonizing bacteria like *Rhizobium* sp., reduce the need for chemical fertilizers.

Principle of Fairness

Fairness means equity and justice for farmers, workers, traders and consumers. Organic farming emphasizes fair prices, safe working conditions and the ethical treatment of animals. Farmers in cooperative groups, such as organic rice collectives in Kerala, benefit from better bargaining power and fair-trade opportunities (Ravisankar *et al*., 2021).

Principle of Care

Organic farming should be managed with precaution and responsibility for future generations. Farmers must avoid practices or technologies whose risks are unknown or potentially harmful, such as genetically modified organisms (GMOs). This principle encourages careful, science-based and socially responsible farming (IFOAM, 2020).

These four principles ensure that organic cultivation is not only a farming method but also a system that respects health, ecology, fairness and care.

Practices of Organic Cultivation

Organic farming practices are built around the above four principles and adapted to local conditions. They combine traditional wisdom with scientific methods to ensure productivity and sustainability.

Soil Fertility Management

Maintaining soil fertility is at the heart of organic farming. Instead of synthetic fertilizers, organic farmers use compost, farmyard manure, green manures, crop residues and biofertilizers *viz., Rhizobium, Azospirillum, Phosphobacteria,* K solubilizing bacteria, PPFM *etc.* Vermicomposting, where, earthworms convert organic matter into nutrient-rich compost, is also widely adopted. These methods increase soil organic carbon and improve microbial activity which enhances nutrient availability (Ravisankar *et al*., 2021). Research across 74 cropping systems in India shows that soil organic carbon is consistently higher under organic management than under conventional chemical farming (DES, 2023).

Crop Rotation and Mixed Cropping

Organic production system encourages crop rotation and diversification. Rotating cereals with legumes improves nitrogen levels and prevents the buildup of pests and diseases. Mixed cropping provides resilience against crop failure and uses natural synergies between plants (FAO, 2021). Maize intercropped with beans in hilly regions of Himachal Pradesh improved the soil fertility and supported dietary diversity for farmers.

Pest and Disease Management

Instead of synthetic pesticides, organic farming uses biological and botanical approaches. Neem oil (3%), neem seed kernel extract (5%), ginger, garlic, green chilli extract (5%) and five leaves extract (10%) and other plant extracts are common remedies. Natural enemies such as ladybird beetles, spiders and parasitoids are encouraged to control harmful insects. *Bacillus, Trichoderma* and *Pseudomonas* are the biocontrol agents used in the management of plant diseases, nematodes and enhances the systemic resistance of plants to the biotic and abiotic stressors. Long-term studies revealed that the population of natural enemies like coccinellids and syrphids is higher in organic fields compared to conventional ones (Ravisankar *et al*., 2021).

Weed Management

Weed management is a major challenge in organic production systems, as synthetic herbicides are avoided. Farmers rely on mulching with crop residues, hand weeding, crop rotations and cover crops. In some areas, stale seedbed techniques are effective, where, weeds are allowed to germinate and then removed before planting the main crop (DPPQS, 2023).

Water Management

Water is managed carefully in organic farming. Drip irrigation saves water and reduces weed growth, while, rainwater harvesting ensures availability during dry periods. Over-irrigation is avoided to prevent soil degradation and salinity (FAI, 2022). Crop residue mulching used for weed management also conserve the soil moisture. Integrated organic farming systems in states like Tamil Nadu and Meghalaya, combine field crops with livestock and fishery, which recycle water and nutrients effectively.

Table 1. Differences between organic and conventional farming

Feature	Organic Farming	Conventional Farming
Fertilizers	Compost, manures, biofertilizers and green manures, jeevamrit	Chemical fertilizers
Pest management	IPM, botanical pesticides like neem, bio-pesticides, natural enemies, sticky trap and pheromone traps	Chemical pesticides
Soil health	Builds fertility and organic matter	Declines over time
Input costs	Low (local resources)	High (external inputs)
Environment	Eco-friendly and sustainable	Pollution and loss of biodiversity

(FAO, 2021)

Ecological Implications of Organic Farming

Ecological benefits of organic cultivation extend beyond the farm.

- **Soil health** improves significantly due to higher organic carbon, better soil structure and more microbial activity. Long-term experiments in India confirm that soils with organic practices have higher nitrogen, phosphorus and potassium availability compared to conventional soils (Ravisankar *et al*., 2021).
- **Water quality** is also improved, as organic farming prevents chemical runoff into rivers and groundwater. The water-holding capacity of organic soils is higher, making them more resilient in drought conditions (FAO, 2021).
- **Biodiversity conservation** is one of the strongest contributions of organic farming. Fields managed without pesticides provide safe habitats for pollinators, beneficial insects and soil organisms. Traditional crop varieties are also preserved, contributing to genetic diversity.
- **Climate change mitigation** is another ecological implication. Soils with organic farming practices sequester more carbon, reducing greenhouse gas emissions. Studies suggest that continuous organic farming can increase carbon storage up to 63% over a decade (Khurana *et al*., 2022).
- **Human health** benefits from reduced exposure to toxic residues. Organic food is free from harmful chemicals and often has better nutritional quality. For farmers, reduced occupational exposure with pesticides lowers the risk of poisoning and long-term health issues.

Latest Developments in Organic Farming

Organic farming is supported by several new developments. Digital tools and mobile apps now provide farmers with advice on organic inputs, pest management and certification (GoI, 2022). Participatory Guarantee System (PGS) offers low-cost certification for smallholders.

Biofertilizers based on beneficial microbes *viz., Rhizobium, Azospirillum, Phosphobacteria* and biopesticides *viz., Trichoderma*, *Bacillus* and *Pseudomonas* are increasingly available in the market (FAI, 2022). The demand for organic food is growing rapidly, especially in urban areas and online platforms are making distribution easier. Government schemes such as the Paramparagat Krishi Vikas Yojana and Mission Organic Value Chain Development for North-Eastern Region provide support through training, input supply and market linkages (GoI, 2022). These developments show that organic cultivation is no longer marginal but becoming an important part of India's agricultural future.

Conclusion

Organic cultivation is more than a farming method; it is an ecological and ethical approach to agriculture. Its principles of health, ecology, fairness and care ensure that farming supports not only productivity but also sustainability. Its practices such as composting, crop rotation, natural pest management and water management work in harmony with nature.

The ecological implications are far-reaching: improved soil fertility, clean water, conserved biodiversity, reduced greenhouse gases and healthier people. Although yields may be lower in the beginning, organic farming reduces input costs, improves resilience and provides long-term benefits.

With India's strong traditions and modern research, organic farming can be a major solution for safe food, sustainable livelihoods and environmental protection. By supporting farmers with training, certification and fair markets, organic cultivation can shape a healthier and more sustainable future.

6.2. A. Organic Nutrient Management-Types of Organic Manures – Bio-fertilizers- Efficient use of Organic sources of Nutrients

"Feed the Soil to Feed Mankind"

1. Introduction

Good nutrient management keeps the soil fertile and healthy in organic farming. Soil stays healthy when its physical, chemical, and biological properties are balanced. Organic matter, the ***key input***, added through composted manures and farm wastes, helps maintain this balance. Organic farming aims to maintain soil nutrients, recycle them efficiently, and reduce the need for outside fertilizers.

According to the "Law of Return," nutrients taken from the soil must be returned. Adding organic matter helps maintain this balance, keeping the soil fertile and productive for the long term. Organic matter improves water holding, aeration, and porosity and reduces soil hardness and temperature. It also provides essential nutrients, improves nutrient holding capacity, and prevents nutrient loss. Biologically, organic matter increases the number of helpful microorganisms, supports nitrogen fixation, and helps make phosphorus available to plants.

2. Importance of Organic Nutrients Management

Organic nutrient management builds a living, fertile soil system that supports sustainable and eco-friendly organic farming.

2.1. Improves Soil Health: Organic materials increase soil organic matter, which improves soil structure, aeration, and water-holding capacity. This creates a healthy environment for plant roots and soil microbes.

2.2. Enhances Nutrient Recycling: Organic farming recycles crop residues, animal wastes, and bioresources to return nutrients back to the soil, reducing dependence on external inputs.

2.3. Supports Soil Microorganisms: Organic manures and biofertilizers promote beneficial microbes that help in nutrient fixation and decomposition, improving nutrient availability to plants.

2.4. Reduces Environmental Pollution: Unlike chemical fertilizers, organic inputs release nutrients slowly and reduce the risk of water contamination and soil degradation.

2.5. Improves Crop Quality and Resilience: Crops grown with organic nutrients have better taste, quality, and tolerance to stress and diseases.

2.6. Sustains Long-Term Fertility: Continuous use of organic sources maintains soil fertility and ensures sustainable productivity for future generations.

3. Types of Organic Manures

Organic manures are natural materials derived from plants and animals that supply essential nutrients to the soil and improve its physical, chemical, and biological health. They are free from harmful chemicals, pathogens, and weed seeds. Organic manures are grouped based on their source and nutrient content.

3.1 Based on Source

3.1.1. Animal Manures: Those organic materials derived from animal wastes like dung, urine, and bedding residues.

- Farmyard Manure (FYM): Mix of cattle dung, urine, and straw; supplies N, P, and K.
- Cattle Dung and Urine: Provide organic matter and readily available nitrogen and potassium.
- Poultry Manure: Rich in nitrogen and phosphorus; should be composted before use.
- Sheep and Goat Manure: More concentrated in nutrients than FYM.

3.1.2. Plant Manures: Derived from plants and crop residues.

- Green Manure: Crops like sunnhemp and dhaincha grown and ploughed into soil to improve fertility.
- Green Leaf Manure: Leaves and twigs of trees like Gliricidia and Leucaena used as nutrient sources.
- Crop Residues: Straw and husks composted before soil application.

3.1.3. Industrial Byproducts: Nutrient-rich wastes from agro-industries used after proper treatment.

- Pressmud: Sugar industry waste; rich in organic carbon and nutrients.
- Fly Ash: From power plants; improves soil structure and provides micronutrients.
- Bone Meal and Meat Meal: Slaughterhouse byproducts; high in phosphorus and calcium.

3.1.4. Human and Domestic Wastes (Anthropogenic Sources): Recycled human and household organic wastes used safely after composting.

- Night Soil and Human Urine: High in nitrogen and phosphorus; must be treated to remove pathogens.

- Household Organic Waste: Kitchen and food residues composted for safe use.

3.2. Based on Nutrient Concentration

3.2.1. Bulky Organic Manures: These contain low nutrient content but improve soil structure and water-holding capacity. Examples include FYM, compost, and green manure.

3.2.2. Concentrated Organic Manures: These are nutrient-rich organic materials supplying large quantities of N, P, and K. Examples include oil cakes (neem, groundnut), bone meal, fish meal, and blood meal.

4. Types and Uses of Biofertilizers

Biofertilizers are living microorganisms that help plants get nutrients naturally by fixing nitrogen, solubilizing phosphorus, or stimulating plant growth. They are eco-friendly and improve soil health and fertility.

4.1. Nitrogen-Fixing Biofertilizers

These microorganisms convert atmospheric nitrogen into forms plants can use.

- Rhizobium: Forms nodules on legume roots (e.g., peas, beans) and fixes nitrogen.
- Azotobacter: Free-living bacteria used for non-legume crops like maize, wheat, and vegetables.
- Azospirillum: Associates with grasses and cereals (e.g., rice, sorghum) to enhance nitrogen uptake.
- Blue-Green Algae (BGA) and Azolla: Used in paddy fields; add organic nitrogen and improve soil fertility.

4.2. Phosphate-Solubilizing Biofertilizers (PSB)

They convert insoluble phosphorus in soil into a form available to plants.

- Bacillus, Pseudomonas, and Aspergillus species are common PSB used in cereals, pulses, and vegetables.

4.3. Potassium and Zinc Solubilizers

These microbes release potassium and zinc from soil minerals, making them available to plants.

- Used in crops like sugarcane, tomato, and cereals.

4.4. Mycorrhizal Fungi (VAM – Vesicular Arbuscular Mycorrhizae)

They form a symbiotic relationship with roots, improving nutrient and water absorption, especially phosphorus.

4.5. Plant Growth-Promoting Rhizobacteria (PGPR)

These bacteria promote root growth, enhance nutrient uptake, and protect plants from diseases.

Biofertilizers reduce the need for chemical fertilizers, improve soil fertility, and promote sustainable crop growth in an eco-friendly way.

5. Efficient Use of Organic Sources of Nutrients

5.1. Select the Right Organic Source

Different organic materials supply different nutrients, hence choose based on crop needs and soil condition. Few examples are given below.

Organic Source	Main Nutrients Supplied	Examples
Farmyard Manure (FYM)	N, P, K, micronutrients	Cattle manure, straw, bedding materials
Compost	Balanced nutrients + organic carbon	Crop residues, kitchen waste, vermicompost
Green Manure	Nitrogen, organic matter	Sunnhemp, Sesbania, Dhaincha
Oil Cakes	Nitrogen, phosphorus	Neem cake, groundnut cake, sesame cake, pungam cake
Biofertilizers	Specific nutrients	Rhizobium, Azospirillum, PSB
Crop Residues	Organic matter, K, micronutrients	Straw, husks, stubbles
Animal- and Plant-based Liquids	Nutrient-rich biostimulants	Panchagavya, Jeevamrutha, Fish amino acid

5.2. Proper Preparation and Composting

- Always compost manure and crop waste before using to remove weeds and harmful microbes. Eg. Farm wastes compost, vermicompost
- Keep 50–60% moisture and ensure good aeration during composting.
- Turn the compost every 15–20 days for even decomposition.
- Use compost when it becomes dark brown, crumbly, and odorless.

5.3. Right Method of Application

- During land preparation, apply 5–10 tons of FYM or compost per hectare and mix it well with the top 15 cm of soil for slow nutrient release.
- After crop establishment, spray liquid organics like panchagavya or vermiwash every 15–20 days to support plant growth.
- Grow green manure crops like sunnhemp or dhaincha before the main crop and plough them into the soil while tender to improve fertility.
- Enrich compost or FYM with rock phosphate, wood ash, or biofertilizers before application. This improves phosphorus, potassium, and microbial content.

5.4. Ensure Favorable Soil and Field Conditions

- Maintain adequate soil moisture, avoid waterlogging or dryness, and apply organics during cooler hours (morning or evening).

5.5. Integration with Biofertilizers

- Combine organic manures with suitable biofertilizers for better nutrient use efficiency. Example: FYM + PSB or Compost + Azospirillum
- This boosts nutrient mineralization and uptake by plants.

5.6. Crop Rotation and Residue Recycling

- Follow legume-based crop rotations to naturally enrich soil nitrogen.
- Incorporate crop residues instead of burning — improves soil carbon and nutrient recycling.

6. Recent Innovations in Organic Nutrient Management

- Turning Waste into Organic Manure: The mechanical dewatering and drying system (MDDS) in Chandrapur, Maharashtra converts faecal sludge into safe organic manure, recovering N and P efficiently.
- Integrated Nutrient Management (INM): Combining organic manures, minerals, and biofertilizers improves soil health, yield, and nutrient use efficiency over chemical fertilizers.
- Precision Nutrient Monitoring: Imaging, sensors, and AI tools detect nutrient stress early and guide nutrient use through digital soil and weather models.
- Organic Nutrients in Special Crops: In crops like mulberry, using FYM, compost, vermicompost, and oil cakes maintains yield and soil fertility while reducing chemical inputs.
- Waste Recycling for Nutrients: Agricultural Produce Marketing Committee (APMC), Mysuru plans to convert 20–25 tons of market waste daily into biogas and organic manure, promoting agro-waste recycling.
- Policy and Industry Support: States such as Andhra Pradesh promote biofertilizers, nano-fertilizers, and neem-based products; drones assist in precise nutrient application.
- Focus on Soil Health: Recent studies emphasize soil microbial biomass, enzyme activity, and organic carbon as key indicators—showing organic amendments enhance soil quality and sustainability.

Conclusion

Effective organic nutrient management involves the integrated use of organic manures and biofertilizers to sustain soil fertility, enhance microbial activity, and improve nutrient availability. The combined application of farmyard manure, compost, green manures, and microbial inoculants reduces dependence on chemical fertilizers while maintaining soil health and ensuring sustainable crop productivity.

6.2. B. Weed management in Organic Farming –Cultural-mechanical-Biological –Bioherbicides

1. Introduction

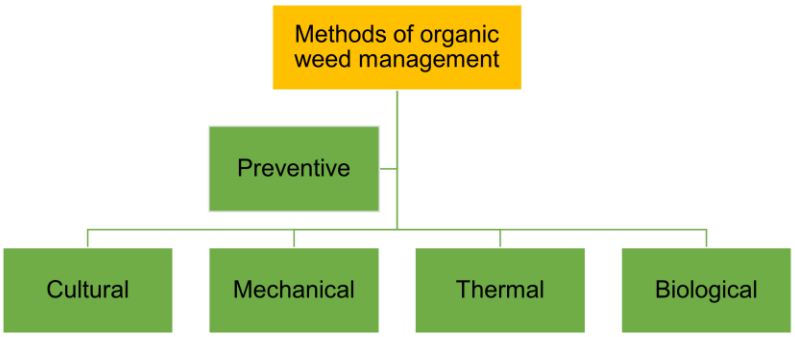
Weeds are plants that grow where they are not wanted. They compete with crops for sunlight, water, and nutrients, reducing crop growth and yield. Managing weeds properly helps maintain soil health, improves crop quality, and supports sustainable agriculture. In organic farming, weed management is essential because no synthetic chemicals are used. Farmers must combine natural methods to prevent weeds from growing and spreading.

2. Importance of Weed Management in Organic Farming

Weeds can also host pests and diseases, make harvesting difficult, and increase production costs. Effective weed management helps crops grow better, improves soil health, and supports sustainable farming. Hence organic weed management must follow a holistic approach and use only non-chemical methods. Weeds can be controlled effectively by combining different natural and cultural practices in an integrated system.

3. Weed Management Practices in Organic Farming

Weed management in organic farming focuses on prevention, cultural, mechanical, biological, and organic methods. Different methods of weed management practices could be adopted in organic farming are given below as flow chart.



3.1. Preventive

Preventing weed introduction and spread is the most effective and low-cost method. Use certified, weed-free seeds and clean farm machinery to stop weed contamination. Remove weeds before they produce seeds and use well-decomposed manure to avoid weed seed spread. Regular field inspection helps identify weed problems early

3.2. Cultural Methods:

Cultural methods involve changing the way crops are grown to reduce weed growth. These are preventive methods that make it hard for weeds to survive. Cultural practices like crop rotation, intercropping, cover crops, and stale seedbed techniques help suppress weeds naturally.

- **Crop rotation** means growing different crops in sequence to break weed life cycles. Changing crops alters growth conditions and competition, preventing weeds from dominating. Example: grow maize one season and legumes like beans or peas the next.
- **Intercropping** uses short-duration or smother crops between main crops to block sunlight and reduce weed growth.
- **Multi-species intercropping** grows two or more crops together to boost biodiversity and resource use, suppressing weeds by competing for light, nutrients, and space, and reducing the need for chemical herbicides.
- **Cover crops** Cover crops are plants grown to cover the soil and block sunlight to stop weeds. Examples are clover, cowpea, sun hemp, and dhaincha. They also add nutrients like nitrogen to the soil.
- **Stale seedbed** involves early soil preparation to let weeds sprout and then removing them before planting the main crop.
- **Mulching:** Mulching covers the soil with materials like straw, leaves, or crop residues to block sunlight, prevent weed growth, retain moisture, keep the soil cool, and add organic matter as it decomposes. There are two types as living mulches like clover grow alongside crops and suppress weeds and non-living mulches such as straw, crop residues, or plastic sheets cover the soil and prevent weed growth.

- **Flooding:** Keeping fields flooded for a period creates oxygen-poor conditions that kill weeds. It is especially useful in rice fields for managing grasses and sedges.

3.3. Mechanical Methods:

Mechanical methods involve physically removing weeds. These methods are labor-intensive but very effective in organic farming. They are as follows.

- **Tillage** buries weed seeds or exposes them to the sun, reducing weed population.
- **Hand hoeing** removes young weeds and loosens soil.
- **Mowing and slashing** prevent weed seed production in non-crop areas like bunds and roadsides.

3.4. Thermal Methods:

Heat-based control methods like **soil solarization** and **flame weeding** use high temperatures to kill weeds and weed seeds. Covering soil with plastic during hot months can sterilize it, while flame weeders burn weeds without using chemicals.

3.5. Biological Methods

Biological methods use living organisms or formulations obtained from living organisms to control weeds naturally. They are eco-friendly and safe.

3.5.1. Biological control

Biological control uses insects, fungi, or pathogens to reduce weeds. Insects help control weeds in grasslands, but this method is less effective in short-term or annual crops. Similarly allowing animals to graze like goats, sheep, and ducks eat weeds, reducing their growth. For example, ducks in rice paddies consume weeds and pests, supporting crop growth. Examples are as follows.

Target Weed	Bio Agent	Type
Parthenium hysterophorus	*Zygogramma bicolorata*	Leaf-eating beetle
Cyperus rotundus	*Bactra verutuana*	Shoot-boring moth

3.5.2. Bioherbicides

Bioherbicides are natural products derived from plants, fungi, or bacteria that kill or control weeds. They work like chemical herbicides but are safe for the environment. Can be used along with other organic methods for better results. They kill weeds by interfering with weed seeds germination and or targeting growth of roots, or leaves. Eg. The bioherbicide Biolophos containing *Streptomyces hygroscopicus*, controls general weed growth.

3.5.3. Allelopathy

Allelopathy is the natural ability of some plants to release chemicals that stop the growth of nearby weeds. These chemicals come from plant roots, leaves, or residues. Crops like sorghum, sunflower, barley, rye, and wheat have strong allelopathic effects and help reduce weed populations. For example, sunflower extracts have been shown to reduce weed density in fields.

4. Integrated Weed Management in Organic Farming

In organic farming, no single method can control weeds completely. Farmers use a combination of methods:

- Cultural + Mechanical: Crop rotation, mulching, and hand weeding together reduce weeds effectively.
- Biological + Cultural: Grazing animals and cover crops prevent weed growth naturally.
- Bioherbicides + Mechanical: Spraying plant-based herbicides while manually removing weeds gives better control.

Combining methods reduces labor, maintains soil health, and ensures sustainable crop production.

5. Benefits of Organic Weed Management

- Protects soil, water, and beneficial organisms.
- Reduces the use of harmful chemical herbicides.
- Improves crop yield and quality.
- Maintains long-term soil fertility and ecosystem balance.
- Supports eco-friendly and sustainable farming practices.

6. Recent Advancements in Sustainable Weed Management

6.1. Enhancing Crop Competitiveness: Growing crops with strong competitive traits help suppress weeds naturally. Traits like rapid early growth, dense canopy, and tough plant structure reduce weed access to light and nutrients. Plant breeding can develop crops with improved weed-suppressive abilities.

6.2. Organic Bioherbicides: Natural products from plants offer safe alternatives to synthetic herbicides. Common bioherbicides include vinegar (acetic acid), clove oil (eugenol), citric acid, lactic acid, corn gluten meal, fatty acid soaps. These products are biodegradable, target specific weeds, and reduce environmental risks. For example, 5–20% vinegar effectively controls small young weeds.

6.3. Precision Weed Management: Site-specific crop management uses sensors, unmanned aerial vehicles (UAVs), satellites, and Internet of Things (IoT) devices to monitor and control weeds efficiently. UAVs help map weed infestations, enabling targeted actions that save resources and protect the environment. Smart farming technologies optimize herbicide application, reduce waste, and improve yield.

6.4. Robotic Weed Control: Robotic systems address limitations of manual and mechanical weeding. Robots like Robovator, Robocrop, IC-cultivator, and Remo weed detect and remove weeds within and between crop rows with precision. In trials, robots reduced hand-weeding time by 27–39% in crops like lettuce and broccoli, enhancing efficiency in organic farming.

Conclusion:

Effective weed management in organic farming uses natural, eco-friendly methods instead of chemicals. Farmers can control weeds by removing them early, mulching, rotating crops, introducing grazing animals, and using safe bioherbicides. Combining cultural, mechanical, and biological approaches, along with modern strategies like competitive crops, precision monitoring, and robotic tools, reduces labor, minimizes chemical use, protects soil health, and maintains crop yield. Adopting these integrated methods ensures cost-effective, productive, and environmentally sustainable farming while helping students understand the principles of sustainable agriculture and its role in future food security.

6.3. Insect Pest and Disease Management in Organic Farming: Key Components and Strategies

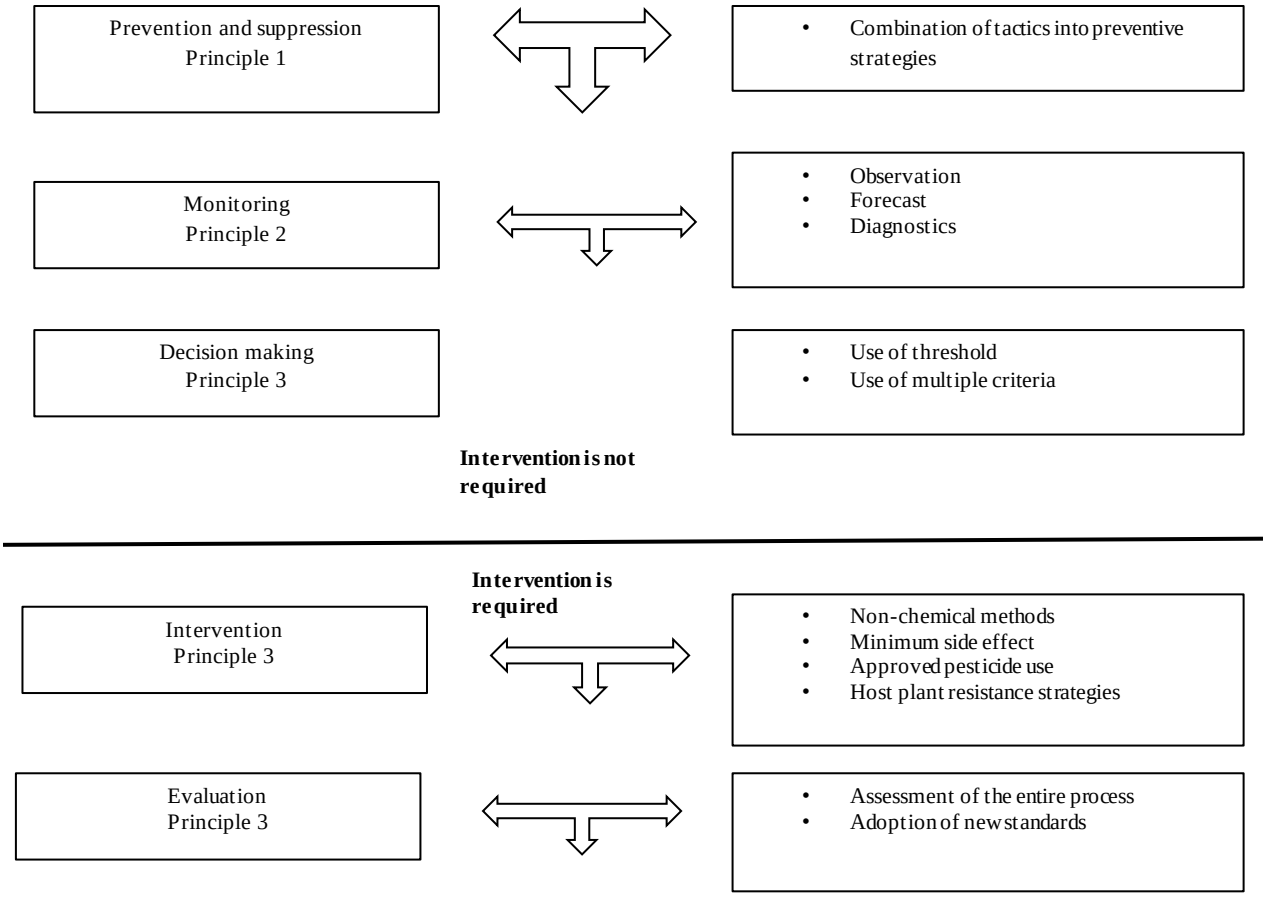
Organic pest management includes practices that prevent pest problems through soil health, crop rotation, biological diversity, habitat enhancement, and only permits use of natural substances to control pest populations without synthetic pesticides or genetically modified organisms (GMOs).

Scope of the pest management in organic farming

- The fast-growing organic food industry offers high profitability.
- With rising population and limited resources, sustainable production is essential for food security.
- Organic farming supports environmental sustainability by maintaining a clean and green ecosystem.
- It ensures human and animal safety by reducing health risks from chemical toxic residues.

Main features of pest management in organic farming

- Maintain soil fertility through organic matter, biological activity, and minimal mechanical use.
- Supply nutrients through soil microorganisms acting on natural, insoluble sources.
- Control pests, weeds, and diseases mainly through rotations, predators, diversity, manures, resistant varieties, and minimal interventions.
- Ensure environmental protection and conserve wildlife habitats.



Steps of pest management in organic farming

Organic pest management is an important part of organic farming, focused on long-term sustainability. It is based on three main steps: prevention, monitoring, and timely intervention using only natural methods like botanical and microbial pesticides (bio-pesticides). Chemical pesticides are not allowed. This approach respects the environment, suits local conditions, protects natural farm resources, reduces waste, saves energy, and helps in preventing pollution.

Commonly used inputs for organic pest management in India

i. Plant based inputs

Neem: Widely used in India for fruits, vegetables, and spices, Neem is incorporated as neem cake for soil fertility and nematode control, and neem oil as a broad-spectrum repellent for aphids and other insects.

Garlic and chili sprays: These are natural repellents that deter insects from attacking crops when mixed into a spray.

Soap water: A mixture of mild soap and water effectively controls soft-bodied pests like aphids and mites.

Plant extracts: Various other plant extracts, such as those from papaya, and mango leaves, are used in formulations to manage pests.

ii. Cow based inputs

Cow based formulations: Indian farmers use traditional formulations like Panchagavya and Jivamrutha, prepared from cow dung and urine, to strengthen plants natural defenses against insect-pests and diseases.

iii. Biological inputs

Natural predators: Farmers encourage beneficial insects like ladybugs, lacewings, and predatory beetles to control pest populations naturally.

Beneficial nematodes: These are used to control soil dwelling pests in agricultural settings.

Microbial biopesticides: These products, based on bacteria, fungi, or viruses, offer an effective alternative to chemical pesticides.

iv. Bio stimulants

Plant bio-stimulants are products containing naturally occurring substances, microorganisms, or their synthetic equivalents that, when applied to seeds, plants, or the rhizosphere, stimulate natural processes to enhance nutrient uptake, nutrient efficiency, tolerance to abiotic and biotic stress, or crop quality and yield.

Protein hydrolysates: Amino acid-based biostimulants are created through chemical and enzymatic methods commonly associated with protein hydrolysis from crop residue and animal excrement. These essential amino acids and peptides are commonly referred to as the building blocks of protein.

Humic and fulvic acids: As organic soil matter breaks down, humic and fulvic acid biostimulants naturally form in the soil. This can be due to the decay of plant, animal, and microbial residues and the biochemical reactions of soil microbes like bacteria and fungi.

Seaweed extracts and botanicals: Seaweed extract and botanical biostimulants have been used in agriculture for centuries, though only recently studied in depth for their biostimulant properties. When applied to soil, seaweed can enhance water retention and support overall soil health.

Chitosan and other biopolymers: Chitosan is a plant biostimulant that is extrapolated from the biopolymer chitin, which is a fibrous substance used in the cell walls of fungi. In the agricultural sector, chitosan has been used to increase plants' ability to handle abiotic stressors like cold and hot weather conditions.

Inorganic compounds: Inorganic element biostimulants, including silica, selenium, cobalt, sodium, and aluminum, can strengthen plant cell walls and promote growth when applied in appropriate amounts.

v. Other organic inputs and practices

Crop rotation and polyculture: Rotating different crops and growing a variety of plants together disrupts pest life cycles and makes it harder for specific pests to establish.

Green and green leaf manures: Using de-oiled Neem cake, which acts as both a fertilizer and a pest repellent, enriches the soil and protects plant roots from pests.

Approaches for pest management in organic farming

In order to survive reproduce, insects/pathogens require a basic set of materials. Production strategies that deny a pest species of at least one essential component of life can keep pest populations at levels that are not economically destructive for long periods of time.

However, cultural methods are unlikely to provide long-term control since the most bothersome insect species are ones that are well adapted to agricultural production systems. Under a given production system, populations of these nuisance insects will tend to rise, whereas numbers of less well adapted species will decrease. The following common methods are used to manage the insect pests and disease at organic farming.

Cultural Methods

The modification of cultural practices can increase the agricultural biodiversity and thus have a greater role to play in the management of pathogens. These methods have certain limitations as they have to be planned well in advance and these are preventive in nature rather than curative.

a) **Higher seed rate:** A higher seed rate will help to maintain the needed plant population even after pests such as shoot borer and stem borer have uprooted and destroyed the interested plants.
b) **Planting distances:** A high plant density lowers groundnut necrosis, whereas a low plant density minimizes nursery damping and sorghum charcoal rot. Rice with wider row sparing has less brown planthopper (BPH). Higher seed rates would aid in maintaining the requisite plant population even after pests such as shoot borer and shoot fly have uprooted and destroyed the afflicted plants. In many cases increasing in spacing helps in reducing disease pressure like in case of sheath blight of rice caused by *Rhizoctonia solani*.
c) **Use of trap crops:** Bhendy/Okra can be used as a trap crop in cotton (10:1) to help trap boll worms and stem weevils. Similarly, Castor can be used as a trap crop against Spodoptera in groundnut and tobacco, and Marigold can be used as a trap crop in tomato (16:1) to help reduce the incidence of Helicoverpa.
d) **Soil Fertility management:** Fertilizer usage that is excessive results in succulent and sensitive circumstances for insect pests/pathogens and illnesses. As a result, using too much nitrogen fertilizer in most crops would exacerbate the pest issue, but using organic manures will increase pest and disease resistance. The organic manures create a partial nitrogen stress up to certain period without any negative effects on crop growth and thus induce resistance through intrinsic production of defense compound such as phenols, tannins and lignins that make the leaf toughness and production of more cell wall related structural compounds. Antifungal activity among various organic composts has been reported by various workers against soil borne and foliar pathogens. Aqueous extracts of vermicompost and organic compost inhibited the mycelial growth of *Botrytis cinerea, Sclerotinia sclerotiorum, S. rolfsii, R. solani and Fusarium oxysporum f. sp. lycopersici.*
e) **Use of resistant cultivars:** Pest and disease resistance has been bred into several crop varietiesGenetically modified crops (GMOs, transgenic crops) most of which are not permitted in the organic production systems.
f) **Trap Cropping:** This is when a secondary crop is planted near a cash crop to draw pests away from the primary crop. The trap crop should be more appealing to the insect attempting to eradicate than the main crop.
g) **Crop rotation:** Crop rotation is used either to starve the pathogen or to kill it with toxic root exudates. To be most effective, rotations between susceptible crops should be about three to seven years. A number of soil borne pathogens like *Fusarium* spp., *Verticillium* spp., *Ralstonia* spp., *Rhizoctonia* spp. those that cause soil born diseases can effectively be managed by crop rotation. Similarly, in fields where rice-solanaceous crop rotation is followed the severity of bacterial wilt is reduced.
h) **Planting time**: Adjustment of sowing time helps in managing disease by avoiding the concurrence of susceptible host and favorable environment. For example, early sown crop escapes the blast in rice.

i) **Water management:** Several naturally occurring pathogens, especially insect-pathogenic fungi, provide effective pest suppression when high humidity microenvironments are created. Similarly, in case of potato scab maintaining soil moisture near field capacity during tuber formation protects the crop from scab because of favourable effect of irrigation on bacterial microflora antagonists to *Streptomyces scabies*.
j) **Tillage:** Infrequent disturbance of soils in natural systems can preserve food webs and diversity of organisms and habitats. Organic producers usually depend on tillage to control weeds and to prepare the soil for planting. Some practices to reduce tillage in organic systems include zero tillage, ridge tillage, and including a perennial crop in the rotation (Halder et al, 2017).

Pest/Disease	Crop	Effect of tillage
Stem borer (larvae)	Rice, Maize	Larvae in stubble are killed when buried by tillage
Root-knot nematodes	Vegetables	Deep plowing exposes them to heat and predators
Soil-borne fungi (e.g., Fusarium, Pythium)	Multiple crops	Tillage improves aeration and drainage, reducing fungal growth

Cutworms and armyworms	Vegetables, Maize	Tillage destroys pupae in the soil

k) **Mulches:** Mulching systems include plastic and natural materials. Although, the use of plastic mulch is frequently not allowed by organic certification agencies because it relies on a non-renewable resource. Biodegradable plastic mulches are being developed and may affect pests in a similar way to that of conventional, non-biodegradable mulches. Organic farmers often use straw mulch which provides good weed suppression. New systems, such as hydro-mulch may one day supplement, plastic and straw if they are developed with organically allowable components. For now, plastic and straw mulches becoming high in popularity.

l) **Sanitation:** Sanitation involves the destruction of crop debris, weeds, diseased plant parts which eventually reduces the inoculums load and subsequent the disease. Like in case of leaf blotch of turmeric, removal of infected leaves reduces the disease severity and further spread.

Mechanical methods

a) Collection and destruction of insect pests: Handpicking insects or pulling weeds is one of the most basic manual or mechanical pest management methods. When the pests are visible and easily accessible, this strategy is most effective. Hand picking and destroying is effective against shoot and fruit borer larvae of brinjal, cotton bollworms, rice leaf folder larvae, sugarcane early shoot borer–infested tillers, and cabbage/cauliflower caterpillars of diamondback moth.

b) Destruction of stubbles and agricultural residues: Sorghum and maize stubbles are known to provide shelter to stem borer larvae, which reproduce after the summer. As a result, the stem borer larvae and pupae will be killed if such stubbles are burned or buried in the soil. Spodoptera, Bihar hairy caterpillar egg masses and early larval stages may be readily gathered and destroyed on tobacco, soybean, peanuts, and other crops shortly after hatching to prevent the pest from spreading further. In diseases, removal and destroying infected plant parts are effective management strategy for late blight of potato, powdery mildew of grapes, bacterial wilt of tomato and brinjal, chilli anthracnose and ground nut and banana leaf spot.

c) Pheromones and other attractants: Pheromones and other chemical attractants can be employed in a variety of ways, including monitoring pests, disrupting mating, mass capturing, spreading an insect disease, and luring pests to eat poisoned bait. Any attractant-baited trap must be utilized with caution.

Biological methods

Identification of insect pests and diseases and their natural enemies is an important step in any pest management program. Biological control of insect pests is grouped into three categories: **importation** or classical biological control, which introduces pest's natural enemies to the locations where they do not occur naturally, **augmentation** involves the supplemental release of natural enemies, boosting the naturally occurring population, and **conservation**, which involves the conservation of existing natural enemies in the environment.

Soil serves as a natural home and reservoir for many kinds of insect pathogens, including viruses, bacteria, protozoa, fungi, and nematodes. The microbes involved in insect control are referred to as the insect pathogens. Some of them can be easily mass produced and are reported to be utilized in the management of insects as microbial insecticides. Some mobile predators have good vision, such as ground beetles (Carabidae) and jumping spiders (Salticidae), and they chase their prey. Others with poor vision, use a combination of vision and chemical cues to find their prey.

Applying biological control agents such as insect predators, parasitoids and insect pathogens can have a greater role to play in controlling the insect pests in an insecticide free environment. These agents can be used as curative control methods in case of sudden outbreak in the insect population.

CIB&RC approved entomopathogenic bio-agents used in Indian agriculture are as follows in the table.

CIB&RC-approved bio-agents for agriculture insect-pest managements in India

Bio-agent (common name)	Typical formulation(s)	Main target pests / use
***Bacillus thuringiensis* (Bt)** (var. kurstaki, israelensis, galleriae, etc.)	Wettable powders, suspension concentrates, granules; strain/cry gene specified on label	Lepidopteran larvae (Bt-kurstaki), mosquito larvae (Bt-israelensis), other specific targets depending on strain.

Bacillus sphaericus	Larvicide formulations for mosquito control (liquid/granules)	Mosquito larvae (vector control / public health & some ag wetlands).
Beauveria bassiana (entomopathogenic fungus)	Liquid or wettable powder (e.g., 1.15% LF / WP listed)	Wide range of sucking/chewing insects (whiteflies, thrips, aphids, some beetles).
Metarhizium anisopliae (entomopathogenic fungus)	WP / LF formulations (e.g., 1.0% WP)	Soil and foliage insects — beetles, grubs, locusts in some programs.
***Verticillium / Lecanicillium (Verticillium lecanii / Lecanicillium* spp.)**	Liquid/formulation (LF / WP)	Soft-bodied insects (aphids, whiteflies, thrips, mealybugs).
Baculoviruses / NPVs (nuclear polyhedrosis viruses)	Aqueous suspensions (AS) — species-specific NPVs (e.g., Helicoverpa, Spodoptera)	Highly specific control of major lepidopteran pests (*Helicoverpa armigera, Spodoptera litura, etc.).*
Paecilomyces / Pochonia / other fungal nematode agents	WP / granules for nematode control or insect targets (strain / specification matters)	Soil-borne pest suppression and nematode control (Paecilomyces / Pochonia used for nematodes).
Entomopathogenic nematodes (EPNs) — *Steinernema*, *Heterorhabditis*	Live infective juveniles (commercial packets / on-farm releases) — often used in IPM advisories	Soil/soil-surface pests (white grub, cutworm, root maggots) — used in field releases and IPM SOPs.

Biological control of plant diseases relies mainly on microbial bioagents such as ***Trichoderma spp.***, ***Pseudomonas fluorescens,*** and ***Bacillus subtilis,*** which suppress soil-borne and foliar pathogens through mechanisms like competition, antibiosis, and induced resistance. These bioagents are available in various commercial formulations (WP, LF, or AS) approved by CIB&RC and are used as seed treatments, soil applications, or foliar sprays to manage diseases such as wilt, root rot, damping-off, sheath blight, and foliar blights, providing an eco-friendly alternative to chemical pesticides.

CIB&RC-approved bio-agents for plant disease managements in India

Bio-agent (microbe)	What diseases / target crops
Trichoderma viride 1.5% WP (Wettable Powder)	Soil borne fungal pathogens; general biofungicidal action; used across many crops
Trichoderma harzianum 1.0% WP	Soil borne fungal disease suppression, damping-off etc.
Pseudomonas fluorescens 1.0% WP	Used for disease suppression, root & soil pathogens, wilt etc.
Beauveria bassiana 1.15% WP	Primarily used for insect control (entomopathogenic), but occasionally linked with disease vector suppression etc.
Verticillium lecanii 1.15% WP	Targets soft scale insects, certain disease vectors; also used in biopesticide portfolio.
Trichoderma asperellum 2% WP	Specifically to manage bakane/foot-rot in basmati rice caused by *Gibberella fujikuroi*

Organic pesticides

There are a variety of organically appropriate pesticides on the market, and each one may be effective in certain situations. In the environment, many organically approved insecticides disintegrate quickly. Repeated

treatments may be required to control a persistent insect infestation. Some of the chemicals that are approved to be used in organic agriculture are:

a) Oils, soaps, and pyrethrum/rotenone mixtures can help lower aphid numbers. If flea beetle numbers are high when young plants are in the cotyledon stage, use of soaps and pyrethrin/rotenone combinations to decrease adult damage are found to be effective.

b) Sprays containing azadirachtin, pyrethrins, and rotenone will kill some of the Leaf miner adults and help to limit the population. Leafhopper numbers can be reduced with applications of pyrethrins and rotenone if the nymphs come into contact with the materials.

c) Sulfur dusts or sprays can be used to combat russet mites. Against pest mites, light mineral, vegetable-based, or neem seed oils can be beneficial.

d) Kaolin is used to control both insect-pest and disease of various crops.

e) Panchagavya, prepared by mixing five important ingredients, obtained from the cow including urine, dung, milk, curd and ghee along with tender coconut water, sugarcane juice and ripe bananas. The preparation after maturation period is diluted to 3% with water and used as foliar spray. This works well in making plants disease resistant.

Conclusion

The growth of organic farming is often constrained by concerns about increased insect pest and disease incidence in the absence of chemical pesticides. However, pests can be effectively managed in organic farming through the adoption of integrated approaches that combine cultural, mechanical, physical, and biological methods, targeted to the specific insect pests or pathogens affecting each crop.

6.4. Organic Certification Process.

Organic farming is a holistic production management system that promotes agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. In India, it is defined as a method of growing plants or rearing animals without synthetic inputs such as chemical fertilizers, growth hormones, allopathic medicines, or pesticides. Organic food consists of products produced in accordance with specific organic production standards, ensuring they are produced in a manner close to nature. Because organic products often appear identical to conventional ones, certification is the essential process that verifies a farm or food product follows the National Standards for Organic Production (NSOP). This process involves a set of production standards for growing, storage, processing, packaging, and shipping. It aims to regulate production,

maintain an audit trail through detailed records, and facilitate the sale of authentic organic products to consumers.

India's Dual Certification Systems

India operates two distinct organic certification systems, both based on common national standards but adopting different approaches for verification.

- **National Programme for Organic Production (NPOP):** This is a third-party certification system managed by the Ministry of Commerce and Industry through the Agricultural and Processed Food Products Export Development Authority (APEDA). It is a mandatory requirement for organic products intended for export and is also used for domestic retail.
- **Participatory Guarantee System for India (PGS-India):** Managed by the Ministry of Agriculture and Farmers Welfare, this is a locally focused system for domestic and local markets. It is built on a foundation of trust, social networks, and knowledge exchange, where farmers in a group inspect and verify each other's practices.

The National Programme for Organic Production (NPOP)

The NPOP provides an institutional mechanism for the implementation of the NSOP and the accreditation of Certification Bodies (CBs).

➢ **Organizational Structure**

The NPOP is governed by the Department of Commerce (Apex Body) and the National Steering Committee (NSC), which is responsible for policy formulation and approving procedures. The National Accreditation Body (NAB), serviced by APEDA, is responsible for the accreditation of CBs that carry out the actual inspections and certifications.

➢ **The Certification Process for NPOP**

1. **Application:** An operator (farmer, processor, or trader) applies to an accredited CB with an Organic System Plan (OSP) detailing practices and inputs.
2. **Review and Evaluation:** The CB reviews the application and sends an inspector to conduct a physical site visit.
3. **Inspection:** The inspector verifies all facilities, accounts, field maps, and contamination control measures.
4. **Residue Testing:** Samples are taken from at least 5% of operators annually for laboratory analysis to detect prohibited substances.
5. **Decision:** A certification committee, separate from the inspector, reviews the report to decide on granting a Scope Certificate.
6. **Traceability:** All transactions are recorded on Tracenet, a web-based traceability system that issues Transaction Certificates (TCs) for every sale.

➢ **Grower Groups and Internal Control Systems (ICS)**

To cater to small and marginal farmers, NPOP allows for Grower Group Certification. This system requires the group to establish an Internal Control System (ICS).

- **Structure:** A group must consist of 25 to 500 farmers in geographical proximity with similar production systems.
- **Management:** The ICS must have an ICS Manager, internal inspectors, and an approval committee.
- **Inspection:** Internal inspectors must conduct 100% internal inspections of all farmers twice annually.

- **External Audit:** The accredited CB then audits the ICS and inspects a sample of farms (calculated as the square root of the total members) to verify the system's integrity.

The Participatory Guarantee System (PGS-India)

PGS-India is a quality assurance initiative emphasizing stakeholder participation and operating outside the frame of third-party certification.

➢ **Guiding Principles**

- **Participation:** Stakeholders are engaged in the design, operation, and decision-making of the system.
- **Shared Vision:** Responsibility is driven by common goals supported by all members.
- **Transparency:** All standards and decisions are documented and made public through the PGS-India portal.
- **Trust:** The system is an expression of trust in producers, verified through producer pledges.
- **Horizontality:** The structure is non-hierarchical, with sharing and rotating responsibilities.

➢ **Operational Structure**

The National Advisory Committee (NAC) is the apex policy body, while the National Executive Committee (NEC) manages implementation. The PGS-India Secretariat is based at the National Centre for Organic and Natural Farming (NCONF). Below them are Zonal Councils and Regional Councils (RCs), which coordinate and monitor Local Groups (LGs).

➢ **The PGS-India Certification Process**

1. **Forming a Local Group:** A minimum of five farmers from the same or nearby villages form a group.
2. **Organic Pledge:** Each member signs a pledge to follow organic standards and avoid synthetic inputs.
3. **Meetings and Training:** The group must meet 2 to 4 times a year and participate in at least one annual training session.
4. **Peer Appraisal:** Farmers conduct field inspections of each other's farms at least twice a year (once per season).
5. **Group Decision:** The group meets to review appraisal reports and collectively decides which members conform to standards.
6. **RC Approval:** The summary of peer appraisals is uploaded to the PGS-India portal, and the Regional Council issues the Scope Certificate.
7. **Transaction:** Transaction Certificates are generated online for every sale of certified produce.

National Standards for Organic Production (NSOP)

The NSOP defines strict rules for various farming systems to maintain organic integrity.

➢ **Organic Crop Production**

- **Habitat Management:** Sufficient diversity must be maintained through hedge rows, nitrogen-fixing trees, and agro-forestry.
- **Diversity:** Mono-cropping is prohibited; farmers must use crop rotations, intercropping, and green manures.
- **Conversion Period:** Land must be managed organically for 24 months for seasonal crops and 36 months for perennial plants before products are certified.
- **Seeds:** Only certified organic seeds should be used; Genetically Modified Organisms (GMOs) are strictly prohibited.
- **Fertility:** Nutrient management relies on compost, recycled biomass, and microbial preparations like bio-fertilizers.

- **Pest Control:** Relies on cultural and biological methods such as pheromone traps, sticky traps, and natural predators.

➢ **Organic Livestock and Poultry**

- **Animal Welfare:** Animals must have access to open-air exercise areas and be allowed to express natural behaviour. Caging of poultry or rabbits is prohibited.
- **Feeding:** At least 85% of feed for ruminants and 80% for non-ruminants must be certified organic.
- **Health Care:** Focuses on prevention. Synthetic hormones, growth boosters, and antibiotics are prohibited. Vaccinations are permitted as required by law.
- **Breeding:** Preference is given to natural methods; embryo transfer and genetic techniques are forbidden.

➢ **Beekeeping (Apiculture)**

- **Site Location:** Apiaries must be within a 3 km radius of organic farms or natural forests.
- **Hives:** Must be made of natural materials; bee wax for foundations must be from organic sources.
- **Extraction:** No chemical repellents are allowed; only **smoke** may be used.

➢ **Aquaculture**

- **Ecosystem:** Conversion of mangrove forests to ponds is prohibited.
- **Stocking Density:** Limited to ensure animal well-being (e.g., maximum 6 shrimps per square meter).
- **Health:** Allopathic drugs and harmful chemicals are prohibited; probiotics are allowed.

➢ **Food Processing and Handling**

- **Ingredients:** Products labelled "Organic" must contain at least 95% organic ingredients. If they contain 70–95%, they are labelled "made with organic ingredients".
- **Methods:** Only mechanical, physical, or biological processes (like smoking or filtration) are allowed. Irradiation is strictly prohibited.
- **Separation:** Organic and non-organic products must be processed and stored separately to prevent co-mingling.

Specialized Certification Modules

➢ **Large Area Certification (LAC)**

This module certifies large contiguous traditional organic areas (like villages or districts) where there is no history of synthetic input use. It requires an administrative ban on synthetic chemicals by the local government and verification by a national committee.

➢ **Mushroom, Seaweed, and Green House Production**

- **Mushrooms:** Substrate must be from organic sources; composting must reach 65°C for 6–7 days to ensure safety.
- **Seaweed:** Collection areas must be far from human activity and free from external contamination.
- **Green House:** Hydroponic and aeroponic systems cannot be certified organic as they are not grown in healthy soil ecology.

Identifying Certified Organic Products

➢ **Unified Logos**

Consumers can identify organic food by three primary marks (See Figure 1 below)

1. **Jaivik Bharat Logo:** The unified identity mark for all organic products in India, indicating adherence to NSOP.

2. **India Organic Logo:** Used specifically for products certified under the NPOP system.
3. **PGS-India Organic/Green Logos:**

    - **PGS-India Organic:** For products that are fully converted.
    - **PGS-India Green:** For products still in the **conversion period** (grown without chemicals but not yet finished the full waiting time).



Figure 1: Logos for Various Types of Organic Certification in India

Unique ID and Traceability

Every certified product must carry a Unique ID (UID) code. Consumers can enter this code on the PGS-India portal or Tracenet to verify the producer's details and the authenticity of the organic claim.

Non-Compliance and Sanctions

Both systems maintain integrity through a "Catalogue of Sanctions".

- **Minor Offences:** Incomplete documentation or missing meetings result in warnings and advice for future compliance.
- **Major Offences:** Use of prohibited synthetic fertilizers or fraud results in decertification, suspension for one year, or returning the farm to the start of the conversion period.
- **Appeals:** Operators have the right to appeal any sanction to a higher authority (like a Zonal Council or the Zonal Appellate Authority) within a set timeframe, usually 15 to 30 days.

Marketing Organic Produce

The Government of India promotes organic farming through schemes like Paramparagat Krishi Vikas Yojana (PKVY). Certified farmers can market their produce through dedicated online platforms such as the Jaivik Kheti portal, which facilitates direct sales from farmers to consumers. This system empowers small farmers by providing them with increased marketing opportunities and a credible organic guarantee without the high costs of traditional third-party inspections.

Table 1: Key difference between Participatory Guarantee System (PGS-India) and National Programme for Organic Production (NPOP)

Feature	Participatory Guarantee System (PGS-India)	National Programme for Organic Production (NPOP)
System Philosophy	• Participatory approach based on a foundation of trust, social networks, and peer-to-peer verification.	• Third-party certification involving independent, methodical assessments by accredited agencies.
Administrative Authority	• Ministry of Agriculture and Farmers Welfare (Secretariat at NCONF).	• Ministry of Commerce and Industry (Secretariat at APEDA).
Primary Market Focus	• Domestic and local markets within India.	• Export markets; mandatory for shipping organic products out of India.
Verification Method	• Peer Review/Appraisal: Farmers in a group inspect and verify each other's practices.	• Professional Inspection: Annual audits conducted by qualified inspectors

		from accredited Certification Bodies (CBs).
Group Structure	• Local Groups (LG): Minimum of 5 members from the same or nearby villages.	• Grower Groups: Minimum 25 to maximum 500 members in geographical proximity.
Control System	• Group members share collective responsibility for integrity.	• Requires a formal Internal Control System (ICS) with a manager and specific staff.
Cost to Farmers	• Low-cost and affordable for small and marginal farmers; minimal paperwork.	• Higher costs due to professional inspection fees and extensive documentation for international compliance.
Traceability Tool	• PGS-India Web Portal: Publicly accessible database for tracking products via Unique ID (UID).	• Tracenet: A mandatory web-based traceability system for exporters and CBs.
Certification Logos	• PGS-India Organic (fully converted) and PGS-India Green (in-conversion).	• India Organic Logo (Certification Trade Mark).
Conversion Period Labelling	• Products are labelled as "PGS-Green" during the conversion process.	• Products are labelled as "Produce of organic agriculture in conversion".
Recognition	• Primarily local/domestic recognition.	• Recognized by the European Commission, Switzerland, Great Britain, and Taiwan (MRA).
Decision Making	• Certification decisions are made collectively by the Local Group or its committee.	• Decisions are made by an impartial Certification Committee separate from the inspector.

Glossary

- **Accreditation**: Accreditation means a procedure adopted by the National Accreditation Body for ascertaining the competence of a Certification Body to certify organic farms, products and processes as per the National Standards for Organic Products.
- **Buffer zone:** A clearly defined and identifiable boundary area bordering an organic production site that is established to limit application of, or contact with, prohibited substances from an adjacent area.
- **Certification:** Certification shall refer to the procedure by which the accredited Certification Body by way of a Scope Certificate assures that the production or processing system of the operator has been methodically assessed and conforms to the specified requirements as envisaged in the National Programme for Organic Production.
- **Certification Body:** The Certification Body is the body responsible for inspection and certification of the operators as per NPOP standards
- **Co-mingling**: Accidental or intentional mixing of organic and conventional produce.
- **Compliance:** Compliance shall mean the adherence to the norms laid down under NPOP / PGS.
- **Conformity Report:** Conformity report shall mean the assessment report of the Evaluation Committee on the accredited Certification Body.
- **Consignment:** Consignment shall mean a quantity of product(s) under one or more HS codes covered in a single transaction certificate of the Certification Body, conveyed by same means of transport for export and import of organic products.
- **Consultancy:** Consultancy shall mean the advisory service for organic operations, independent from inspection and certification procedures.
- **Contamination**: Pollution of organic product or land; or contact with any material that would render the product unsuitable for organic certification.
- **Conventional Farming:** Conventional farming shall mean the farming systems dependent on input of artificial fertilizers and/or chemicals and pesticides or which are not in conformity with the basic standards of organic production.

- **Conversion Period:** The conversion period is the time between the start of organic management and the certification of crops as organic.
- **Facilitating agency**: An agency hired by the Local Group to assist in management and implementation of PGS norms, including data management on PGS website on behalf of Local Group/(s).
- **Habitat management**: Practices and protocol for management of an area in which ideal environment is created for existence of various plant or animal species naturally.
- **Inspection:** Inspection shall include the site visit to verify that the performance of an operation is in accordance with the production, processing and chain of custody as per NPOP standards.
- **Inspector:** A person assigned by the accredited Certification Body for assessment /evaluation of the operator at the site of activity.
- **Internal Control System (ICS):** Internal Control System means the control system organised by the member farmers in the grower group to ensure that the NPOP requirements are met.
- **Labelling:** Labelling shall mean any written, printed or graphic representation that is depicted on the label of the certified organic product, for the purpose of promoting its sale.
- **Licence:** The license is the permission granted to the operator by the accredited Certification Body on behalf of the National Accreditation Body to use the Certification Trade Mark "India Organic Logo" to certify that their products or processes are organic.
- **Livestock:** Livestock refers to any domestic or domesticated animal including bovine (including buffalo and bison), ovine, porcine, caprine, equine, poultry and bees raised for food or in the production of food. The products of hunting or fishing of wild animals shall not be considered part of this definition.
- **Local Group**: A group of farmers working together for participatory organic guarantee programme under PGS-India norms and guidelines.
- **Major Non-Conformities**: Major non-conformities are severe violations that affect the integrity of the organic system in the implementation of the standards prescribed in NPOP.
- **Minor Non-Conformities**: Minor non-conformities shall mean such non-conformities in the organic certification system of an accredited Certification Body that do not affect the integrity of organic certification.
- **National Programme for Organic Production:** The National Programme for Organic Production is an overarching architecture and a programme of the Government of India which provides an institutional mechanism for implementation of the National Standards for Organic Production.
- **National Standards for Organic Production (NSOP):** The National Standards for Organic Production sets out the standards to be followed in the cultivation/ harvest/ production /processing and trading of organic products.
- **No Objection Certificate (NOC):** An approval issued by the accredited Certification Body when its operator wants to shift to another accredited Certification Body.
- **Non-Conformity**: Non-conformity is a condition when a product, process, procedure, system, or structure deviates from requirements of the standard.
- **Organic Agriculture:** Organic agriculture is a system of farm design and management to create an eco-system, which can achieve sustainable productivity without the use of artificial external inputs such as chemicals, fertilizers and pesticides.
- **Parallel Production:** Parallel production shall mean any production where the same unit is growing, breeding, handling or processing the same products both in a certified organic quality and a non-certified organic quality. Similarly a situation with "organic" and "in conversion" production of the same product is also parallel production.
- **Part Conversion**: Means when part of a conventional farm or unit has already been converted to organic production or processing and a part is either conventional or in the process of conversion.
- **Participatory Guarantee System (PGS)** - PGS is a quality assurance initiative that is locally relevant, emphasize the participation of stakeholders, including producers and consumers and operate outside the frame of third party certification.
- **Peer Review:** A process whereby people in similar situations (in this case small holder producers) in some way assess the production practices of their peers. The process can be formal or informal.
- **Pledge:** Pledge is a written document by the operator or local group member committing to abide by the organic production system as per the PGS-India norms.
- **Scope Certificate:** A certificate issued by the accredited Certification Body to its operator annually for their specific activity in terms of production, processing and trading.

- **Service Provider**: The service provider is an external body (e.g., Self-Help Groups / NGOs / Private Agency / State Govt. Agency) contracted by Grower Groups for maintaining the documentation, training quality control, facilitating certification by an accredited Certification Body and for marketing of the produce of the Grower Groups.
- **Stocking Density (Aquaculture):** Stocking density shall mean the number of animals stocked per unit area of the production unit, such as square meter area of the pond.
- **Tracenet:** A web based traceability system for use by the registered operators and accredited Certification Bodies under the NPOP.
- **Third Party Certification:** An organic guarantee programme operated under National Programme on Organic Production involving an independent agency for verification and certification of organic production processes.
- **Transaction Certificate**: A certificate issued by the accredited Certification Body to its operator for every sale of his product to the buyer.

6.5. Natural Farming – Principles and Methods

"The real path to natural farming requires that a person know what unaltered nature is, so that he or she can instinctively understand what needs to be done – and what must not be done – to work in harmony with its processes."— Masanobu Fukuoka

1. Background

During 1960s, India was importing food grain to meet the food security. Realising the urgent need of chemical farming for the required production in the country after independence, chemical use in farming systems was recommended along with organic manures to bring green revolution.

However, the intensified use of synthetic fertiliser and pesticide has increased crop yields but resulted in negative environmental, health and economic impacts due to less use of organic manures over the years. Furthermore, the affordability and availability of synthetic inputs could be at risk as a result of rising natural gas and coal prices, and export restrictions and uncertainty around Indian fertiliser subsidies. Now its negative consequences are visible.

Therefore various alternative production systems such as organic farming, regenerative farming, conservation agriculture etc. are explored. Natural Farming is one such system for transition which could contribute to the sustainable development.

Natural farming is an agricultural production system which mainly emphasis on use of locally available on farm/traditional inputs integrated system with good agronomic practices which encourages coexistence, soil health, ecology, natural cycles, natural micro flora and fauna, diversity, production density and good production management system.

Today, natural farming is gaining attraction globally as a sustainable farming paradigm that ensures food security, ecological balance, and farmer well-being. Natural farming is not merely a technique but a philosophy. Government of India is promoting natural farming across the country under National Mission on Natural Farming. Natural farming is guided by a set of principles that distinguish it from chemical and organic farming. Some of the core principles of natural farming are presented in Fig 1.

Fig. 1: Core Principles of Natural Farming

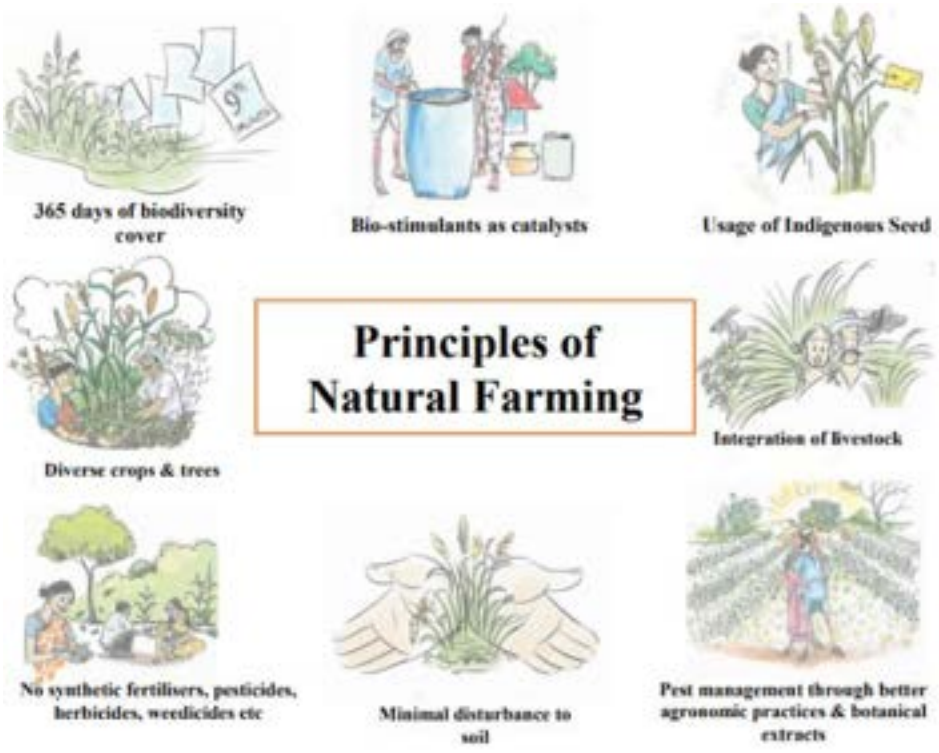


Table 1: Differences between Natural and Organic Farming

Practices/inputs	Natural Farming (NF)	Organic Farming (OF)
Concept	NF mostly relies on on-farm inputs for nutrients, insect-disease management with mandated practice of multi-cropping (intercrop, cover crop, trap crop), mulching (soil and crop residue mulch),	OF allows use of off-farm inputs as per national standards for organic farming apart from on-farm inputs for nutrient, insect-disease management. Practices such as multi-cropping (intercrop, trap crop,

	Whapasa and application of concoctions prepared from cow dung and urine.	cover crop etc), mulching etc are optional.
Seed treatment	Seed treatment with beejamrit prepared using desi cow dung, cow urine, lime, virgin soil and water	Seeds are treated with bio-control agents such as Trichoderma, Pseudomonas and bio-fertilizers such as Azospirillum, Azatobacter, PSBs etc
Nutrient management	Application of an enriched microbial culture such as jeevamrit and Ghana jeevamrit prepared using desi cow dung, cow urine, jaggery, pulse flour and virgin soil as a microbial enhancer for native nutrient supply	Mainly through green manuring, legume crops, biofertilizers, vermicompost, enriched composts, VAM, panchagavya, cow urine, non-edible oilcakes, effective microorganisms (EM) consortium cultures and biodynamic (BD) formulations (BD-501, BD-502 etc).
Plant protection	Pest and disease control are carried out using bio-formulations such as Neem Seed Kernel Extract, Neemaster, Brahmaster, Agniaster, Dashparni ark, Butter milk etc., prepared from desi cow urine, cow dung, tobacco, green chilli, garlic; neem, karanj, custard apple, castor & datura leaves and water etc.	Pest and disease control is primarily through bio-control agents such as Pseudomonas spp., Trichoderma spp., Trichogramma spp. etc; Bio-pesticides like Neem based formulations, plant based extracts, pest repellent plants (trap crops) on the ridges and borders; and using Yellow / blue sticky traps etc. light traps and Inter-cultivation practices.

2. Components of Natural Farming

Beejamrutha

It is a fermented microbial solution, with loads of plant-beneficial microbes, and is applied as seed treatment. Fungal and other seed and soil-borne infections may impact the seeds sown in the field. The seeds are shielded against soil borne pathogen infections by seed treatment with "Beejaamrut". Any planting material, including seeds and seedlings, can be treated with it. Bijamrita works well to shield young roots from fungal infections and seed-borne illnesses that frequently strike plants following the monsoon season. It is made of the same components as Jeevamrutha, including soil, lime, and cow dung from the area. Cow urine is a potent natural fungicide. Any crop's seeds can be coated and manually mixed with Bijamrita before being thoroughly dried and used for sowing.

Preparation:

5 kg cow dung
5 liters cow urine
50 g lime
Handful of soil
Mixed with water and used to coat seeds before sowing.

Jeevamrutha

Jeevamrutha is a fermented microbial concoction which enhances the fertility of soil using cow urine, cow dung, gram flour and jaggery and hand full of undisturbed soil.

Benefits: By promoting soil microbial activity, this culture improves the availability of native nutrients to plants and helps to increase the N-fixers, P-Solubilizes and K-Mobilizers in the soil.

In addition to providing nutrients, it serves as a catalytic agent, which stimulates earthworm activity and the activity of microorganisms in the soil. During the 48-hour fermentation process, the aerobic and anaerobic bacteria found in the cow dung and urine multiply as they consume organic ingredients (like pulse flour). As an inoculant of native species of microbes and organisms, a handful of undisturbed soil is also added.

Jeevamruth also aids in the defence against bacterial and fungal plant illnesses. Successful practitioners feels that Jeevamrutha is only required during the initial three years of the transition, after which the system can function on its own.

Preparation (for one acre):

10 kg local cow dung

5–10 litres cow urine

2 kg jaggery

2 kg pulse flour (gram flour preferred)

Handful of soil from field bunds

Dilute in 200 litres of water and ferment for 3-5 days

Application: Spray on crops or apply to soil every 15 days

Ghana-jeevamrut: It is a solid form of microbial consortium and it is prepared by mixing the following:

100 kgs of indigenous cow dung (air dried for 4-5 days)

2 kgs of jaggery

2 kgs of gram flour

10 litres of indigenous cow urine

Handfull of undisturbed soil (undisturbed bunds/ forest/tree cover).

After adding all the components, this can be prepared like cakes, dried and stored in shade

Ghanajeevmritha can be applied by broadcasting method during field preparation. Depending upon the soil organic carbon level, the doses of ghanjeevamrit is to be applied. The dose starts from 400 kg per acre per crop season.

Acchadana/Mulching: The process of mulching involves adding cover crops, organic debris, or agricultural residue to the top soil

Benefits: Decomposing the materials used for mulching results in humus, which not only improves soil nutritional status but also conserves topsoil, boosts soil water retention, reduces evaporation loss and promotes soil fauna. It also inhibits weed growth. Leguminous cover crops in the system helps for biological nitrogen fixation besides the above benefits.

Whapsaa /Moisture (Soil Aeration): Whapasa means the mixture of 50% air and 50% water vapour in the cavity between two soil particles. It is the soil's microclimate on which soil organisms and roots depend for most of their moisture and some of their nutrients.

Benefits: For plants to grow and thrive, the soil must have adequate aeration. Applying Jeevamrita and mulching promotes soil aeration, humus content and availability of water, water retention capacity, and soil structure, all of which are essential for crop growth, particularly during dry spells. This also helps for harnessing the water vapour.

3. Pest and Disease Management

Natural farming replaces synthetic pesticides with eco-friendly, farm-made formulations.

Neemastra: It is made from neem leaves, cow dung, and cow urine, effective against sucking pests. The world's most insecticidal plant, neem, has been shown to be effective against 410 different species. It has been used as a botanical insecticide against pests since ancient times. Neem pulp is the main component of this mixture. Five kilograms of leaves are ground into a fine paste, and five kilograms of cow dung are added to five litters of cow urine. The mixture is then allowed to ferment for a full day, filtered, and sprayed to protect against mealy bugs and sucking pests.

Agniastra: A mixture of cow urine, chili, garlic, and neem leaves to repel harmful insects. It is a concocted mixture made from cow urine- 10 litres, tobacco- 1 kg, green chili and garlic paste-500 g, and neem pulp-5 kg. The mixture is then continuously boiled for 5 times then filtered. Then the mixture is then fermented for 24 hours before being used. Leaf roller, pod borer, stem borer and fruit borer are all successfully controlled by its application.

Brahmastra: It is a herbal concoction using neem, custard apple, papaya, guava, and other leaves boiled in cow urine. It is a mixture that includes 3 kg of pulp, 2 kg of papaya, 2 kg of pomegranate, 2 kg of guava, 2 kg of Lantana camera, and 2 kg of white datura leaf pulp. Sitapal (custard apple) leaf pulp makes up 2 kg of the mixture. (If Datura leaves and Lantana camara are available, use them.) Like Agniastra the above composition has to be mixed in ten liters of cow urine. Further, the mixture is continuously boiled five times, then filtered and allowed to ferment for a full day. It works well to control fruit borers, pod borers, and sucking pests when sprayed at a concentration of 2%.

4. Crop Diversity and Mixed Cropping / Multi-variate cropping / Multi layer cropping

Natural farming discourages the practice of monocultures. Instead, intercropping cereals with pulses improves nitrogen fixation and balances soil fertility. The practice of Agroforestry integrates trees with crops and livestock, providing shade, fodder, and biomass. And integration of bee keeping improves the pollination and productivity.

Barah Anaaj in India: A traditional system where 12 crops are grown together, including cereals, pulses, and oilseeds. This system is also practiced in Natural Farming.

5. Zero Tillage and Natural Seed Sowing

Minimal soil disturbance is practiced in natural farming. Seeds are sown directly without deep ploughing, allowing soil organisms to thrive.

Also, clay seed balls (mixing seeds with clay and compost) are scattered before rains to ensure natural germination/ Pre-monsoon dry seeding in fallow.

6. Integration of Livestock

Native cows, especially indigenous breeds, are central to natural farming. Cow dung and urine serve as the base for most formulations. Goats, poultry, and buffaloes are integrated for nutrient recycling and diversified income. Cow dung and Cow urine is part of natural farming for preparation of inputs.

Advantages of Natural Farming

1. Environmental Benefits

- Soil Health Restoration: Improves soil organic matter, microbial activity, and fertility.
- Biodiversity Conservation: Encourages mixed cropping, agroforestry, and beneficial insects.
- Reduced Pollution: Avoids chemical fertilizers and pesticides that contaminate soil and water.
- Climate Change Mitigation: Enhances carbon sequestration in soil and reduces greenhouse gas emissions.

2. Economic Benefits

- Low Input Costs: Relies on locally available resources (cow dung, urine, crop residues) instead of costly chemicals.
- Farmer Self-Reliance: Reduces dependency on external markets for seeds and agrochemicals.
- Debt Reduction: By lowering expenses, it prevents farmers from falling into debt traps.
- Sustainable Livelihoods: Ensures steady income even at moderate yields due to low expenditure.

3. Health and Nutrition

- Chemical-Free Food: Provides safe, toxin-free crops for consumers.
- Higher Nutritional Value: Naturally grown food is richer in micronutrients and antioxidants.
- Food Safety: Minimizes health risks linked to pesticide residues.

4. Social Benefits

- Community Empowerment: Encourages farmer groups and knowledge sharing.
- Preservation of Traditional Knowledge: Revives indigenous practices and wisdom.

- Inclusive Farming: Suitable for small and marginal farmers, women, and resource-poor households.

5. Resilience and Sustainability

- Drought Resistance: Practices like mulching and Whapasa improve water retention and reduce irrigation needs.
- Pest and Disease Resistance: Biodiversity and natural repellents reduce crop losses.
- Long-Term Sustainability: Maintains soil fertility and ecological balance for future generations.

6. Weed management in Natural farming:

In Natural farming use of any herbicides and bio herbicides are not recommended. The only way for weed management is mulching, hand weeding, cover crops with higher biomass legume crops, Intercrops with leafy vegetables will become a live mulch and also a source for extra income. In high weed infestation areas, stale seed beds (allowing weeds to grow and incorporating in the soil before flowering) helps to reduce the weeds significantly.

Continuous monoculture, or "monocropping" where the same crop is grown year after year, can lead to unsustainable environment such as building up disease pressure and reducing particular nutrients in the soil. The practice has also been criticized for its environmental impacts, in which soil degradation being one of the major impact due to non-rotational cropping.

Natural farming encourages multiple cropping system as to broaden the scope of diversity in farming with efficient usage of land, water, nutrient recycle and pest protection strategies that are operating in this agro ecosystem. This in turn raises the net income by minimizing the risk of crop loss.

Natural farming is suitable for all crops provided proper planning and integration of all the components are made. However, hybrids of crops are not preferred and GMO are not allowed considering the principles of localized on-farm input based farming. Further hybrids require higher amount of nutrients in short time for such crops it is difficult to provide sufficient quantity of nutrients through natural farming.

Conclusion

Natural farming represents a paradigm shift in agriculture, moving away from input-intensive systems toward ecological self-sufficiency. It restores the health of soil, water, and ecosystems while providing safe, affordable food. Though challenges remain in terms of scalability, policy support, and market development, natural farming holds immense promise for sustainable agriculture. With growing evidence from India and other countries, it can serve as a blueprint for climate-resilient, farmer-friendly, and environmentally sustainable food systems.

Module VII: IRRIGATION AND WATERSHED MANAGEMENT

7.1. A. Basic Principles of Irrigation

It is generally defined as an application of water to soil for the purpose of supplying the moisture essential for normal plant growth and development.

1. Basic Principles of Irrigation

The key principles of irrigation include understanding crop water requirements (Table 7.1) selecting the correct irrigation method, efficient water application, uniform water distribution and scheduling of irrigation properly.

The primary objective of irrigation is to provide sufficient water while minimizing waste and maximizing crop yield.

Table 1: Water requirement of principal food crops

Crop	Water requirement (mm)
Rice	1100-1250
Maize	500-600
Ragi	350
Sugarcane	1800-2200
Cotton	500-600
Groundnut	500-550
Black gram, Greengram	200-250
Red gram	300-500
Citrus	900-1200
Tomato	600-800
Chilli (green)	400-600

2. Soil water relations:

The availability of water in the soil depends on the soil water relations.

Soil properties influencing soil-water relations

Soil depth

Soil depth refers to the thickness of soil cover over hard rock or hard substratum below which roots cannot penetrate. Soil depth is directly related to the development of root system, water storage capacity, nutrient supply and feasibility for land leveling and land shaping.

Soil Conservation Division, Ministry of Agriculture, New Delhi, recognizes the following classes for irrigation purposes:

Table 2: Classification of Soil depth

Soil Depth (cm)	Class
Less than 7.5	Very shallow
7.5-22.5	Shallow
22.5-45.0	Moderately deep
45.0-90.0	Deep
More than 90.0	Very Deep

A Shallow soil has limited moisture holding capacity, restricted feed zone, restricted root growth, need frequent irrigations. Soil depth is important for interpreting water storage capacity.

Soil texture

Soil texture (most fundamental soil property) is closely related with soil water relationship. It refers to the relative proportions of different sized mineral particles in the soil i.e sand (coarse), silt (medium) and clay (fine).

Table 3: Common soil textural classes

Common Name	Texture	Basic soil textural class
Sandy Soils	Coarse	Sands and Loamy sand
Loamy Soils	Moderately coarse	Sandy loam and Fine sandy loam
	Medium	Very fine sandy loam, Loam, Silt loam & Silt
	Moderately fine	Sandy clay loam, Silty clay loam and Clay loam
Clayey Soils	Fine	Sandy clay, Silty clay & Clay

Effective root zone depth:

The soil depth from which the crop extracts most (nearly 90%) of the water needed to meet its evapotranspiration requirements is known as effective crop root zone depth. The reference moisture extraction depth for various crops is shown in Table 7.4.

Table 7.4 Design moisture extraction depths for various crops

Rooting Depth of Crops	Crops
Shallow rooted (60 cm)	Cauliflower, Cabbage, Onion, Potato, Lettuce
Moderately deep rooted (90 cm)	Carrot, French bean, Pea, Chilli, Musk melon, Banana
Deep rooted (120 cm)	Tomato, Water melon, Sugar beet
Very deep rooted (180 cm)	Apple, Citrus, Guava, Grapevine, Mango, Pomegranate

Moisture extraction pattern refers to the amount of soil moisture expressed as percentage extracted from different layers in the soil profile. In most plants, the concentration of absorbing roots is greatest in the upper part of the root zone (usually in the top 45 cm) and near the base of the plant (fig 7.1). Hence extraction of water from the topsoil layers is usually more as compared to lower layers.

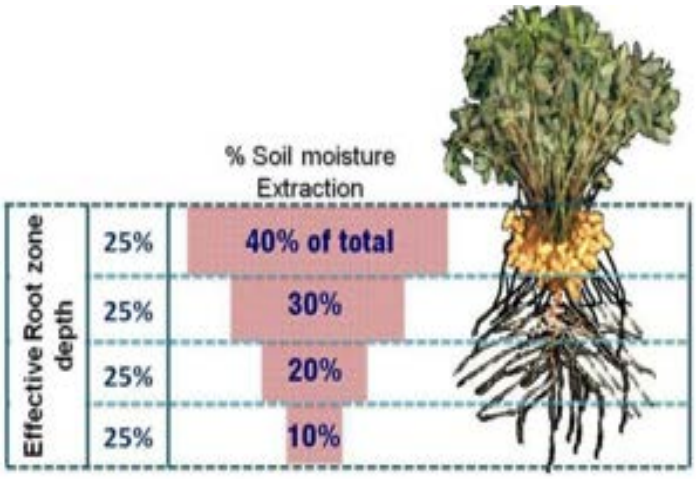


Fig 7.1: Basic soil moisture extraction pattern

Critical growth period is the stage or stages of growth of the crop (Table 7.5) at which moisture stress has the greatest effect on quality and quantity of yield. If the crop faces water stress during this period, the yield loss cannot be compensated, even with good water and other management practices at other growth stages.

Scheduling of irrigation to crops – Different criteria

Scientific irrigation scheduling is a technique that determines the correct time and optimum quantity of water to apply during each irrigation. It aims to optimize crop yields with maximum water use efficiency while protecting soil health.

Irrigation is scheduled based on different approaches *e.g.* soil water regime, plant indices, meteorological, rough methods of farmers, water balance etc.

Table 4: Critical growth periods of crops for water supply/moisture stress

	Crop	Critical growth period for water supply/moisture stress
1	Rice	Primordial Development, Heading and Flowering
2	Sorghum	Booting, Blooming, Milky and Dough stages
3	Ragi	Primordial Initiation and Flowering
4	Maize	Tasseling, Silking
5	Bajra	Heading and Flowering
6	Wheat	Crown Root Initiation, Shooting and Earing
7	Sesame	Flowering to Maturity
8	Sunflower	Flowering and Seed development
9	Soybean	Flowering and Seed formation
10	Cotton	Flowering and Boll development
11	Chilli	Flowering and Fruit development
12	Tomato	Flowering and Fruiting
13	Citrus	Flowering, Fruit Setting and Fruit Enlargement
14	Mango	Flowering and Fruit Development

Feel and appearance of soil:

This is one of the oldest and simple methods of determining the soil moisture content. It is done by visual observation and feel of the soil by hand (Fig 7.2). The accuracy of judgment improves with experience.



Fig 7.2 Rough methods for farmers-Feel and Appearance

Depletion of the Available Soil Moisture (DASM):

In this method the permissible depletion level of available soil moisture in the effective crop root zone depth is commonly taken as an index for scheduling irrigations to field crops.

In general, for many crops scheduling irrigation at 20-25% DASM in the soil profile was found to be optimum at moisture sensitive stages. At other stages, irrigations scheduled at 50% DASM were found to be the optimum (Table 7.6).

Table 5: Optimum DASM levels for various crops:

Crop	Optimum soil moisture depletion levels
Maize	25-50% DASM
Sugarcane	25-65% DASM
Groundnut	25-40% DASM
Cotton	65% DASM
Sesame	50% DASM
Leafy Vegetables	20% DASM
Tobbaco	35% DASM
Wheat	50% DASM

Soil Moisture Tension:

Soil moisture tension (a physical property of film water in soil) may also be used as an indicator for scheduling irrigation to field crops. It is monitored by tensiometers at a specified depth in the crop root zone. They are installed in pairs, one in the maximum rooting depth and the other below this zone. The irrigation is commenced whenever the critical soil moisture tension is reached to a certain limit (for e.g. 0.4 or 0.6 or 0.75 nars etc) in the upper tensiometer (Threshold shown in Table 7.7)

Table 6: Threshold soil moisture tension values for scheduling irrigation

	Crop	Critical soil moisture tension (centi bars)	Depth of maximum rooting density (cm)
1	Wheat	40-50	30
2	Maize	25-50	30
3	Sorghum	50-65	60
4	Sugarcane	30-65	30
5	Cotton	40-50	30
6	Tobacco	30-40	30
7	Soybean	50-60	30
8	Potato	25-50	30

Visual Plant Symptoms:

In this method the visual signs of plants are used as an index for scheduling irritations. It may be rolling, curling, may lead to appearance of carotenoid (yellow and orange colour) and anthocyanin pigments etc for various crops (Table 7.8)

Table 7: Visual symptoms w.r.t. irrigation scheduling for different crops

Plant	Visual symptoms for irrigation scheduling
Maize	Plant wilting, drooping, curling and rolling of leaves
Beans	Change in foliage colour and leaf angle
Sugarcane/Cotton	Shortening of internodes
Grapes	Retardation of stem elongation
Almond	Leaf abscission, lack of new growth, redness in terminal growth points

Soil-cum-sand mini-plot technique:

In this method (also referred to profile modification technique) a mini plot is prepared by mixing sand with it. The basic principle is to reduce the available water holding capacity of soil profile (i.e., effective root zone depth). The prepared plot shows moisture deficiency symptoms earlier than the plants in the rest of the field. An area of 1 m x 1 m is selected in the field and a pit of 1 m depth is excavated. About 5% of sand by volume is added to the dug up soil and mixed well. The pit is then filled back with the mixture and while filling up every 15 cm layer is compacted well. This makes sure the pits bulk density is the same as that of surrounding soil. The crop is allowed to grow normally both in the mini plot along with the rest of the field. The field is irrigated when the plants in the mini plot show wilting symptoms, considering it as a warning of water stress.

Plant population:

An area of 1 m^2 is demarcated, preferably in a high spot. In that area same crop is planted with 1.5 to 2 times (or even more) the plant population. The crop in the demarcated area droops/wilts earlier than the crop in the rest of the field. It can be treated as an indication of water deficit and irrigation is scheduled for the crops accordingly.

Indicator plants:

Some workers have suggested the use of indicator plants as a guide for scheduling irrigations. In wheat, scheduling irrigations on the basis of wilting symptoms in maize and sunflower gave the highest grain yields.

7.1. B. Water use Efficiency and Methods of Irrigation

Water use efficiency measures the quantity of water taken up by the crop during its crop life to produce a unit quantity of the output i.e., crop yield. In general, the lower the water resource input requirement per unit of crop yield produced, the higher the efficiency.

Crop water use efficiency

Crop water use efficiency is a ratio between marketable crop yield and water used by the crop in evapotranspiration.

$$\text{WUE (kg/ha.mm)} = \frac{Y}{ETc}$$

Where,

WUE = Water use efficiency in kg/ha-mm
Y = Marketable crop yield in kg/ha
ETc = Crop evapotranspiration in mm

Table 8: Water Use Efficiency of various crops

Crop	Water Requirement (mm)	Grain Yield (kg/ha)	WUE (kg/ha.mm)
Rice	1200	4500	3.7
Sorghum	500	4500	9.0
Maize	625	5000	8.0
Finger millet	310	4137	13.7

Field water use efficiency

Field water use efficiency is a ratio between marketable crop yield and field water supply which includes water used by the plant in metabolic activities, ET and deep percolation losses.

$$\text{FWUE (kg/ha.mm)} = \frac{Y}{WR}$$

Where,

FWUE = Field water use efficiency in kg/ha-mm
Y = Crop yield in kg/ha
WR = Water used in metabolic activities + ET and deep percolation losses in mm

Water Conveyance Efficiency

It is the ratio between the water delivered to the irrigated field and the total quantity of water delivered from source.

$$Ec = \frac{Wf}{WD} \times 100$$

Ec= Water conveyance efficiency
Ef= Water delivered to the field / plot (L/sec)
WD= Water delivered from the source (L/sec)

Water Application Efficiency

It is the ratio between the quantity of water stored in the root zone and water delivered to the irrigated field/ plot.

$$Ea = \frac{Ws}{Wf} \times 100$$

Ea= Water application efficiency (%)
Ws= Water stored in the root zone/ plot (cm)
Wf= Water delivered to the plot (cm)

Water Storage Efficiency:

It is the ratio between the water stored in the root zone and water needed in the root zone prior to irrigation.

$$Es = \frac{Wsx}{Wn} 100$$

Es= Water storage efficiency (%)
Ws= Water stored in the root zone (cm)
Wf= Water needed in the root zone (cm)

Water Distribution Efficiency

It is the ratio between the average numerical deviations in depth of water stored from average depth (Y) stored during irrigation and the average depth (d) stored during irrigation.

$$Ed = (1 - Y/d) \times 100$$

Ed= Water distribution efficiency (%)
Y = average numerical deviations in depth of water stored from average depth stored during irrigation
d= average depth of water stored during irrigation

Project Efficiency:

It is the ratio between average depth of water stored in the root zone during irrigation and water diverted from the reservoir.

$$Ep = \frac{Ws}{Wr} \times 100$$

Where,

Ep= Project efficiency (%)
Ws= Water stored in the root zone (cm)
Wr= Water diverted from the reservoir (cm)

Over all irrigation efficiency of a farm is a product of

Ef= Ea x Es x Ed

Over all irrigation efficiency of a project is the product of

Ep= Ea x Es x Ed x Ec

The factors influencing water use efficiency is categorized.

Factors Influencing WUE

Climatic	Genetic	Agronomic
Temperature	Crop species	Time of sowing
Precipitation	Crop Varieties	Depth of Sowing
Sunlight		Plant Population
Wind Velocity		Fertilizers
Relative Humidity		Irrigation Method
		Pests and Diseases
		ET control measures

Methods of Irrigation

i. Uncontrolled Surface Flooding (Wild Flooding)
ii. Controlled Surface Flooding
iii. Pressurized Irrigation systems

i. Uncontrolled Surface Flooding (Wild Flooding):

- Application of water in the field without any bund
- Wets the soil surface completely
- Practiced in areas of abundant irrigation water
- Practiced in rice, low value pastures, lawn and millets

Merits:

- No land levelling and land shaping
- Less labour and land preparation charges
- Less skill required by irrigator

De-Merits:

- Most of the applied water is lost as deep percolation and surface run off.
- Low Irrigation efficiency

ii. Controlled Surface Flooding

Basin: Check Basin, Ring Basin
Border Strip
Furrow: Deep Furrow

- Field is divided into 4-4000 m^2 plots guided by bunds on all sides
- Practiced in nearly levelled lands
- No run off, wetting depth is uniform
- Particularly useful for fine textured soils with low permeability
- Useful for crops such as groundnut, ragi, sorghum, vegetables
- Also useful to leach out salts below crop root zone depth for reclamation of saline soils

Merits:

- Uniform application of water
- Smaller streams also can be used for irrigation of crops
- Simple and cheaper when equipment is used for bund construction

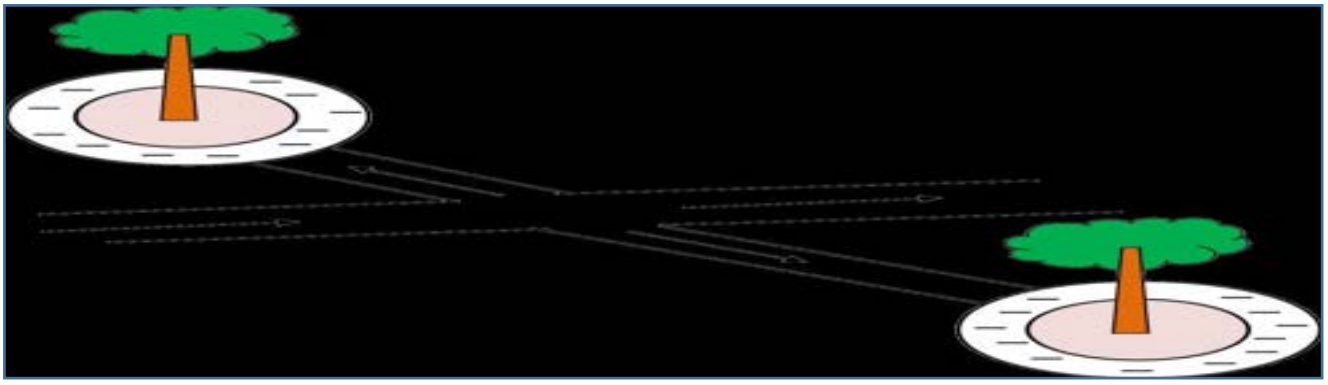
Demerits:

Limited for levelled land
Considerable area is lost under construction of bunds and channels
Bunds interference with inter-cultivation equipments
Laborious work

iii. Ring basin method:

Modification of check basin method

Suitable for sparsely grown orchard crops and cucurbits
Circular bunds are constructed around each tree or group of trees
Basins are suitably connected to irrigation channel so that each basin is irrigated separately



Supply Channel Field Channel

Merits:

High irrigation application efficiency
No skilled person required, no threat of erosion

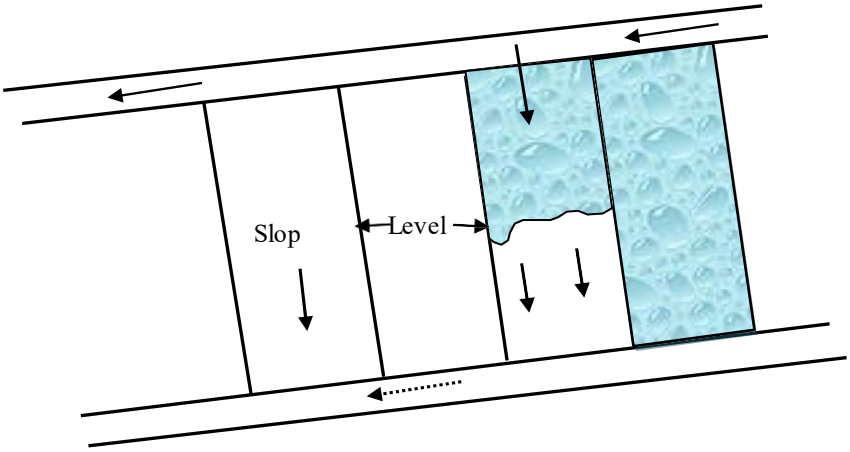
Demerits:

- High labour cost
- Restricted use of machinery
- Limited to uniform lands

iv. Boarder Strip Method

- Field is divided into number of long parallel strips of 5-15 m width and 75-300 m long

- Separated with small dykes or ridges of 15 cm height
- Laid out in the slope direction
- Water is released into each strip directly from irrigation channel in the upstream
- Slope must be uniform and transverse slope must be negligible
- Suitable for close growing crops such as wheat, barley, groundnut, bajra, berseem etc.,



Merits:

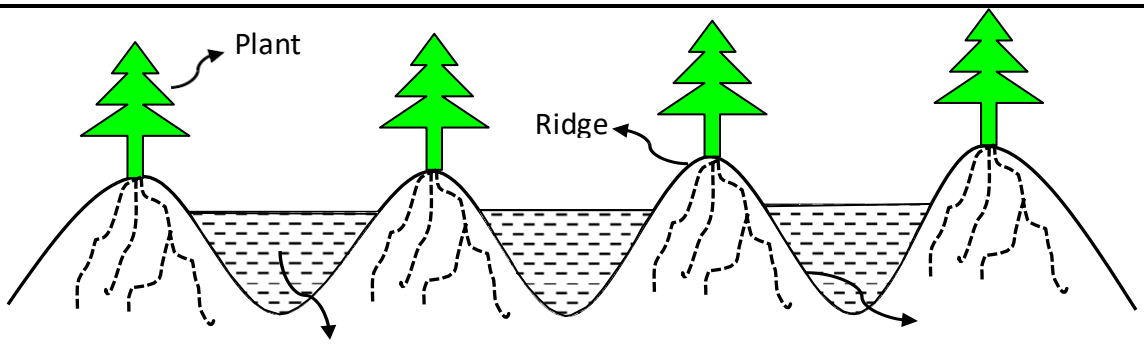
- Large water streams can be used safely
- Provides uniform wetting of soil profile
- Low labour requirement

Demerits:

- Requires relatively large water streams
- Wastage of water by deep percolation in coarse textured soils

v. Deep Furrow Method

- Flat bed surface is converted into a series of ridges and furrows running down the slope
- The spacing of the furrow is based on the row crop
- The length of furrow and shape depends on texture, intake rate
- Coarse textured soils: V shaped, furrow length < 70 m
- Fine textured soils: U shaped, furrow length < 200m
- Used to irrigate potato, sugarcane, maize, cotton, melons, sugarbeet, vegetables etc.



Merits:

- High WUE
- Furrows act as drains in the event of heavy rainfall
- Low evaporation losses

Demerits:

- Not suitable for coarse textured soils with high infiltration rates
- Possibility of intra furrow soil erosion
- Labour intensive

vi. Pressurized Irrigation

a. Sprinkler Irrigation

Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall. Water is pumped at a pressure of 2–5 kg/cm² through main and sub-main pipes and then to laterals and riser pipes. It is ejected finally through nozzles or perforations like a projection. It is sprayed in the air as small drops (0.5–4 mm) that fall evenly on the land or crop surface in a uniform pattern and at a rate (0.06–5000 LPH) lower than the soil's infiltration rate.

Merits:

- Increases the cultivable are by eliminating field channels and their maintenance
- Close control over water application i.e., no runoff losses because water is applied below or equal to infiltration rate
- Convenient for giving light and frequent irrigations
- Suitable in undulated lands, soils with shallow depth and areas located at higher elevation than the water source
- Feasibility of frequent, short water applications for germination, cooling & frost protection to plants, etc
- Less soil erosion
- Higher conveyance, application efficiency and yield than surface methods, water saving (upto 30-50%)

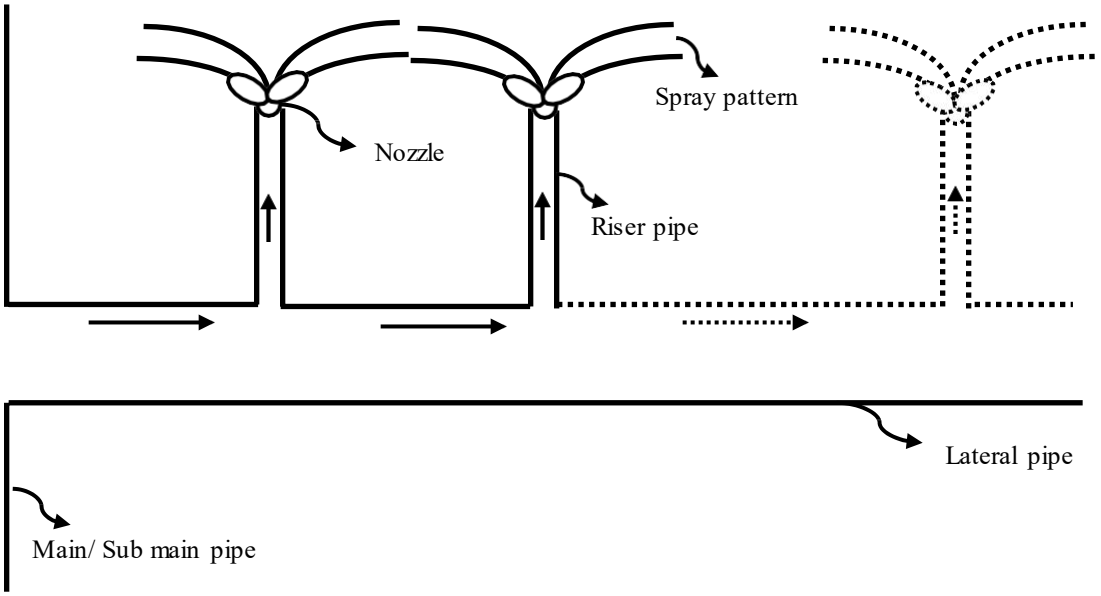
Suitable crops

Sprinkler irrigation is suited for most field crops viz., wheat, lucerne, groundnut, bengal gram, green gram, black gram, potato, leafy vegetables, sunflower, barley, bajra, maize, wheat etc wherein water can be sprayed over the crop canopy.

b. Drip Irrigation

Drip irrigation is defined as the precise, slow and frequent application of small quantities of water to the soil in the form of discrete drops, continuous drops, and tiny streams through emitters located at selected points along a water delivery lateral line.

Water is applied directly to the crop's root zone as drops or tiny streams through emitters. The discharge rate is below 8 L/h for point source emitters and below 4 L/h for line source emitters.



Merits:

- Enhanced plant growth, crop yield and premium quality produce
- Water saving due to higher water application efficiency
- Precise and uniform delivery of water to crops due to controlled water application
- Suitable for irrigating high-value crops raised in greenhouses, plastic tunnels, potted plants and under plastic mulches
- Limited weed growth because only a fraction of the soil surface is irrigated
- Reduced operational and labour costs
- Feasible to irrigate crops raised in small & irregularly shaped narrow lawns, and on undulated land terrains
- Suitable to highly permeable & low water holding sandy and desert soils, saline and slowly permeable alkaline soils, wastelands, slopy lands and rocky hills, road embankments, abandoned mine areas etc.
- Less soil erosion
- Fertilizer can also be applied with irrigation

Limitations:

- Sensitivity to emitter clogging
- Salt accumulation in soil
- Mechanical damage to system components
- Lack of microclimate control such as frost protection and evaporative cooling.
- Operational constraints such as high technical skills, stringent filtration and operating pressures etc

Suitable crops

Presently drip irrigation has the greatest potential in the following crops:

Fruit crops – Mango, Citrus, Grapes, Guava, Pomegranate, Banana, Papaya, Watermelon, Litchi, Fig, Ber, Amla, Sapota

Vegetable crops – Tomato, Brinjal, Bhendi, Cabbage, Cauliflower, Capsicum, Chilli, Gourds

Plantation crops – Oil palm, Coconut, Arecanut, Cashewnut, Coffee, Tea

Field crops – Cotton, Sugarcane, Tobacco, Sugarbeet, Castor

Tuber & Bulb crops – Potato, Cassava, Onion, Sweet potato, Radish, Colocasia

Spices – Turmeric, Ginger, Cardamom

Flowers – Rose, Gerbera, Orchids, Anthurium, Gladiolus, Carnations, Jasmine, Chrysanthemum, Marigold

7.1. C. Importance of Water Management in Crop Production

Water is one of the most essential inputs for crop production, as plants require it constantly for various physiological processes like photosynthesis, respiration, absorption, nutrient transport, cell division and other activities. Both shortage and excess of water adversely affect plant growth, yield and quality. Without enough water, crops may experience stunted growth, lower yields or even complete failure. Again excess water application leads to reduced metabolism, increased vegetative growth, less aeration etc. Since rainfall is highly erratic in India, often causing droughts and floods, proper irrigation and drainage systems are vital for successful farming. The construction, operation and maintenance of canal network system with dams/reservoirs is expensive. Problems like water logging, salinity, unproductive farmland etc arises due to misuse of water. Efficient water management includes providing irrigation with right time, amount, methods and less wastage. It is also crucial for retaining good crop health, soil quality and overall productivity.

1. Why is Water Management Important in Agriculture?

Proper water management is essential for the following reasons.

i. Sustaining Crop Health and Yield:

It ensures plants receive the right amount of moisture without the risk of overwatering. It helps to maintain consistent crop yield

ii. Conserving Water Resources:

It helps in saving of water and ensures its availability for future generations. In drought-prone areas, it prevents crop failure and endorses food security.

iii. Reducing Environmental Impact:

It reduces runoff and soil erosion, preserves ecosystems, defends wildlife habitats and ultimately protects the natural environment. It also minimizes the risk of fertilizer and pesticide contamination in water bodies.

iv. Economic Benefits:

It reduces expenses associated with water procurement and energy for pumping, thereby, promotes economic sustainability. It also maximizes farmers' returns on investment.

v. Climate Resilience:

It enables farms to adjust to changing weather and climate conditions, improving resilience.

2. The Role of Water in Agriculture

- Water is essential for photosynthesis, the process by which plants produce food
- It also helps in the absorption of nutrients from the soil
- It aids in temperature regulation (for both soil and plant)
- It provides structural support to plants
- It is needed for germination
- It helps to dilute/leach salts in the soil

3. Key Water Management Techniques

i. Micro irrigation (drip and sprinkler irrigation):

In this method water is applied directly to the plants' root zone (drip)/ plants (sprinkler) like natural rainfall through a network of plastic pipes via pump/overhead tank. It minimizes evaporation and runoff, improves irrigation efficiency, promotes better growth and higher yields.

ii. **Rainwater Harvesting:**

This technique involves capturing rainwater from roofs or other surfaces and storing it in tanks or reservoirs for later use especially in dry periods. The dependence on ground water, municipal or village supply, other external water sources etc can be minimized. It also lowers water bills.

iii. **Soil Moisture Monitoring**:

Soil moisture sensors can be used for precise application of irrigation water to plants. Based on real-time data monitoring, water is applied only when soil moisture drops to a specific level. It prevents over-irrigation and leads to water saving and better plant growth.

iv. Mulching:

Mulching (organic /inorganic) helps to retain soil moisture, reduce evaporation, suppress weed growth, facilitates soil solarization, improves organic matter and soil fertility etc.

v. Lining of Ponds:

Ponds are lined with polythene to prevent seepage loss

vi. Recharging of Groundwater:

Ground water is replenished by allowing rainwater or surface water to seep into aquifers.

4. Sustainable Water Management Practices

i. Crop Rotation:

Different types of crops are grown in the same area in sequential seasons. Nutrients are extracted from various soil layers depending on the requirement and root structure. It prevents soil nutrient depletion, improves soil structure, water retention, biodiversity and reduces pests and diseases.

ii. **Cover Cropping:**

Cover crops are grown during off-season (no primary crops). They (ground cover), reduce evaporation, keep soil moist and lowers irrigation needs. Their roots hold soil in place, preventing erosion from wind and water. They also add organic matter to the soil as they decompose.

iii. Water Recycling:

Water is reused from various sources (agricultural runoff, treated wastewater, or rainwater) for irrigation and other agricultural purposes. It reduces reliance on freshwater sources, water expenses and fertilizer needs. (As it contains residual nutrients from previous use)

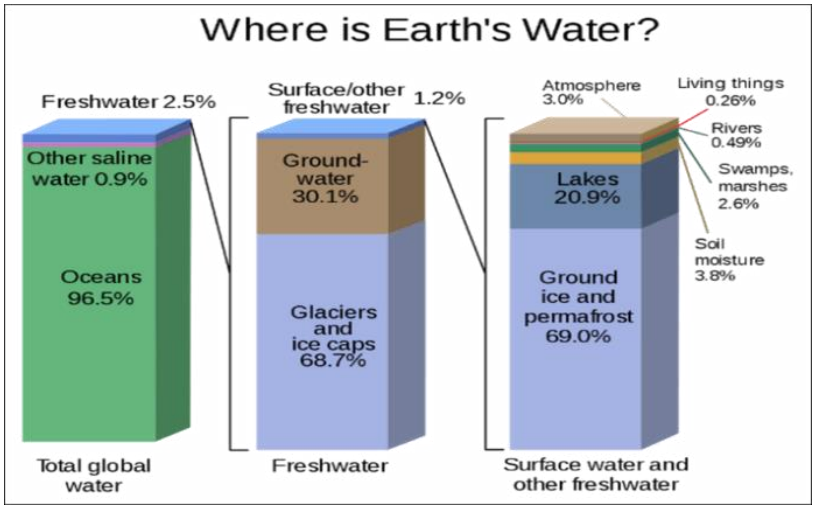
Conclusion

The significance of water management in farming is very crucial. It ensures that crops get the necessary water, promotes resource conservation, supports sustainable and productive farming and reduces the impacts of climate change on agriculture.

7.2. A. Installation and Management of Micro irrigation Systems (Sprinkler & Drip Irrigation)
7.2. B Budget Requirement for Installation of Micro Irrigation System

Only 2.5% of earth's water is fresh water and rainfed agriculture contributes significantly to meet food requirements. We need to conserve this precious water and use it judiciously for irrigating different crops based on their water requirement. Roughly 70% of freshwater resources are used for agriculture. Irrigation is the process through which controlled amount of water can be supplied through artificial means such as pipes, ditches, sprinklers etc. the main objectives of irrigation systems is to help agricultural crop growth, landscape maintenance, reduce the effect of inadequate rainfall etc.

Irrigation is the artificial application of water to land, essentially for different agricultural activities to assist the growth of crops. It's very important process in areas where rainfall is insufficient or unreliable, ensuring plants to receive the required moisture for healthy development during various critical crop growth stages like germination, growth, nutrient uptake and high yields. Farmers have used irrigation for thousands of years with traditional methods like canals, wells evolving into modern and efficient irrigation systems and supply water for the nutrition and growth of a plant. Irrigation is the artificial application of water to land for agricultural production, especially in areas with insufficient rainfall. It ensures year-round crop availability, reduces reliance on unpredictable rainfall, and strengthens food security. Irrigation is crucial for agriculture because it enables the cultivation of crops in arid and semi-arid regions, where water scarcity would otherwise limit or prevent farming. Additionally, irrigation can supplement rainfall in other areas to boost crop yields. Irrigation allows for the full use of farming technology, including appropriate fertilizer application, crop rotations, and the use of higher-yielding crop types.



Objectives of Irrigation

- To leach or wash out injurious salt from the soil.
- To remove the stress (moisture deficit) condition of plants.
- To release nutrients in soil solution for absorption by plants.
- To keep the activity of soil microbes at the optimum level and to hasten the decomposition of organic matter in the soil.
- To maintain the temperature and humidity of the soil.
- To control harmful soil insects.
- To create water stagnation for controlling dryland weeds.
- To create conditions suitable for puddling.
- Irrigation is necessary to reclaim fallow land and sometimes brings desirable conditions for tillage. Importance of irrigation
- Plants must be supplied with water as required for successful crop production. Irrigation is necessary for crop production due to following reasons:

Importance of Irrigation

1. Uncertainty of monsoon rainfall: Monsoon rain is very uncertain. There is no like schedule that exactly when the rain starts and the duration of the season. In fact, these are variable every year. So irrigation is very important to supply water to plants when needed, i.e., at the right time and in the right amount.
2. Uneven distribution of rainfall: Rainfall is uneven in all the places. Irrigation is essential for crop production in an area having low and uncertain rainfall.
3. Winter rainfall: Rainfall is rare in the winter season in our country. Rabi crops need much water for their growth and development. Therefore, irrigation is very important for the cultivation of Rabi crops.
4. Cultivation of high yielding crops: The high yielding crops are being cultivated in our country, which requires sufficient water for their growth and development. Irrigation has a key role in the successful cultivation of high-yielding crops.
5. Difference in the water-holding capacity of soil: Different types of soil in our country have a difference in water holding capacity. In such cases, irrigation must be provided depending on the soil texture.

Sources of Irrigation: The important sources of irrigation are rainfall, surface water (tanks, ponds, lakes, pools, or artificial reservoirs such as dams, barrages, and diversionary bunds with different storage capacities) and ground water (wells and bore wells).

Irrigation for agriculture faces several global challenges. A major issue is water waste, as many areas still use flooding techniques that inundate fields and lead to significant water loss through evaporation. Salinity is another major problem, where salts in irrigation water accumulate in the soil, reducing its productivity. Additionally, the quality of water is affected by pollutants from agriculture, such as agrochemical runoff and animal waste, which contaminate water bodies. Addressing these challenges requires sustainable practices, improved irrigation technologies, and integrated water resource management.

India, where irrigation has been practiced since ancient times, illustrates some of the problems. During the late 20th century, more than 20 percent of the country's cultivated area was under irrigation. Both large dams, with canals to distribute the water, and small tube, or driven, wells, made by driving a pipe into water or water-bearing sand, controlled by individual farmers, have been used. Some have been affected by salinity; however, as water containing dissolved salts has been allowed to evaporate in the field. Tube wells have helped in these instances by lowering the water table and by providing sufficient water to flush away the salts. The other major problem has been to persuade Indian farmers to level their lands and build the small canals needed to carry the water over the farms.

Irrigation Method	Water Efficiency	Energy Efficiency
Surface Irrigation	50–65%	Low
Level Basin	60–80%	Low
Sub irrigation	50–75%	Low to Medium
Overhead irrigation	60–80%	Medium
Sprinkler irrigation	60–85%	Medium
Drip irrigation	80–90%	Medium to High

Source:https://www.google.com/search?q=irrigation+method+wise+water+efficiency+and+energy+efficiency

1. Sprinkler Irrigation

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil.

Response of different crops to sprinkler irrigation

Crops	Water Saving %		Increase in Yield %
Bajra	**56**		**19**
Barley	**56**		**16**
Bhindi	**28**		**23**
Cabbage	**40**		**03**
Cauliflower	**35**		**12**
Chillies	**33**		**24**
Cotton	**36**		**50**
Cowpea	**19**		**03**
Fenugreek	**29**		**35**
Garlic	**28**		**06**
Gram	**69**		**57**
Groundnut	**20**		**40**
Jowar	**55**		**34**
Lucerne	**16**		**27**
Maize	**41**		**36**
Onion	**33**		**23**
Potato	**46**		**04**
Sunflower	**33**		**20**
Wheat	**35**		**24**

Source: INCID (1998) adapted from Tab 6.5

Components of Sprinkler Irrigation System:

General components which include the pumping unit, tubing, couplers, sprinklers, and other accessories along with percent cost structure is given below

Pumping Unit		30%
Tubing's: mains /submains and lateral		50%
Couplers		10%
Sprinklers		05%
Other accessories-Bend, valves, plugs, riser		05%

2. **Drip Irrigation**

Drip irrigation is the most efficient irrigation method, delivering water directly to plant roots and significantly reducing evaporation and runoff. Research shows that surface irrigation wastes 40 to 50% of water due to deep percolation and runoff, resulting in an average efficiency of only 50 to 60%. Drip systems minimize water loss to weeds, making every drop count by targeting water precisely where it is needed. This method is particularly beneficial for clay soils, as it allows for slow absorption of water without runoff.

Response of different crops to Drip Irrigation System

Crops		Water saving (%)	Increase in yield (%)
Banana		**45**	**52**
Cauliflower		**68**	**70**
Chilly		**68**	**28**
Cucumber		**56**	**48**
Grapes		**48**	**23**
Ground nut		**40**	**52**
Pomegranate		**45**	**45**
Sugarcane		**50**	**99**

Sweet lime		**61**	**50**
Tomato		**42**	**60**
Watermelon		**66**	**19**

Source: agriculture.vikaspedia.in

The two primary types of drip irrigation emitters are On-line Drippers, and Inline Drippers. On-line drippers are mounted on top of lateral pipes, while inline drippers are emitters that are part of the laterals themselves.

A sprinkler system uses pressurized water sprayed through nozzles, while a "laser system" refers to modern pipes with laser-punched holes that create a fine mist for irrigation, often called a "laser spray" or "rain hose" system. The laser system is more efficient and less damaging to soil than a traditional sprinkler's larger droplets, but both methods deliver water to fields.

Laser system (laser spray / rain hose): Function: A hose with many small holes precisely punched by a laser. Spray pattern: Creates a fine mist that wets a wide area along the length of the hose. Pressure: Operates at low pressure, which is gentle on the soil. Efficiency: Highly efficient, especially for small and marginal farmers, due to lower energy use and better water application. Cost: A more affordable option compared to traditional drip systems.

Key Differences

Feature	Laser System	Sprinkler System
Water distribution	Mist sprayed from a hose with laser-punched holes.	Sprayed through rotating nozzles in a circular pattern.
Pressure	Low pressure (0.5−1.00.5 minus 1.0 0.5−1.0 kg cm	High pressure (>2 kg cm).
Droplet size	Minute to very fine.	Larger droplets.
Soil impact	Minimal impact on soil structure.	Can alter soil structure.

Laser irrigation is suitable for a wide range of field crops, cereals, pulses, and oilseed crops. Sprinkler irrigation may affect the flowering, pollination, fruit set etc., in certain crops, may be replaced with laser irrigation. Even it can be helpful in the horticultural crops and in greenhouses too.

Components of a laser spray irrigation system

The components of this advanced micro-irrigation system are similar to other pressurized systems but with a specialized pipe.

a. **Water source:** A pump unit delivers water from the source, such as a well or reservoir, to the irrigation system.
b. **Laser-punched pipe (lateral line):** This is a flexible, thin-walled, high-density or low-density polyethylene (HDPE/LDPE) pipe with tiny, laser-drilled holes at precise intervals. These holes create the fine spray or drip pattern.
c. **Main and sub-main lines**: These larger-diameter pipes deliver water from the pump to the lateral lines in the field.
d. **Fittings and connectors:** Connectors, valves, end caps, and saddles (used for linking the lateral to the sub-main) are used to assemble and control the pipe network.
e. **Filters:** A simple filtration unit is used to prevent any debris from clogging the laser-punched holes.
f. **Accessories:** The system can include valves, pressure gauges, and fertilizer applicators to precisely control the application of water and nutrients.

g. **Maintenance** of a laser sprinkler system involves regular checks for clogs, leaks, and proper alignment, alongside seasonal adjustments. Key tasks include cleaning nozzles and filters, flushing lines.
h. **Water use efficiency** varies significantly by irrigation system, with drip irrigation being the most efficient (90%), followed by sprinkler systems (75%)) and surface irrigation (flood, furrow, basin) which is the least efficient (60%)). Higher efficiency means more water is used by crops and less is lost to evaporation or runoff, leading to better crop yields and water conservation. Overall irrigation efficiency also includes conveyance losses from canals, so system efficiency can be lower when considered as a whole.

Maintenance

Most efficient way to clean the drip system is by cleaning with chlorine bleach (cleaning of organic contamination) and nitric acid (cleaning of mineral contamination

Filtration of the water through the Primary (Sand Filter (open water source) and Screen Filter (Borewell)) and Secondary Filters (Disc Filter (Costly) and Screen Filter (Cheaper)) do not remove the microorganisms and dissolved salts,

Only phosphoric acid can be used in the standing crop, whereas the other three acids should be used in the off season, where there is no crop. Other acids are

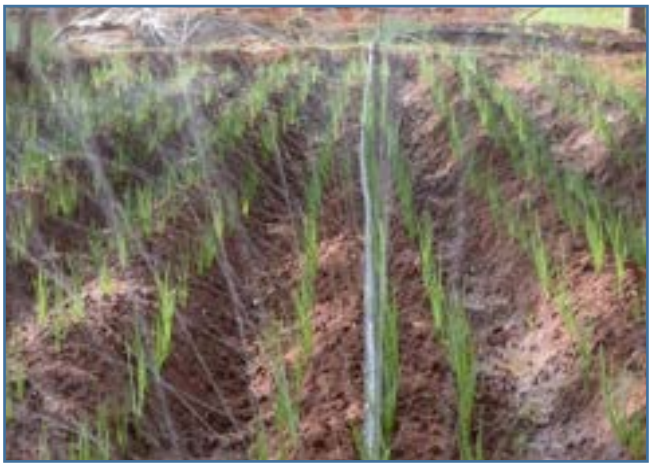
a. Hydrochloric Acid 35%-used only when 50% of the emitters are clogged or blocked, should not be used for chlorine sensitive crops- potatoes, strawberry, pepper, avocado and almonds -, should not be used in the standing crop
b. Nitric Acid 33%- can be used in the standing crop, when the clogging/blocking is less.
c. Sulfuric acid 65%- when the clogging is severe-Should not be used in the standing crop

d. Ortho Phosphoric Acid 85%-can be used in the standing crop

Precautions

a. Acid treatment is recommended when Electrical conductivity (EC) of the water is above 0.5
b. Irrigation water of EC above 2.5 is not suitable for drip irrigation, if used the system will collapse due to severe clogging frequently.
c. Acid treatment is not necessary if purely water soluble fertilizers are used for fertigation.
d. When no acid injection occurs check whether throttle valve is fully closed, if it is fully closed then opens it fully and start closing again till the desired suction rate is obtained.
e. Venturi system should be leakage free, if it is leaking, then replace the old venturi with new venturi.





7.3. A. Agricultural Drainage – Surface and Sub-Surface Drainage Systems

The basic purpose of agricultural drainage is to removal of water from surface as well as from sub surface to maintain the root zone of a crop free from excess water. Adoption of agricultural drainage systems are not only essential in Irrigated agriculture but also in rainfed agriculture. After the introduction of canal network for irrigation purposes, due to improper maintenance of canals and cultivation of crops like sugarcane and rice have led to increase in water tables (Bhattacharya and Michael, 2006). Increased water tables and high evaporation rate resulted in salinization of soils especially in hot regions of the country.

1. Need and Types Agricultural Drainage Systems

Excessive use of fertilizers, increased soil salinity and temporary waterlogging in the root zone of the crops necessitates the adoption of agricultural drainage systems for enhanced crop production. The leachates of inorganic fertilizers along with the natural properties of soil, irrigation canals, untimely and flash rains are the reasons for the increase in problematic soils in the country (Bhattacharya and Michael, 2006). Inorder to address these issues the agricultural drainage systems is the only option left out for the farmers. These systems can be laid either on surface or in subsurface. If the drained water is disposed safely using the gravity of the field it is classified as gravity drainage and if the drained water is collected in a sump and drained out using a pump set then it is called pump drainage. Based on the layout and also on interception of drain water the drainage systems can be classified.

2. Principles and Methods of Agricultural Drainage Systems:

The initial data that is required for execution of any agricultural drainage systems includes: topography of the site with soil survey maps, water table fluctuations and well log, irrigation methods and network as well as natural drainage network and outlets available for free drainout, metrological data, cropping systems data, land holdings etc. The visual observations of farmers or officials during the rainy season will also help in designing the appropriate drainage systems.

The surface drainage systems mostly adopted by the Indian farmers are easy to construct, however, they may interfere with the mechanical operations if not properly laid. The surface drainage systems works on the principle that the hydraulic gradient of a surface drain helps in draining out the water from the fields to an outlet through gravity. The surface drainage systems mainly consists three components: i) collection system to collect excess water, ii) conveyance system to drain out the collected water and iii) outlet where the conveyed water is drained. The surface drainage systems can be of three types: i) Bedding system ii) Furrow system iii) Ditch system.

In bedding system can also be called as ridge and furrow system, where in the length and the width of the bed varies with the type of soil. Generally the beds are laid with 0.2% slope for safe disposal of excess water from the agricultural fields. In furrow system, the furrows formed on the surface will help in draining excess water from the fields and they are generally laid with 0.2% slope. The draining of water in ditch system would be achieved by forming random drains to dispose of stagnated water in scattered depressions or by forming parallel ditches connected to a main ditch or by forming ditches across the slope in case of elevated topographical locations upto 2% slope.

The design principle of surface drainage system can be of two types i) Hydrologic design and ii) Hydraullic design.

In the Hydrological design, the rainfall intensity, duration, quantity and frequency along with the runoff volume plays major role in deciding the design of drainage channels. Once the runoff volume is known the drainage coefficient is estimated. The drainage coefficient is defined as the quantity (mm) of water to be drained per unit time (day). Since some of the crops are sensitive to waterlogging and some are resistant, therefore, draining excess water at a short period of time has to be taken up for waterlogging sensitive crops such as maize, ground nut, soybean etc. In the hydraulic design the dimensions channel that is to be designed to carry out the excess water are decided using Manning's formula (Smedema, 2000). Based on the soil type, the slope and the length of drain are decided.

The subsurface drainage systems are generally used to bring down the water table from the root zone of the crop. The high intense storms for short duration or low intense storms for longer duration will result in

temporary waterlogging conditions either at surface or at sub surface. The working principle of sub surface drainage is the removal of gravitational water from the soil subsurface upto the drain depth. The subsurface drainage system can be of four major types, i) Horizontal drainage ii) Vertical drainage iii) Mole drainage iv) Bio-drainage.

Horizontal drainage system could be open ditch type or closed pipe networks. In this system, the laterals collect the water from smaller areas and conveys to collectors or submains which inturn is/are connected to a main drain. The drained water collected in the main drain are either be disposed of by gravity to a natural outlet or by collecting the water in sumps and later pumped into a nearby outlet. When there is no possibility of natural outlet, construction of sump and subsequently pumping is recommended.

In the vertical drainage, tubewells are drilled to bring down the water table beyond the root zone of a crop.

In mole drainage, the unlined drains are formed in clay soils using a mole plough which is drawn with a high horse power tractor (beyond 60 hp). The drains are generally formed at around 50 to 60 cm depth. Since no material is used while formation of drain, this drainage is also known as pipe less drainage.

To bring down the ground water table few species like Casurina, Eucalyptus, Bamboo trees are used and such method is known as bio drainage (Sarvade et.al. 2017).

Design principle of subsurface drainage system consists of i) Hydrologic design, ii) Hydraulic design and iii) Structural design.

Hydrologic design: The hydrologic design of either surface or subsurface systems are worked out by analyzing rainfall, peak runoff rate, drainage coefficient and recharge rate. The amount of rainfall, its duration, intensity and the interval plays an important role in hydrologic design.

Hydraulic design: The depth at which the subsurface drains are installed (drain depth) and the spacing between centre of one drain to another drain (drain spacing), size of the drain pipe, slope at which the drains are installed, roughness of pipes and stream flow patterns are considered in hydraulic design of subsurface drainage systems.

Structural design: In the structural design the height of watertable that is to be drained out to free the root zone is influenced by drain spacing, drain depth, drain cross sectional area, recharge rate, evaporation and the hydraulic conductivity of the soil (Skaggs and Ghescheir,1999). The texture of the soil and the depth of impermeable layer, topography are also important in structural design while considering the drain depth and length of lateral drains The depth of drains are in general limited to 1.0 to 2.0 m and the lateral length may vary from 200 to 500k m depending upon the topography (natural slope of the soil) and the layout of the drainage system. On the subsurface drain pipes (corrugated PVC pipes or tile pipes) the envelope materials are wrapped around the pipe to prevent entry of soil particles as well as to increase the water flow into the drains.

7.3. B. Water harvesting, importance and its techniques- In-situ and Ex-situ water harvesting in arid and semiarid areas

7.3. C. Principles and concept of Integrated Watershed Management

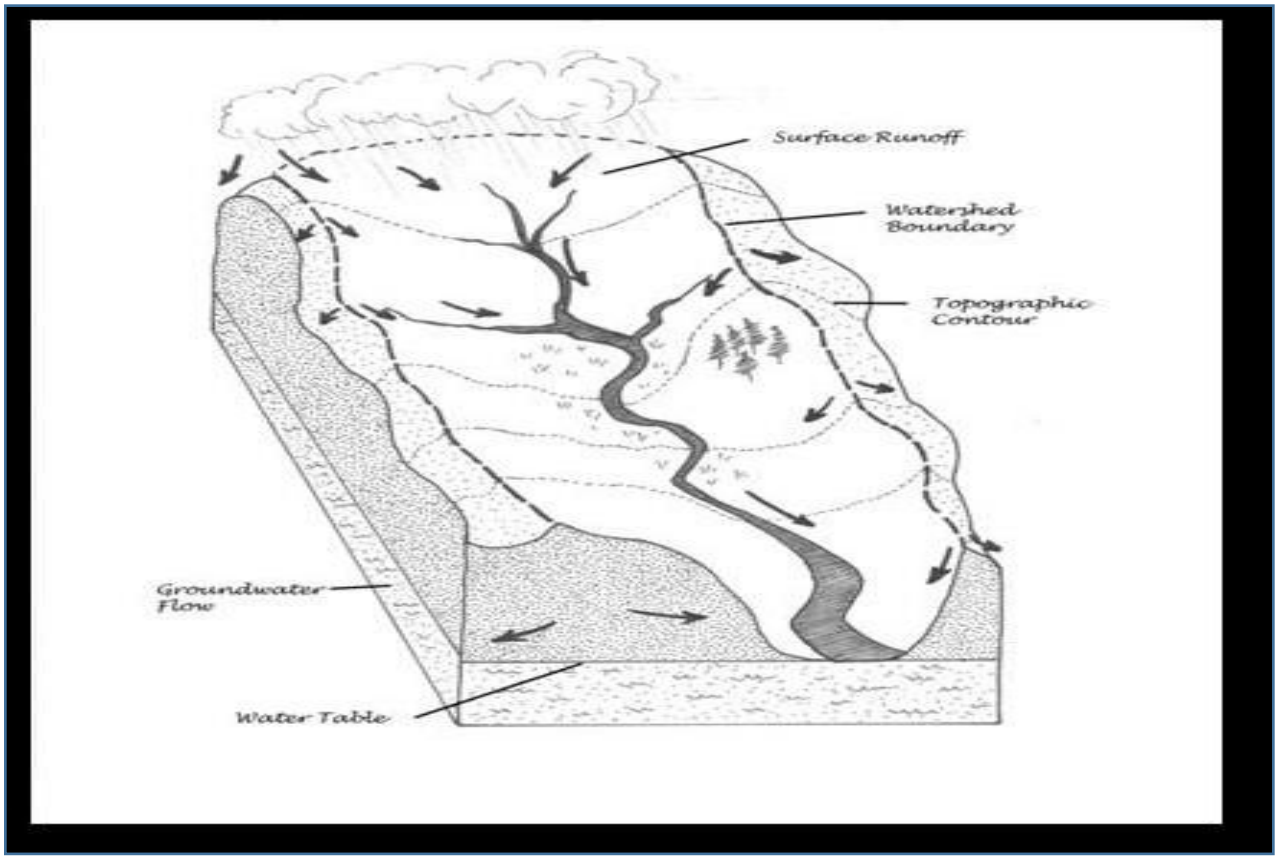
Water, soil and vegetation are the important natural resources for the life and livelihoods of organisms. Water is called an elixir of life. In India the annual soil loss due to erosion is estimated to be around 16.4 to 21 tons per ha per year. The generally accepted soil tolerance limit (SLTL) in India is 11.2 tons /ha/year. India's annual essential nutrient loss to erosion from water and wind is approximately 8 million tons. Also, if we can take a look at the fresh water availability in the world is hardly 3% of total water. In view of this treatment of land on watershed basis assumed greater significance than treating on piece-meal approach

(Source:https://www.google.com/search?q=soil+and+nutrient+loss+per+ha+per+annum+in+india&oq=soil+and+nutrient+loss+per+ha+per+annum+in+india&gs)

Watershed

It's a hydrological unit of an area draining to a common out let point. It is recognized as an ideal unit for planning & development of land, water & vegetation resources. It is a natural drainage unit.

The flow of water through well-defined channels is known as 'drainage' and the network of such channels is called a 'drainage system'. A watershed's drainage system consists of different reaches that can be categorized by their location and the terrain, such as headwater reaches/upper reaches (the source), mid-reach (where tributaries join), and lower reaches (closer to the sink or delta).



Shows how the runoff's flow starts from the ridgeline through a network of Drainage system and reaches a common outlet

i. Drainage Pattern:

It refers to the system of flow of surface water mainly through the forms of rivers and basins.

The drainage system depends upon factors such as slope of land, geological structure, amount of volume of water and velocity of water. These can also be classified by their drainage pattern (e.g., dendritic, trellis, radial) based on how the streams are arranged. Gullies can be ordered by size (small, medium, large) or by their place in a gully network (1st order, 2nd order, etc.). The ordering by network, or stream order, is based on how they collect water, with 1st-order gullies being the main runoff-collecting channels that feed into larger 2nd and 3rd-order gullies. Other classifications are based on their shape (V-shaped, U-shaped) or continuity (continuous vs. discontinuous).

The entire river systems of the country have been divided into 6 Water Resources Regions, which have been further, divided into 37 basins and 112 catchments. These catchments have been further divided into 588 sub-catchments and 3854 watersheds and these watersheds again divided into 49618 sub-watersheds

and are further divided into 321324 micro-watersheds. Alfa-numeric system has been followed to codify the different hydrologic units. The details of hydrologic units, size-range and the average size are given below.

Table 1: Size Ranges of different Hydrologic Units

S. No.	Hydrologic Units	Alfa-Numerical Code	Size Range(ha)	Average size(ha)
1	Water Resource Region	1,2,3,4,5,6	2,70,00,000-11,30,00,000	550,00,000
2	Basin	A,B,C,D,E,F ……	30,00,000-300,00,000	95,00,000
3	Catchments	1,2,3,4 ……..	10,00,000-50,00,000	30,00,000
4	Sub Catchments	A,B,C,D,E,F,G ……	2,00,000-10,00,000	7,00,000
5	Watersheds	1,2,3,4,5,6,7,8,9	20,000-1,50,000	80,000
6	Sub-Watershed	a,b,c,d……z (except i, o and I)	5000-9000	7000
7	Micro watershed	1,2,3,4,5,6,7,8,9	500-1500	1000

(Source-Micro watershed atlas of India)

ii. **History of Watershed Development**

The history of watershed development in India can be traced back to the late 40s and early 50s. Water and soil conservation has been the mainstay on piece meal approach. Earlier, the importance has been given only for the physical structures and no provision was made for the establishment of plant cover/vegetation. Later due importance has been given for the implementation of watersheds by including soil and water conservation works, bio-physical works, production systems, afforestation, reforestation, horticulture, livestock development for the community who own land and for the land less provision has been made for the landless and vulnerable sections by providing income generation activities with the main intention of improving the livelihoods of watershed community.

Based on the experience gained from the establishment of soil conservation department in 1949- 50,a network of soil conservation research ,demonstration and training centres in 1954,42 small research watersheds in 1956,centrally sponsored scheme of soil conservation in the catchments of River Valley Projects in 1961-62,Four Operational Research Projects for integrated watershed management approach with peoples participation in mid- seventies ,Watershed programmes under Flood Prone Rivers project in 1980-81,establishment of 47 model watersheds in different agro- ecological regions in 1983,watershed development areas in 1984 and 1987, Launching of programmes like DPAP,DDP and WGDP in 1987,Indo-German watershed projects in 1990- 91,NWDPRA and IWDP (plains & hills) in 1991,Doon Valley project of U.P in 1993, EAS in 1993. The 1994 E. Hanumantha Rao Committee recommendations marked a fundamental shift in India's watershed development approach, moving from a top-down, department-driven model to one emphasizing community participation and decentralized planning. The committee's recommendations, outlined in the "Common Guidelines," became the foundation for subsequent government programs like Hariyali.

IWDP in 25 states in 1994, Restructuring of EAS based on common guidelines in 1999.The year 2008 saw the programmes –IWDP, DPAP and DDP brought under a comprehensive programme called IWMP. Merging of IWMP in 2015-16 with PMKSY and called as WDC-PMKSY.

Later, several externally aided agencies and GoI and state governments are involved in the implementation of integrated watershed development projects have implemented in different parts of the country. Extended version of WDC-PMKSY 2.0 took place from 2021-2026. In addition to this, Atal Bhujal Yojana with the emphasis on community participation in sustainable ground water management. MGNREGS also supports watershed development through employment generation. A tripartite programme (World Bank, Participating States, and DoLR of MoRD-GoI) called REWARD (Rejuvenating Watersheds for Agricultural

Resilience through innovative Development) has been implementing in Karnataka and Odisha.

iii. **Importance of Watershed**

Due importance has been given for watershed development as we see today and witnessing serious threats to food, environmental, social and economic security, declining per capita land, declining per capita fresh water availability, Soil erosion, depleting / degrading land & Water resources and the rain fed areas constitute 63 % of cultivated area with resource poor with low levels of productivity which provide 45 % of food production and Green revolution by passed the rainfed areas. Whereas irrigated areas occupy 37 % of cultivated area with 55 % of total food production and Green revolution confined only to irrigated area. Even if 20 MH of additional area is brought under irrigation, nearly 60 MH will still be left under rainfed conditions

iv. **Watershed Management-The Approach**

The approach of the watershed management should be multi- disciplinary & participatory and the planning and implementation necessarily move from the traditional approach of top-down to bottom up with a cent percent participation of CBOs in developing and implementation of action plans based on master plans. There should be adequate scope for integration for Social resource management natural resource management. Due importance has to be given production enhancement, livelihood support activities and protection & conservation activities. It is a single window, integrated, participatory & sustainable area development programme. Watershed concept is an integrated approach to harmonize use of natural resources like land, water, vegetation, livestock, fisheries & human resources. So to say it is the management of both natural and social resources. So, watershed management is a single window, integrated, participatory and sustainable area development programme.

Objectives of Watershed Management

a. To reduce soil degradation through suitable land treatments by taking up soil and water conservation in an integrated way.

b. To increase the potential of land and increase ground water level.

c. To promote land use as per land use classification.

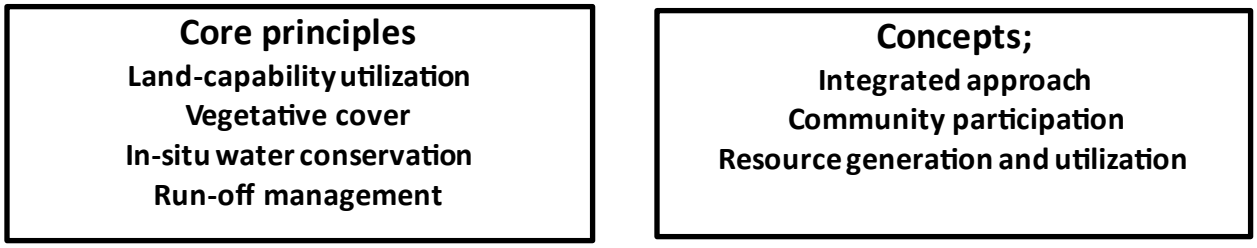
d. To reduce silt load and increase life span of multi- purpose reservoirs/dams.

e. To conserve, manage and integrate natural resources (soil, water and vegetation) and social resources for sustainable production.

f. To mitigate drought and increase the water-holding capacity of reservoirs.

g. To improve agriculture and agriculture dependent activities by using locally available natural resources -this will go a long way in improving social and economic conditions of the community.

Principles and concept of integrated watershed management:



Water and soil conservation works/treatments suitable for arable, non-arable and drainage line are given below;

Different types of measures are meant for treating arable lands.

Mechanical Measures-are series mechanical barriers constructed across the slope and for both the length and the degree of slope. Examples-Bunding with waste weirs, levelling, trenching, Zingg terracing and stone wall etc.

Biological Measures-Biological measures or vegetative measures for resource conservation have gained momentum recently due to many advantages over mechanical measures. These measures are normally adopted on lands having milder slope without any disturbance/movement of surface soil or modification of land surface. These can be adopted singly and /or in combination with mechanical measures depending upon the intensity of soil erosion problem. Examples- Vegetative barriers (live bunds), alley cropping,ley cropping, strip cropping, contour farming, land configurations, tillage, mulching and residue management. Management of rain water especially ***in-situ*** conservation is a vital component. Appropriate land configurations such as land smoothening, compartmental bunding, formation of ridges and furrows, broad based beds, graded border strips, terracing, inter-row inter-plot water harvesting systems hold a greater promise for ***in-situ*** conservation soil, water and nutrients.

Prioritized field-based soil and water/ moisture conservation measures for different rainfall zones in India

Seasonal rainfall (in mm)			
<500	500-700	750-1000	>1000
• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Mulching • Scoops • Tied ridges • Off-season tillage • Inter row waterharvesting system • Small basins • Compartmental bunding • Graded border strip • Contour bunds • Field bunds • Khadin/Nadi	• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Scoops • Tide ridges • Mulching • Zingg terrace • Off-season tillage • BBF • Inter row water harvesting system • Small basins • Modified contour bunds • Compartmental bunding • Graded border strip • Field bunds • Khadin/Nadi	• Broadbed and Furrow (BBF) (Vertisols) • Conservation furrows • Sowing across slopes • Tillage • Field bunds • Vegetative bunds • Graded bunds • Khadins/Nadi • Zingg terrace	• BBF (Vertisols) • Field bunds • Vegetative bunds • Graded bunds • Zinggterraces

Conservation Measures for Non-Arable Lands:

In highly degraded lands, establishment of vegetation is difficult due to high run-off/debris movement. Engineering or mechanical measures are often needed to stabilize slopes and create conditions conducive to plant growth by arresting fine soil and improve moisture status.

Examples are given below.

a. Diversion drains
b. Contour Trenches-Continuous and Staggered
c. Orchard Terraces
d. Stone Walls
e. Half-moon(Crescent) Terraces
f. Watling(Brushwood dams)
g. Geo-jute matting(Jute matting with an open mesh)
h. Crib Structures(Long wood crib structures)
i. Gunny Bag Structures
j. Retaining Walls

Treatments Suitable for Drainage Line System:

Effective treatments for drainage lines in a watershed area reduce water velocity, conserve soil and moisture, and recharge groundwater. Choosing the right treatment depends on the specific location within the watershed, the size and slope of the gully, and the materials available.



Earthen Bund



Diversion Channel

Structural treatments involve constructing barriers or channels in the drainage line to slow down water flow and prevent erosion. These structures can be temporary or permanent.

Upstream and mid-slope

- **Gully plugs/check dams:** Small, temporary or permanent dams built across drainage ditches or gullies to reduce the velocity of concentrated flows. They can be constructed from:
- **Loose stones:** An economical and natural method that uses readily available local boulders.
- **Brushwood:** Made from posts and brush, these are temporary and particularly useful for smaller gully heads.
- **Earthen embankments:** Simple to build and effective for holding water, though a spillway may be needed to prevent overflow erosion.
- **Contour trenches:** Trenches excavated across the slope with bunds on the downstream side. They help break the velocity of runoff and impound water.
- **Contour stone walls:** Dry-packed stones arranged across the slope to intercept runoff.
- **Bench terraces:** A more permanent, intensive treatment for steep slopes, where the land is converted into level steps.

Mid- to downstream

- **Gabion structures:** Wire baskets filled with rocks that form gravity retaining walls. They are highly effective for stabilizing steeper gully sections and can be used to construct check dams or reinforce riverbanks.
- **Spillways:** Engineered channels designed to safely carry excess water flow over a dam or control structure, preventing damage from overflowing. Permanent gully control structures may feature drop spillways or chute spillways, depending on the height and flow of the gully.
- **Percolation tanks:** Artificial reservoirs built across a stream to capture and hold rainwater. This allows

the water to slowly seep into the ground, recharging the local groundwater table and nearby wells.

Vegetative measures

Vegetative treatments use plants to stabilize soil, slow runoff, and filter sediment. They are often used in conjunction with structural measures to provide a long-term, sustainable solution.

- **Live staking:** Inserting dormant, living wood cuttings, such as willow, into the ground. These cuttings grow roots that help bind soil particles together.
- **Bank revegetation:** Planting grasses, shrubs, and trees along the banks of drainage lines to reduce erosion and stabilize the soil.
- **Erosion control blankets:** Biodegradable or synthetic mats applied to disturbed soil to protect it from erosion and promote the establishment of vegetation.
- **Vegetative filters:** Grass strips or rain gardens installed to filter out sediment and pollutants from runoff before it enters a drainage line.

Integrated approach

An effective watershed management plan often combines multiple treatments in a "ridge-to-valley" approach, treating the drainage system from the highest points downstream. For example:

i. **Start at the ridges** and upper slopes with simple, low-cost treatments like contour trenches and vegetative strips.

ii. **Move to the mid-slopes** using loose boulder structures or brushwood check dams in small gullies.

iii. **Implement more robust, permanent structures**, such as gabion check dams or masonry dams, in larger gullies and at the outlet of the watershed.

iv. **Consider percolation tanks** downstream to maximize groundwater recharge from the treated runoff.

7.4. A. Rainfed Agriculture: Introduction, Types- Dry farming, Dryland farming and Rainfed farming.

Agriculture in India is largely dependent on the vagaries of the monsoon, as a significant proportion of cultivated land remains unirrigated. Growing of crops entirely under rainfed conditions, without assured irrigation facilities, is referred to as rainfed agriculture. Generally, rainfed agriculture is divided in to 1) Dry farming - Extremely low rainfall areas (<750 mm) 2) Dryland farming - Semi-arid areas (750–1150 mm) and 3) Rainfed farming - Humid/sub-humid areas (>1150 mm).

Rainfed farming plays a vital role in national food security, livelihood sustainability, and ecological balance. Approximately 68 per cent of India's 142 million hectares of cultivated land is under rainfed agriculture. It accounts for a substantial share of the cropped area under:

- Rice (**42%**)
- Pulses (**77%**)
- Oilseeds (**66%**)
- Cotton (**65%**)
- Coarse cereals (**85%**)

Furthermore, this land supports the majority of India's livestock population-cattle (**78%**), sheep (**64%**), and goats (**75%**). Despite efforts to expand irrigation, projections indicate that, even if the target of 113 million hectares of irrigated area is achieved, around 45 per cent of cultivated land will still remain rainfed. Added to this, stagnating yield growth from irrigated systems emphasizes the strategic importance of rainfed farming. While intensive irrigated farming ensures survival, and improved rainfed agriculture is essential for equity, livelihood security, and prosperity.

Table 2: Agriculture Profile in India

Category	Area (M ha.)	Percentage of total land
Total arable land	143.8	100%
Dryland	34.5	24%
Rainfed	65.5 (15 M ha. flood-prone)	45.5%
Irrigated area	43.8	30.5%
Total geographical area	328.7	
Average annual rainfall	1190 mm	

Table 3: Agriculture Profile in Telangana

S. No.	Category	Value
1.	Total geographical area	11.8 M ha.
2.	Gross cropped area	5.9 M ha.
3.	Net cropped area	4.65 M ha.
4.	Gross irrigated area	2;55 M ha.
5.	Net irrigated area	177 M ha.
6.	Average farm holding size	1.12 ha.
7.	Average annual rainfall	961.0 mm
8.	Cropping intensity	124%
9.	Irrigation intensity	144%

1. **Types of rainfed agriculture**

Rainfed agriculture can be broadly classified into three groups based on annual rainfall and the associated soil-water balance.

i. **Dry farming**

- **Definition**: Cultivation of crops in areas with **< 750 mm** annual rainfall.
- **Characteristics**:
  - Frequent crop failures due to prolonged dry spells.
  - Regions are generally **arid** and highly drought-prone.
  - Moisture conservation practices are critical.
- **Major problems**: Wind and water erosion, low soil fertility, and unstable yields.
- **Crops grown**: Millets, pulses, oilseeds, and drought-tolerant crops.

ii. **Dryland farming**

- **Definition**: Cultivation of crops in areas with 750 - 1150 mm annual rainfall.
- **Characteristics**:
  - Rainfall is higher than dry farming areas but still inadequate due to higher evapotranspiration (ET) losses.
  - Moisture deficit occurs periodically, though complete crop failure is less common.
  - Requires soil and moisture conservation as a key practice.
  - Drainage management is important, especially in black soils.
- **Crops grown**: Sorghum, groundnut, soybean, pulses, and mixed cropping systems.

iii. **Rainfed farming**

- **Definition**: Cultivation of crops in areas with > 1150 mm annual rainfall.
- **Characteristics**:
  - Practiced in humid and sub-humid regions.
  - Crop failures due to dry spells are rare.
  - Excessive water and drainage problems are the major constraints.
- **Crops grown**: Rice, maize, sugarcane, jute, plantation crops.

Table 4:. Major differences between dry farming, dryland farming and rainfed farming.

S. No.	Particular	Dry Farming	Dryland Farming	Rainfed Farming
1	Rainfall/annum (mm)	< 750 mm	750 -1150 mm	> 1150 mm
2	Moisture Availability	Acute shortage	Shortage	Enough
3	Crop Growing Season	< 75 days	75 - 120 days	> 120 days
4	Growing Region	Arid	Semi-arid	Humid
5	Cropping Systems	Single crop/intercropping	Single crop/intercropping	Inter/multi-cropping
6	Dry Spells	Most common	Less frequent	Very less
7	Crop Failure	More frequent	Less frequent	Rare
8	Constraints	Wind erosion	Wind erosion/water erosion	Water erosion
9	Measures Required	Moisture conservation practices	Moisture conservation practices & drainage for vertisols	Proper drainage required

2. Historical development of rainfed agriculture in India

1920 – Scarcity tract development emphasized by Royal Commission on Agriculture.
1923 – Dry Farming Research Station established at Manjri (Pune) by Tamhane.
1926 – Research continued by Kanitkar with ICAR support.
1933-35 – Research stations at Sholapur, Bijapur, Hagari, Raichur, Rohtak.
1942 – Bombay Land Development Act passed.
1944 – Kanitkar published monograph on Dry Farming in India.

1953 – Central soil conservation board established.
1954-55 – Soil conservation research centres and dry farming demonstration centres set up.
1960s – Short-duration cultivars emphasized for efficient use of limited moisture.
1970 – All India Coordinated Research Project for Dryland Agriculture (**AICRPDA**) established with 23 centres.
1972 – ICRISAT established in Hyderabad.
1976 – Operational Research Projects (ORPs) on dryland agriculture launched.
1977 – Krishi Vigyan Kendra (KVK), Hyderabad established.
1983 – 47 model watersheds initiated under ICAR.
1984-86 – Dryland development boards and watershed development programmes launched in several states.
1985 – Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad established.
1986 – National Watershed Development Project for Rainfed Areas (NWDPRA) initiated in 15 states.

Conclusion

Rainfed agriculture remains the backbone of Indian farming, supporting food production, livestock, and livelihoods for millions of small and marginal farmers. While irrigation expansion is critical, the vast extent of rainfed lands necessitates sustainable dryland management practices.

7.4. B. Management of crops and cropping systems in rainfed areas -Intercropping, sequence cropping and crop rotation- Choice of crops and cropping systems based on length of crop growing season, Potential cropping systems.

Most of the world's food is produced under rainfed agriculture, which plays a pivotal role in poverty reduction and livelihood security. A large proportion of the poor population in developing countries depends directly on rainfed farming for food and income. Despite its importance, rainfed agriculture is constrained by the variability of rainfall, long dry seasons, recurrent droughts, and even within-season dry spells and floods. To improve productivity under such challenging conditions, scientific management of crops and cropping systems is crucial. Key approaches in management of crops and cropping systems include intercropping, sequential cropping, crop rotation, and careful selection of crops and cropping systems based on rainfall and the length of the growing season.

Rainfed agriculture occupies a major share of the cultivated area in India. The efficient management of crops and cropping systems is essential to minimize risk, optimize resource use, and stabilize farm income under uncertain rainfall conditions. The key approaches include intercropping, sequence cropping, crop rotation, and the rational choice of crops and cropping systems based on the length of the crop growing season.

1. Crops and cropping systems in rainfed areas

Spatial arrangements in crops and cropping systems refer to how crops are organized in space within a field or agricultural system. This includes the layout, density, and patterns in which they are sown. The significant effect on productivity, pest management and resource utilization depending on rainfall and prevailing weather conditions. Here are some key concepts.

i. Intercropping

Intercropping is the practice of growing two or more crops in the same field during the same season with a specific spatial arrangement. It is most suitable in regions receiving **600 - 850 mm of rainfall**, where at least one crop succeeds even in drought years, while both crops yield well in favourable rainfall years. The special arrangements with different row rations viz, 3:1 (Groundnut: Maize), 4:2 (Cotton: Cowpea), 6-8:1 (Sorghum: Pigeonpea) etc. are most prevalent in India. The inclusion of pulses helps in fixation of atmospheric nitrogen thus, improves the soil fertility in due coarse of time along with improvement in soil health.

Advantages of Intercropping:

- Minimizes risk and provides insurance against complete crop failure.
- Increases yield and income per unit area and unit time compared to sole cropping.
- Provides stability in production.
- Ensures availability of multiple products for household and market.
- Improves soil fertility when legumes are included.
- Suppresses weed growth through canopy cover.
- Increases resource use efficiency (light, water, nutrients).

- One crop may provide physical support to another.

Disadvantages of Intercropping:

- Possible yield reduction due to competition.
- Allelopathic effects between crops.
- Build-up of pests and diseases.
- Less suitable for large farms with mechanized operations.

Examples of intercropping systems in India:

Crops	Geometry/ Special arrangements	Base crop duration (days)	Intercrop duration (days)
Sorghum + Lablab	6-8:2	100-120	150-180
Sorghum + Redgram	6-8:1	100-120	180
Sorghum + Cowpea	2:1	100-120	80
Cotton + Black gram	2:1	150-185	65-75
Groundnut + Redgram	6-8:1	105	180
Groundnut + Castor	6-8:1	105	150-180
Bengalgram + Coriander	4:1	100	80
Maize + Cowpea	2:1	100-110	75-80

ii. **Sequential cropping**

Sequential cropping refers to growing two or more crops in sequence on the same land within one crop year, where one crop is sown immediately after harvesting the previous crop.

- When two crops are taken, it is termed **double cropping**.
- Relay cropping (pairing of overlapping crops) is also practiced in high rainfall areas.

Conditions favouring Sequential cropping:

- Annual rainfall > 900 mm.
- Extended rainy season.
- High soil moisture storage capacity.
- Supplemental irrigation from harvested rainwater in farm ponds.

Important double cropping systems of different location:

- Ranchi: Rice → Linseed / Chickpea.
- Indore: Soybean → Wheat.
- Pune: Rice → Chickpea.
- Bangalore: Cowpea → Finger millet.

Limitation:

- Insufficient rainfall in some areas may prevent double cropping.
- Pest and disease build up
- Insufficient time for proper land preparations

iii. Crop rotation

Crop rotation is the practice of growing different crops in succession on the same land in a planned sequence. In rainfed areas, crop rotation helps conserve soil moisture, improves fertility, and reduces pest and disease incidence. Further, crop rotation with legumes explicitly helps to improve nitrogen fixation in the soil.

Benefits of crop rotation:

- Maintains soil fertility through inclusion of legumes.
- Helps control weeds, pests, and diseases.
- Efficient utilization of residual moisture.
- Ensures sustainable yields under rainfed conditions.

Examples:

- ✓ Sorghum – Pigeonpea rotation
- ✓ Groundnut – *Rabi* pulse rotation
- ✓ Maize – Chickpea rotation

iv. Choice of crops and cropping systems based on length of crop growing season

Choice of suitable cropping system must aim at maximum and sustainable use of resources especially water and soil. Cropping systems depend on rainfall quantity, length of rainy reason and soil storage capacity.

The broad guidelines in choosing a cropping system for dry lands are given below (Table 4). The length of the **effective crop growing season** (**CGS**), often depends on adequate and well-distributed rainfall throughout the growing season. Reliable rainfall patterns are essential for maximizing crop yield and quality. CGS often depends on adequate and well-distributed rainfall throughout the growing season. Reliable rainfall patterns are essential for maximizing crop yield and quality. In areas with erratic rainfall, CGS allows farmers to select a variety of crops with different water requirements and duration. This diversity can help ensure that at least some crops thrive even in less favorable rainfall conditions.

- **Short growing season (75-100 days):** Suitable for short-duration pulses (greengram, blackgram, cowpea), oilseeds (sesamum, sunflower), and millets (foxtail millet, pearl millet).
- **Medium growing season (100-150 days):** Suitable for crops like sorghum, maize, groundnut, castor, redgram (medium duration).
- **Long growing season (more than 150 days):** Suitable for long-duration crops like cotton, pigeonpea (long duration), rice (rainfed lowlands).

v. Potential cropping systems based on rainfall and soil characters

Rainfall (mm)	Soil type	Growing season (weeks)	Profile storage capacity (mm)	Cropping type	Examples
350-600	Alfisols, shallow vertisols	20	100	Single	sorghum / maize / soybean
350-600	Deep aridisols, Entisols(alluvium)	20	100	Single	sorghum / maize / soybean in kharif / rabi
350-600	Deep vertisols	20	100	Single	Post rainy season cropping sorghum
600-750	Alfisols, vertisols, entisols	20-30	100	Intercropping	Sorghum + Pigeon pea Cotton + Black gram
750-900	Entisols, deep vertisols, deep alfisols, inceptisols	30	200	Double cropping-with monitoring	Maize – safflower Soybean – chick pea Groundnut – horsegram
> 900	As above	> 30	> 200	Assured double cropping	Maize – chick pea Soybean - safflower

Under the present cropping systems where monoculture is the rule, farmers do not utilize the farm resources efficiently. The farming practices in which the same crop is repeated year after year and almost no fertilizer is applied have resulted in progressive depletion of soil fertility and declining crop yield. Thus, there is a great need for potential cropping systems that would increase productivity of land through better use of natural and human resources. The most suitable cropping systems that fit the farming conditions would be crop intensification or multiple cropping. The need is to develop cropping patterns that fit the local physical and socioeconomic conditions.

Conclusion

Rainfed agriculture remains the **backbone of Indian farming**, supporting food production, livestock, and livelihoods for millions of small and marginal farmers. Management of crops and cropping systems in rainfed areas is crucial for achieving sustainability and livelihood security under variable rainfall conditions. Intercropping provides insurance against crop failure, sequence cropping utilizes residual soil moisture, and crop rotation maintains soil fertility and reduces pest problems. The choice of crops and cropping systems must be based on the length of the growing season and soil-water availability. In Telangana, potential cropping systems like **sorghum + pigeonpea, castor + redgram, maize → chickpea, and pearl millet + redgram** have shown promise for maximizing resource use efficiency, minimizing risk, and ensuring stable farm income.

Module VIII: SEED AND SEED PRODUCTION

8.1. A. Basics of Seeds, 8.1. B. Difference between Seeds and Grains, 8.1 .C. Importance of Quality Seeds in Crop Production, 8.1. D. Classes of Seeds 8.1. E. Seed treatment- Importance and procedure

For agri-input dealers, a chapter covering the basics of seeds should focus on actionable knowledge that directly impacts their sales, inventory management, and advisory roles to farmers.

Here are the key learning objectives:

1. Technical Knowledge & Product Differentiation

Distinguish Seeds from Grains: Be able to articulate the **fundamental difference between a seed (for propagation) and a grain (for consumption)** to educate customers and prevent misuse of treated products.

Identify Seed Classes: Know the **four main classes of seeds (Breeder's, Foundation, Registered, Certified)** and their **quality assurance standards and tag colors** to explain product value and source to farmers.

Explain Quality Parameters: Understand the key factors of seed quality (e.g., **genetic purity, physical purity, viability, and vigor**) and how they relate to the price and performance of the seed they sell.

2. Advisory & Risk Management

Justify Quality Seed Use: Effectively **communicate the economic benefit and risk reduction** (e.g., 20-25% yield increase, disease resistance) of using certified, high-quality seeds over farm-saved seeds.

Advice on Seed Treatment: Understand the **importance of seed treatment** (fungicides, insecticides, bio-fertilizers) and the correct **procedure** for advising farmers, ensuring proper dosage and safety (handling, warning labels).

- **Diagnose Early Problems:** Recognize symptoms of common **seed-borne and soil-borne diseases** (e.g., damping-off, smuts) that are controlled by seed treatment, linking the problem to the solution.

3. Inventory & Compliance

Handle and Store Treated Seeds: Know the specific **safety protocols and storage requirements** for chemically treated seeds to maintain their efficacy and prevent accidental consumption.

Interpret Seed Labels: Be able to **read and interpret certification tags and labels** regarding germination percentage, physical purity, date of testing, and compliance with local seed laws.

Key Outcomes of the Chapter

The successful completion of the chapter on the basics of seeds should result in the following key outcomes for the agri-input dealer:

- **Enhanced Sales & Profitability:** The dealer can **confidently upsell** certified and treated seeds by clearly explaining their superior value proposition compared to cheaper, uncertified alternatives, leading to increased sales volume and profit margins.
- **Improved Farmer Trust & Loyalty:** By providing **accurate and technical advice** on seed selection, quality, and treatment, the dealer establishes themselves as a reliable expert, building long-term farmer relationships.
- **Reduced Product Misuse & Liability:** The dealer will know the **correct handling and warning protocols** for treated seeds, reducing the risk of accidental poisoning or misuse by farmers.

- **Effective Inventory Management:** Understanding seed class and quality parameters aids in **selecting and stocking the right products** that meet local agricultural standards and farmer demands.
- **Increased Crop Success:** Ultimately, the dealer's knowledge helps farmers choose and use the best seeds, contributing directly to a **better, more uniform crop stand and higher yields** in their service area.

Difference between Seeds and Grains

While the terms "seed" and "grain" are often used interchangeably in everyday language, they have distinct biological and agricultural meanings.

Feature	Seed	Grain
Botanical Definition	An **embryonic plant** enclosed in a protective outer covering (seed coat), containing stored food. It is the ripened ovule after fertilization.	A **small, dry, edible fruit** (botanically a *caryopsis* or kernel) of a cereal grass. The seed coat is fused with the fruit wall.
Purpose/Function	Primarily used for **propagation** (planting) to grow a new crop.	Primarily used as **food** (for humans or livestock) or as a raw material for industrial use.
Viability	**Viability (ability to germinate)** is a crucial quality characteristic and must be high.	Viability is generally **not important** for its primary use (food).
Treatment	Often **treated** with fungicides/insecticides to protect it.	Generally **untreated** (unless for storage/feed).
Example	Seeds of cotton, pumpkin, sunflower, and improved/certified seeds of cereals.	Wheat, rice, maize (corn), barley, oats.

Importance of Quality Seeds in Crop Production

A quality seed is the most crucial and least expensive input in agriculture. It is defined by its genetic purity, physical purity, viability, and vigor, and being free from pests and diseases.

The importance of using quality seeds lies in:

- **Increased Yield:** Quality seeds of improved varieties possess superior genetic potential, which can contribute significantly (often estimated at 20-25%) to overall yield increase.
- **Uniform Crop Stand:** High viability and vigor ensure fast, uniform, and healthy germination, leading to an even plant population and better utilization of resources like sunlight and nutrients.
- **Optimized Resource Use:** Healthy plants established from quality seeds use other expensive inputs (fertilizers, irrigation, pesticides) more efficiently, maximizing the return on investment.
- **Disease and Pest Resistance:** Quality seeds often carry genetic resistance or tolerance to common pests and diseases, reducing the need for chemical sprays and safeguarding the crop during critical growth stages.
- **Adaptability:** They are typically bred to withstand certain abiotic stresses like drought or salinity, making the crop more resilient.
- **Better Produce Quality:** The harvested produce will be uniform and meet the desired standards for market acceptance, which is essential for higher income.

The fundamental concepts of seeds, covering their distinction from grains, their importance in agriculture, their classification, and the practice of seed treatment, are outlined below.

Classes of Seeds

Seed multiplication follows a strict system to maintain genetic purity, resulting in a tiered classification. The four generally recognized classes are:

Seed Class	Description	Tag Colour
1. Nucleus seed	This is cent per cent genetic pure seed with physical purity produced under the direct supervision of the concerned plant breeder.	
2. Breeder's Seed	This is the progeny of the nucleus seed multiplied in large area under the supervision of plant breeder and monitored by a committee. It provides cent per cent physical and genetic pure seed for production of foundation class.	**Golden Yellow**
3. Foundation Seed	Progeny of breeder's seed in handled by recognized seed producing agencies in public and private sector under the supervision of Seed Certification Agency in such a way that its quality is maintained according to the prescribed standard.	**White**
4. Certified Seed	Progeny of foundation seed produced by registered seed growers under the supervision of Seed Certification Agency by maintaining the seed quality as per minimum seed certification standards.	**Azure Blue**

Seed Treatment - Importance and Procedure

Seed treatment refers to the application of chemical, biological, or physical agents to seeds before sowing to improve their performance and protect them from seed-borne or soil-borne pests and diseases.

Importance of Seed Treatment

i. **Disease Prevention:** It protects seeds and young seedlings from seed-borne (pathogens carried on or inside the seed) and soil-borne (pathogens residing in the soil) diseases, such as seed rot, damping-off, and smuts.

ii. **Pest Protection:** Insecticides protect the seeds and seedlings from early-season insect pests like wireworms, cutworms, and certain beetles.

iii. **Improved Germination and Stand:** By preventing decay and disease, treatment ensures a higher percentage of germination and a more uniform, healthy crop stand.

iv. **Enhanced Plant Health:** Some treatments (like micronutrients or biologicals) can boost initial vigor and growth, leading to a more resilient plant.

v. **Biocontrol/Nitrogen Fixation:** Biological treatments involve coating seeds with beneficial microorganisms like Rhizobium (for legumes) or Azotobacter (for cereals) to fix atmospheric nitrogen or enhance nutrient uptake.

General Procedure for Chemical Seed Treatment

The typical procedure, especially for applying fungicides or insecticides, involves the following steps:

i. **Preparation:** Determine the correct dosage of the chemical/biological agent and the volume of seeds to be treated. Ensure the seeds are properly cleaned and dried to the recommended moisture content.

ii. Selection of Method/Equipment: Choose the appropriate method:

- **Dry Dressing (Dusts):** Tossing the seeds with a powdered chemical in a rotating drum mixer or even a simple container/shaker.

- **Wet/Slurry Treatment (Liquids):** Mixing the chemical with a small amount of water to form a slurry, which is then thoroughly mixed with the seeds. This is often done using mechanical slurry treaters for large volumes.

iii. **Mixing:** Apply the calculated amount of treating agent to the seeds and mix thoroughly to ensure uniform coating on all seed surfaces. Coloring agents are often included to visibly mark the seed as treated (and therefore poisonous) and to prevent it from being consumed as food.

iv. **Drying (If Wet):** If a wet treatment is used, the seeds must be dried to their original moisture content to prevent damage and maintain storability.

v. **Bagging and Labeling:** Treated seeds must be promptly and clearly labeled with a warning that they are poisonous and should not be used for food or feed.

Note: When applying both biological (e.g., *Rhizobium*) and chemical treatments, the chemical treatment is typically done first, followed by the biological inoculant just before sowing, as chemicals can harm beneficial microbes.

Summary and Conclusion

- **Seed vs. Grain:** The core distinction is function. A seed is the planting material (high viability, high genetic purity) meant for propagation, while a grain is harvested for consumption. This difference mandates the strict safety handling of chemically treated seeds.
- **Value of Quality Seed:** Using certified, quality seed is the most impactful input, contributing up to 25% yield increase by ensuring uniform crop stand and genetic resistance to major diseases and environmental stress.
- **Seed Purity (Classes):** Genetic purity is maintained through a clear multiplication chain: Breeder's - Foundation -Certified. The Certified Seed (recognized by the Azura Blue Tag) is the final class sold to the farmer, guaranteeing minimum quality standards.
- **Seed Treatment:** This process applies fungicides, insecticides, or inoculants to the seed surface before sowing. Its primary role is to provide essential early-season protection against seed-borne and soil-borne diseases (like damping-off) and pests, ensuring the seedling survives the critical establishment phase.

The knowledge covered in this chapter makes the agri-input dealer an essential technical advisor.

The dealer's mandate is to:

1. **Educate:** Clearly communicate the significant Return on Investment (ROI) from purchasing certified seed over farm-saved seed.
2. **Protect:** Ensure the safe handling, storage, and correct dosage of treated seeds, prioritizing farmer safety and preventing accidental misuse.
3. **Advise:** Recommend appropriate seed treatments based on local pest/disease pressure to maximize the crop's successful establishment.

By fulfilling this mandate, the dealer enhances the farmer's yield success, strengthens customer loyalty, and builds a sustainable, reputable business

8.2. A. Principles and practices of Seed Production

Seed is the most critical and basic input in agriculture.

All other inputs such as fertilizer, irrigation, and plant protection give returns only when quality seed is used. "Good seed alone can increase crop yield by 15–25%."

1. Purpose of Seed - The main purposes of seed are:

i. Propagation of crops Seed is the primary means to multiply plant species.
ii. Genetic transmission Seed carries genetic characters like yield potential, resistance, quality traits.
iii. Ensuring crop uniformity Quality seed ensures uniform growth, maturity, and harvest.
iv. Higher productivity Certified seed ensures better germination, vigour, and yield.
v. Food security Seed is the foundation of national food and nutritional security.
vi. Economic benefit to farmer, Better seed → better yield → higher income.

2. Importance of Quality Seed

i. Quality seed should have:

ii. High genetic purity

iii. High germination percentage

iv. Proper physical purity

v. Free from weed seeds, diseases, and pests

vi. Good seed vigour

3. Seed Classes in India

a. Nucleus Seed

b. Breeder Seed

c. Foundation Seed

d. Certified Seed

e. Truthfully Labelled (TL) Seed

Each class maintains genetic purity and identity of the variety.

4. Principles of Seed Production (Common to All Crops)

i. Selection of Variety Use notified and released varieties Ensure adaptability to local agro-climatic conditions

ii. Selection of Land Fertile soil with good drainage, No volunteer plants of same crop, Proper crop rotation history

iii. Isolation Distance

To prevent genetic contamination:

Self-pollinated crops → low isolation

Cross-pollinated crops → high isolation

Hybrid seed production → very strict isolation

iv. Seed Source

Seed must be sourced from approved class only Maintain proper seed chain

v. Field Preparation

Fine tilth Proper spacing as per crop and variety Uniform sowing depth

vi. Rouging

Removal of: Off-type plants, diseased plants, Volunteer plants

Rouging must be done:

a. Vegetative stage b. flowering stage c. Maturity stage

vii. Crop Management

a. Timely irrigation

b. Balanced fertilization

c. Weed control

d. Pest and disease management

Healthy crop = Quality seed

viii. Field Inspection

Conducted by if certification Seed Certification Agency, if truthfully labelled seed industry

Checks: a) Isolation b) Crop condition c) Off-types Diseases

ix. Harvesting

Harvest at physiological maturity

Avoid mechanical mixture

Separate crop-wise and variety-wise harvesting

x. Drying

Dry seed to safe moisture level

Cereals: 12–13%

Pulses: 9–10%

Oilseeds: 7–8%

xi. Processing

Cleaning, Grading, Treating, Packing

xii. Storage

Cool, dry, and ventilated place

Use moisture-proof containers

Regular monitoring for pests

5. Seed Production in Major Crop Groups

Cereals (Rice, Maize, Sorghum, Bajra)

Mostly self / often cross-pollinated

Focus on: Isolation, Rouging, Moisture control

i. Pulses (Redgram, Greengram, Bengalgram)

Sensitive to moisture

Seed-borne diseases important

Proper drying essential

ii. Oilseeds (Groundnut, Soybean, Mustard)

Low seed viability

Careful handling required

D. Vegetables

Mostly cross-pollinated

High isolation distance

Hand pollination in hybrids

iii. Cotton & Hybrid Crops

Very strict isolation

Parental line purity critical

Skilled labour essential

6. Role of Seed Industry

Production of quality seed

Technology transfer to farmers

Adoption of improved genetics

Ensuring timely availability

7. Conclusion

Seed is not just an input, it is technology packed in a small unit.

Sustainable agriculture depends on: Quality seed

Scientific seed production

Supportive policies

Responsible seed industry

"Strong seed system = Strong agriculture = Strong nation"

Benefits of Quality Seed Production
Higher Yields: Genetically superior seeds express their full yield potential.
Improved Crop Quality: Better appearance, nutritional value, and marketability.
Disease & Pest Resistance: Seeds from resistant varieties protect crops.
Economic Gain: Farmers earn more from higher yields or by selling quality seeds.
Food Security: Ensures a stable supply of reliable food.
Biodiversity: Maintains diverse, well-adapted crop varieties.

8.2. B. Seed Certification Process

In general, seed certification is a process designed to maintain and make available to the general public continuous supply of high-quality seeds and propagating materials of notified kinds and varieties of crops, so grown and distributed to ensure the physical identity and genetic purity. Seed certification is a legally sanctioned system for quality control of seed multiplication and production.

1. **History of Seed Certification in India**

- The field evaluation of the seed crop and its certification started with the establishment of National Seeds Corporation in 1963.
- A legal status was given to seed certification with the enactment of first Indian Seed Act in the year 1966 and formulation of Seed Rules in 1968. The Seed Act of 1966 provided the required impetus for the establishment of official Seed Certification Agencies by the States.
- Maharashtra was the first State to establish an official Seed Certification Agency during 1970 as a part of the Department of Agriculture, whereas Karnataka was the first State to establish the Seed Certification Agency as an autonomous body during 1974.
- Seed Certification Agencies are established under the Seed Act, 1966.
- In India, seed certification is voluntary and labelling is compulsory.

2. **Objective of Seed Certification**

The main objective of the Seed Certification is to ensure the acceptable standards of seed viability, vigour, purity and seed health. A well organized seed certification should help in accomplishing the following three primary objectives.

- The systematic increase of superior varieties;
- The identification of new varieties and their rapid increase under appropriate and generally accepted names.
- Provision for continuous supply of comparable material by careful maintenance.

3. **Certification Agency**

Certification shall be conducted by the Certification Agency notified under Section 8 of the Seeds Act, 1966.

4. **Eligibility requirements for certification**

Seed of only those varieties which are notified under Section 5 of the Seeds Act, 1966 shall be eligible for certification. Any variety to become eligible for seed certification should meet the following requirement:

- **General Requirements** - Should be a notified variety under Section-5 of the Indian Seed Act, 1966. Should be in the production chain and its pedigree should be traceable.
- **Field standards** - Field standards include the selection of site, isolation requirements, spacing, planting ratio, border rows etc.
- **Specific requirements** - Presence of off-types in any seed crop, pollen-shedders in Sorghum, Bajra, Sunflower etc., Shedding tassels in maize crosses, disease affected plants, objectionable weed plants etc., should be within the maximum permissible levels for certification.
- **Seed standards** - Minimum seed certification standards have been evolved crop-wise.

5. **Process followed in Seed certification**

- **An administrative check on the origin of the propagating material:** Source seed verification is the first step in Seed Certification Programme. Unless the seed is from approved source and of designated class certification agency will not accept the seed field for certification, thereby ensuring the use of high quality true to type seed for sowing of seed crops.

- **Field Inspection:** Evaluation of the growing crop in the field for varietal purity, isolation of seed crop is to prevent out-cross, physical admixtures, disease dissemination and also ensure crop condition as regards to the spread of designated diseases and the presence of objectionable weed plants etc.
- **Sample Inspection:** assessing the planting value of the seeds by laboratory tests. Certification agency draws representative samples from the seeds produced under certification programme and subjects them to germination and other purity tests required for conforming to varietal purity. Bulk Inspection: Under certification programme provision has been made for bulk inspection. Hence, the evaluation of the lot for the purpose of checking homogeneity of the bulk seed produced as compared with the standard sample is carried out. This gives an idea about the genuinity of lot and sample.
- **Control plot testing:** Here the samples drawn from the source and final seed produced are grown side by side along with the standard samples of the variety in question. By comparison it can be determined whether the varietal purity and health of the produced seed are equal to the results based on field inspection.
- **Grow-out test:** Evaluation of the seeds for their genuineness to species or varieties or seed borne infection. Here the samples drawn from the lots are grown in the field along with the standard checks. Growing plants are observed for the varietal purity. Grow-out test helps in the elimination of the sub-standard seed lots.

6. **Phases of Seed Certification**

Seed Certification is carried out in six broad phases listed as under:

- Receipt and scrutiny of application.
- Verification of seed source, class and other requirements of the seed used for raising the seed crop.
- Inspection of the seed crop in the field to verify its conformity to the prescribed field standards.
- Supervision at post-harvest stages including processing and packing.
- Drawing of samples and arranging for analysis to verify conformity to the seed standards; and
- Grant of certificate, issue of certification tags, labelling, sealing etc.

7. **Grant of Certificates by Certification Agency**

Section 9 and 10 of the Seeds Act, 1966

- Any person selling, keeping for sale, offering to sell, bartering or otherwise supplying any seed of any notified kind or variety may if he desires to have such seed certified by the certifying agency, apply to the certification agency for the grant of certificate for the purpose.
- Every application under sub-section (1) shall made in such form, shall contain such particulars and shall be accompanied by such fee as may be prescribed.
- On receipt of any such application for grant of certificate, the certification agency may, after such enquiry as it think fit and after satisfying itself that the seed to which the application relates conform to the minimum limits of germination and purity specified for that seed under clause (a) of section 6, grant a certificate in such form and on such conditions as may prescribed.

8. **Validity Period of the Certificate**

The validity period shall be nine months from the date of test at the time of initial certification. The validity period could be further extended for six months provided on retesting seed conforms to the prescribed standards in respect of physical purity, germination and insect damage for all seeds except vegetatively propagating material for which lot shall be re-examined for seed standards specified for respective crop. A seed lot will be eligible for extension of the validity period as long as it conforms to the prescribed standards.

9. **Revocation of Certificate**

If the certificate Agency is satisfied, either on reference made to it in this behalf or otherwise, that

- The Certificate granted by it under section 9 has been obtained by misrepresentation as an essential fact.
- The holder of the certificates has, without reasonable cause, failed to comply with conditions subject to which the certificate has been granted or has contravened any of the provisions of this Act or rules made there under, then without prejudice to any other penalty to which the holder of the certificate may be liable under this Act, the certification Agency may, after giving the holder of the certificate an opportunity of showing cause, revoke the certificate.

8.3. A. Seed Drying – Methods of Seed Drying

Seed drying

The process of eliminating moisture from the seed is called drying.

1. Stage of moisture elimination

There are 2 stages of moisture elimination

i. The air drying initially removes surface moisture from the seed.
ii. Moisture removal from the surface creates an imbalance between the surface and interior of the seed, causing moisture to move from inside to the surface. However, this moisture migration is slower than evaporation, creating a moisture gradient within the kernel.

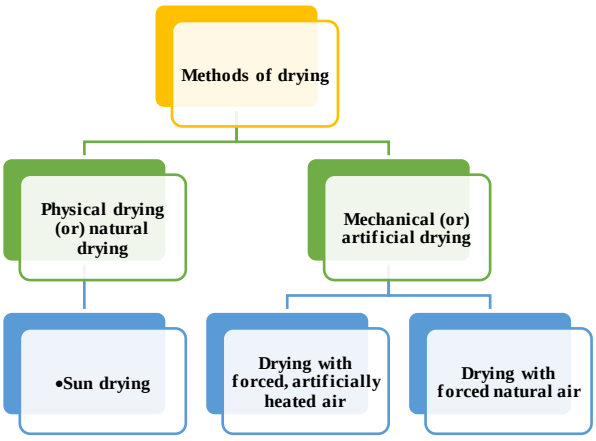
Moisture removal from seeds depends on the surrounding air's temperature and relative humidity (RH). Seeds lose moisture when the atmospheric RH is lower than the seed's moisture content. During drying, oxidation, decomposition, and volatilization must be minimized to prevent dry weight loss, which increases at high temperatures. Therefore, high-moisture seeds should be dried at low temperatures (Chala & Bekana, 2017).

2. Drying temperature

The greater the seed moisture content, the lower the drying temperature and vice versa.

10% MC and below:	110°F (43.3° C)
10-18% MC:	100°F (37.7° C)
18-30% MC:	90°F (32.2 ° C)

3. Methods of drying



i. Physical Drying / Natural drying

This is a conventional method of seed drying, carried out in the field or on the threshing floor, utilising solar energy. To achieve uniform drying, the seed should be spread in a thin layer. High-moisture seeds (>17%) should first be dried in shade, then sun-dried at noon. Seeds shouldn't be left out overnight as they absorb moisture. Drying takes 2-4 days to reduce moisture to 10-12% (Copeland & McDonald, 2001).

ii. Mechanical drying or artificial drying

Mechanical drying involves blowing natural or heated air through seed layers until completely dry.

a) Forced natural air drying

Traditional godowns use two ventilators for natural air circulation, while modern facilities employ electronic blowers for forced air movement. The dry outside air circulates through the storage area, effectively removing moisture from the seeds. However, this method is only effective during dry months when the ambient air has low moisture content (Copeland & McDonald, 2001).

b) Forced heated air drying

In this method, the outside air is heated with the help of a burner heater and circulated into the godown for drying. This principle is employed in several types of modern dryers.

There are two main types of forced air driers: batch driers and continuous flow driers. In batch driers, dry air is blown through a layer of seeds until fully dried, then that batch is removed and replaced with fresh seeds. This method is simple, ideal for small quantities, easy to clean, and perfect for farm-level drying. However, the air temperature must be carefully controlled to prevent overheating seeds at the bottom layer. In continuous flow driers, seeds move constantly through a stream of hot air (either horizontally or vertically) and then pass into a cooling chamber. These driers can handle higher temperatures since seeds are exposed to heat for a shorter duration, but they are more difficult to clean when switching between different crop varieties (Agrawal & Dadlani, 1987).

Tempering

Seeds are dried in multiple stages with rest periods (tempering) in between, where seeds are stored in bins to allow moisture to redistribute evenly from inside to outside. During drying, the surface dries faster than the inside, creating a moisture imbalance, but tempering equalizes this moisture throughout the seed kernel. This staged drying with tempering periods makes the process faster and more efficient than continuous drying (Windhab, 2017).

8.3. B. Seed storage and maintenance- general principles – Stages and factors affecting – Seed longevity during storage – Measures for pest and disease control during storage

What is seed storage?

Preservation of seed with initial quality until it is needed for planting.

Objective of seed storage

To maintain initial seed quality, *viz.,* germination, physical purity, vigour, etc., all along the storage period by providing suitable or even better conditions.

Stages of seed storage

The seeds are considered to be in storage from the moment they reach physiological maturity until they germinate, or until they are thrown away because they are dead or otherwise worthless. The entire storage period can be conveniently divided into the following stages;

i. Storage on plants (Physiological maturity until harvest)
ii. Harvest, until processed and stored in a warehouse
iii. In storage (Warehouse)
iv. In transit (Rail wagons, trucks, carts, railway sheds)
v. In retail stores
vi. On the user's farm

Factors affecting seed quality in storage

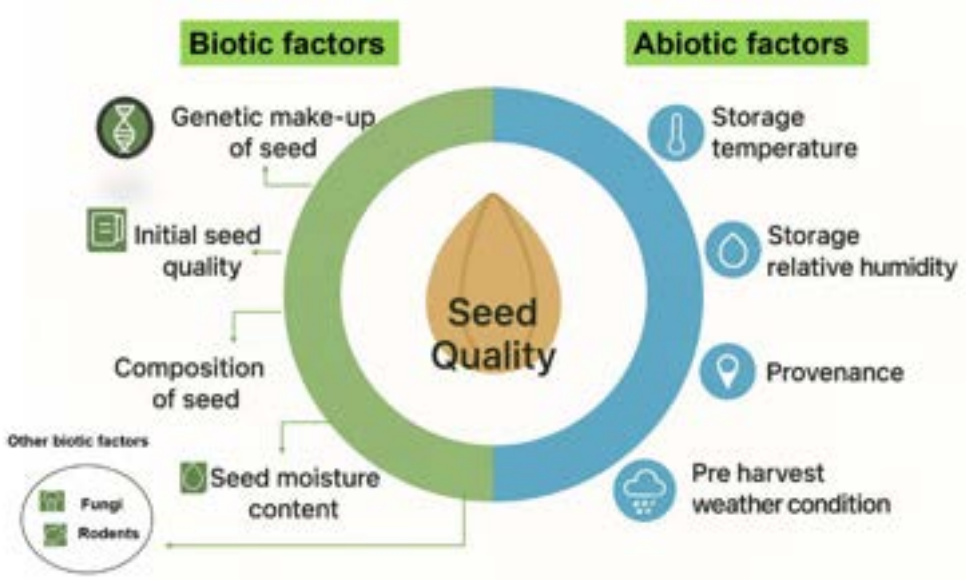
. **Types of seed storage**

- Storage of commercial truthfully labelled and certified seed
- Storage of carry-over seeds
- Storage of foundation seed stocks and enforcement seed samples
- Storage of germplasm seeds

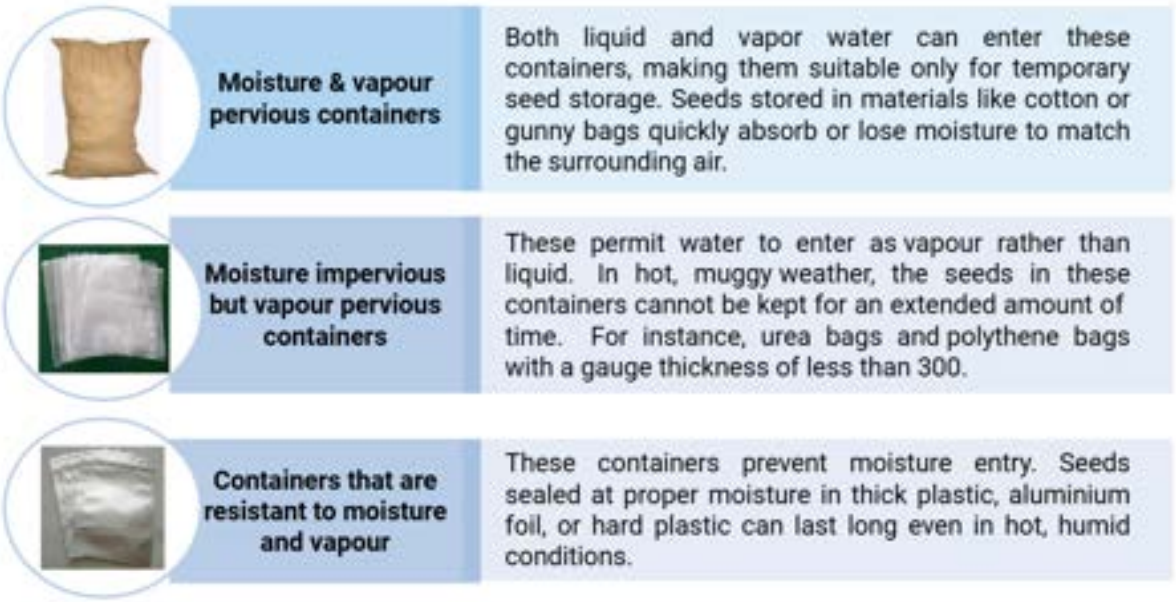
Seed longevity during storage

A list of short-, medium-, and long-lived seeds kept in ambient conditions was developed by Ewart in 1908 (Ewart, 1909). According to Harrington's "Thumb Rules," the effects of temperature and moisture are additive and independent, and the life span of seeds is estimated to be half with every 5 °C increase in seed storage temperature and 1% increase in seed moisture content. Furthermore, Harrington warned that the first

criterion is not applicable at temperatures lower than 0 °C or higher than 50 °C (Harrington & Kozlowski, 1972). According to the seed's behaviour during drying, Roberts, (1973) divided seeds into two primary storage classes: desiccation-sensitive and short-lived (also known as "recalcitrant") and desiccation-tolerant and long-lived (also known as "orthodox").



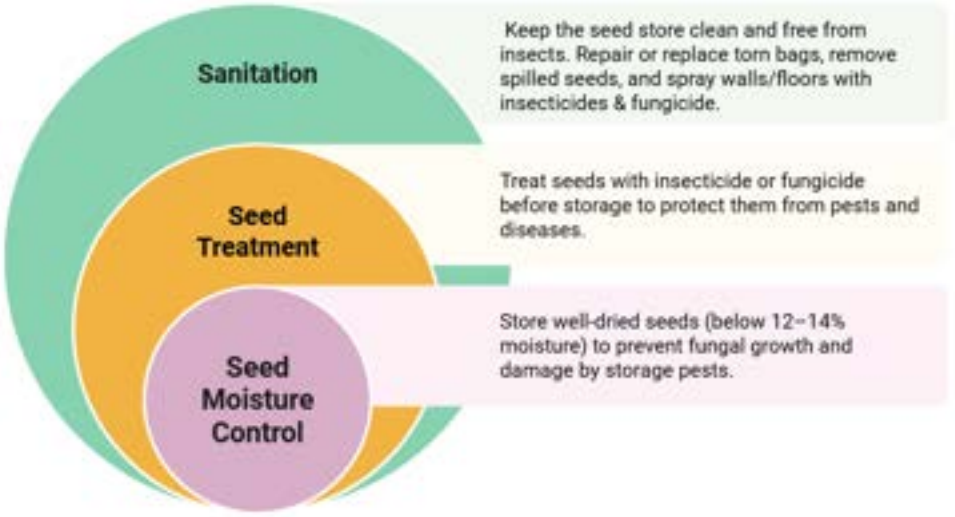
Classification of seed storage packaging materials



Seed Storage Sanitation / Godown Sanitation

- The storage environment must be pest-free, keeping insects and rodents out
- Chemicals like insecticides and fertilizers should be stored separately from seeds
- Storage room must be maintained cool and dry
- Arrange seed bags on wooden pallets in criss-cross pattern for proper ventilation on all sides
- Stack seed bags 6-8 layers high based on seed density
- Restack bags every 3 months or less to prolong seed viability
- Disinfect godowns before storage by spraying malathion 50% E.C. at 5 litres per 100 m^2 area
- Fumigate old gunnies, cloth bags, and containers with aluminium phosphide before reuse
- Maintain a stack size of 30x20 feet for effective fumigation under gas-proof or polythene covers
- Conduct periodic inspections and apply control measures as needed
- Apply malathion 50% E.C. at 5 litres per 100 m^2 area every 3 weeks
- Fumigate whenever necessary
- Caution: Excessive fumigation may reduce seed vigour and germination capacity
- Seeds with moisture content above 14% should be dried below this level before fumigation

Measures for pest and disease control during storage



Conclusion

Proper seed drying and storage are fundamental practices that determine the success of any seed production program. The drying process must be carefully controlled, with temperature selection based on initial moisture content to prevent damage while effectively removing excess moisture. Whether using traditional sun drying methods or modern mechanical dryers, the goal remains the same: reducing seed moisture to safe levels of 10-12% for long-term preservation. Tempering during the drying process ensures uniform moisture distribution throughout the seed, enhancing overall quality.

Equally important is maintaining optimal storage conditions that preserve seed viability from harvest until planting. This requires attention to environmental factors such as temperature and humidity, proper packaging materials, and strict sanitation protocols to prevent pest and disease infestations. Regular monitoring, appropriate stacking methods, and timely fumigation when necessary help maintain seed quality throughout the storage period. By following these scientific principles and best practices in seed drying and storage, seed producers can ensure high germination rates, strong vigor, and maximum crop productivity when seeds are eventually planted. Remember, quality seeds are the foundation of successful agriculture, and their proper handling during drying and storage is an investment in future harvests.



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