Strategies for Abiotic Stress Management in Agriculture

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Preface

The current reality of climate change has brought about heightened instances of abiotic stresses that significantly impact the growth and development of living organisms. Addressing the global challenge of feeding an ever-expanding population amidst shifting climatic conditions and environmental uncertainties has become increasingly urgent. Nearly 90% of arable lands face stress, while just 9% are suitable for crops globally. In India, agriculture grapples with hurdles in the 140 Mha net sown area—only 43 Mha have full irrigation, 23 Mha partial, and 50 Mha lack it. Alarmingly, 68% of India's land faces drought vulnerability, with around 121 Mha degraded by soil-related stresses, harming productivity, income, biodiversity, and causing land degradation and unemployment. Abiotic stresses encompass a range of factors that cause extensive damage to agriculture systems, leading to reduced productivity, income loss, biodiversity decline, land degradation, and unemployment.

In this context, this book offers a comprehensive examination of the intersection between agriculture and environmental stress, amalgamating insights from agronomy, genetics, engineering, and stress management technology. Authors of different chapters provided a holistic perspective, discussed challenges, solutions, and future opportunities. This encompasses cutting-edge technologies such as weather forecasting, soil and water conservation, plant phenomics, climate-smart farming systems, and alternative crops like dragon fruit and medicinal plants, along with agroforestry, aiming to revolutionize agricultural practices.

We express heartfelt gratitude to the contributing authors whose chapters enrich this book with their knowledge. It is our aspiration that this book serves as an invaluable resource for anyone engaged in or intrigued by the world of agriculture and abiotic stress. With this preface, we embark on a journey to comprehend, adapt to, and flourish amidst abiotic stressors, recognizing that the resilience of agriculture is inseparable from the resilience of humanity itself.

Editors

Foreword

Indian agriculture is highly vulnerable to abiotic stress factors, which are non-living environmental stressors that can adversely affect crop production. Abiotic stressors in Indian agriculture include various factors like drought, extreme temperatures, salinity, hailstorms, floods, and waterlogging etc. These stresses can have a significant impact on crop yields, food security, and the livelihoods of millions of farmers in India. Even though India has achieved self-sufficiency in food and horticultural production of 329.6 Mt and 351.9 Mt respectively, the productivity is less due to several factors and one among them is abiotic stress. Among them, abiotic stress which may be drought with heat stress, salinity with drought, water logging followed by soil compaction etc. needs to be addressed together by tolerant varieties, good management practices and crop planning.

Efforts to address abiotic stress in Indian agriculture require a multi-faceted approach, including the development and dissemination of resilient crop varieties, improved agronomic practices, better water management, and policies that promote sustainable agriculture in the face of changing environmental conditions. To make the agriculture successful under stress condition, these technologies has to reach the stakeholders like farmers, entrepreneurs, and industrialists to plan the management strategies accordingly. In this context, ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra is working on several Abiotic stresses to assess the impact and management of these stresses to enhance the tolerance in plants and sustainable production. I appreciate the efforts made by the authors and editors of this book in the compilation of information on abiotic stress, its management, and options for mitigating the stress under changing climatic conditions.

Dr. P Chandrashekara
Director General, MANAGE

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26.02.2024

Message

The widespread impact of climate change is becoming increasingly apparent as abiotic stresses significantly affect the growth and development of living organisms. These stresses arise from various factors such as water (drought and floods), soil (salinity, sodicity, acidity, heavy metals, nutrient deficiency, and toxicity), and temperature (extremes of high and low), presenting serious challenges to both national and global food production. With merely 9% of the world's agricultural land deemed suitable for crop cultivation, the vast majority is subjected to diverse stresses. This situation poses a formidable challenge, especially with a burgeoning population and limited opportunities for harnessing natural resources.

This book offers an exhaustive analysis of the impacts of abiotic stress across different agricultural sectors, including crops, horticulture, aquaculture, and associated sub-sectors, all of which are affected by suboptimal ecological conditions. It presents both technological and strategic measures for managing stress and provides actionable research directions to boost productivity, profitability, and resilience. Highlighting the adaptability of certain crops (such as dragon fruit, fruit crops, fodder crops, medicinal plants, and agroforestry systems) under climate change conditions, it proposes innovative cultivation methods for stressed environments.

A treasure trove of information, this book is designed for students, researchers, and stakeholders engaged in abiotic stress management. I t not only imparts knowledge on plant responses but also acts as an extensive guide for comprehending, mitigating, and addressing the complex challenges abiotic stresses impose on agriculture and related sectors.

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Prof. Balraj Singh
Vice-Chancellor

MESSAGE

Agriculture is susceptible to the adverse impacts of abiotic stressors. These non-living environmental factors can significantly affect crop production and livelihood of farmers. Abiotic stress in agriculture includes challenges such as drought, extreme temperatures, salinity, waterlogging, and soil degradation, among others. These stresses can affect the productivity and quality of food crops as well as horticultural crops.

In our agriculture system occurrence of abiotic stress is common phenomenon due to dependency on monsoon also deteriorating soil health. Along with abiotic stress several biotic stresses also associated which get aggravated due to occurrence of stress. These stresses can have a significant impact on crop yields, food security, and the livelihoods of millions of farmers in India. Therefore, it is most urgent to address the issues of managing the individual as well as multiple stresses.

ICAR-National Institute of Abiotic Stress Management in Baramati, Maharashtra, is actively engaged in addressing various abiotic stresses to assess their impact and enhance plant tolerance for sustainable production. Several aspects such as weather abnormalities, plant phenomics, soil and water conservation, stress tolerant crops and crop varieties, root stock breeding, etc. has been covered in this book. I commend the authors and editors of this book for their efforts in compiling information on abiotic stress, its management, and strategies to mitigate these stresses in the context of changing climatic conditions.

25/01/24

(**Prof. Balraj Singh**)

Date: 24.01.2024
Place: Jobner

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Abiotic Stresses in Agriculture: An Overview

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Introduction

India has achieved self-sufficiency in food production and also a leading producer of horticulture, dairy and poultry in the world. The present food grain production is 329.6 Mt and horticulture production is 351.9 Mt. However, this growth is severely hampered by various abiotic stresses. These adverse environmental factors can curtail crop production by up to 70%. Abiotic stresses such as extreme temperatures, frost, drought, water logging and salinity have a substantial negative impact on crop growth, metabolism, and overall productivity of the agriculture sector.

Apart from the abiotic stresses mentioned, various soil-related challenges significantly impede crop, livestock, and fisheries production. These encompass chemical factors such as nutrient imbalances, excessive soluble salts, salinity, and alkalinity. Physical factors like susceptibility to erosion, steep terrain, shallow soils, surface crusting and sealing, limited water-holding capacity, drainage issues, low structural stability, root-restricting layers, and high soil swell/shrink potential also pose substantial obstacles. In addition, biological factors, such as variations in organic content, have emerged as hindrances. These soil-related challenges result in reduced crop, livestock, poultry, and fish performance due to their adverse effects on growth and development. They also contribute to the emergence of new diseases and pests within these sectors. Moreover, the detrimental impact of these challenges is exacerbated by industrialization, urbanization, and climate change, affecting all facets of agriculture, including crop cultivation, horticulture, livestock farming, and fisheries.

What are abiotic stresses?

Abiotic stresses refer to the adverse effects of environmental factors on living organisms in a specific habitat. These factors must extend beyond the typical range of variation in the environment to significantly impact the performance or physiology of individuals or populations. Abiotic stresses can encompass various non-optimal environmental conditions that, whether acting individually or in combination, negatively affect different aspects of agriculture. Abiotic stressors are typically natural, intangible, and inanimate factors such as intense sunlight, temperature extremes, or strong winds that can cause harm to the organisms inhabiting the affected area (Pathak et al., 2021).

Abiotic stresses could be in many forms related to atmosphere, water and soil. The basic atmospheric stressors include high wind, extreme temperature, drought, flood and natural disasters such as tornadoes and wildfires. Water-related stressors could be excess (flood) or scarcity of water (drought) whereas soil stresses include poor edaphic conditions like rock content and extreme pH levels, compaction and contamination.

Water stress

Water stress is one of the most common stresses across the globe that affects plant growth and development. The plant faces water stress when transpiration exceeds the capacity of the plant to absorb water or when the root factor becomes limiting. Water stress could be due to limited or scarcity (drought) and excess water (flood).

Drought

Drought is characterized by an extended period of insufficient rainfall when compared to the statistical average for a particular region. Drought can manifest in various types: Meteorological Drought: This type of drought is identified by a significant deficit in precipitation relative to the expected or average levels of rainfall. It primarily focuses on the scarcity of rainfall in a given area. Hydrological Drought: Hydrological drought becomes evident when there is a noticeable decrease in river and stream flow, along with critically low groundwater tables. It's concerned with the impact of drought on water sources and availability. Agricultural Drought: Agricultural drought occurs when an extended dry period leads to crop stress and negatively affects crop yields. This type of drought directly impacts the agricultural sector, including crops and farming activities.

The frequency of drought tends to increase in regions with greater variability in rainfall, especially in areas experiencing a reduction in annual rainfall. This heightened variability in precipitation patterns can result in more frequent and severe drought events, which have far-reaching implications for agriculture, water resources, and ecosystems.

Flood/waterlogging

Flooding refers to any situation in which there is an excessive amount of water. It can manifest in different ways. Sudden inundation resulting from heavy rainfall events can impose severe physiological stress on crops. On the other hand, the gradual inundation of croplands, which occurs in a regular cycle as a part of seasonal changes in river levels, presents a different yet equally demanding flooding environment to which plants must adapt. The stress that terrestrial species experience when subjected to flooding is commonly referred to as "waterlogging." The damage symptoms observed in plants are primarily a result of prolonged exposure to hypoxia, a condition characterized by a deficiency of oxygen in the root zone due to water saturation. This lack of oxygen hampers normal plant respiration and leads to a range of adverse effects on plant growth and health.

Soil stress

Soil stress encompasses a range of physical, chemical, and biological factors that hinder the soil's ability to function effectively. These stresses are pervasive and have significant implications for agricultural production. Here are some key aspects of soil stress:

Physical Stresses: These factors can impair soil functions and hinder crop growth. They include:

1. Soil Crusting: The formation of a hard, impermeable layer on the soil surface, which can impede water infiltration and seedling emergence.
2. Subsurface Compaction: Soil compaction beneath the surface, often caused by heavy machinery or livestock, can reduce root penetration and limit water and nutrient uptake by plants.
3. Erosion: The loss of topsoil due to wind or water erosion can deplete the fertile layer needed for crop growth.
4. Waterlogging: Excessive water accumulation in the soil can lead to reduced oxygen levels in the root zone, harming plant health.
5. Shallow Soil: Inadequate soil depth limits the rooting space for plants, affecting their ability to access nutrients and water.
6. High Permeability: Soil with high permeability may not retain enough moisture for crops, leading to drought stress.

Chemical Stresses: These are chemical imbalances in the soil that can negatively affect plant growth. They include:

1. Nutrient Deficiency: A lack of essential nutrients can result in nutrient stress, limiting crop development.
2. Acidity: Acidic soils have a low pH, which can hinder nutrient availability and nutrient uptake by plants.

3. Salinity: High salt concentrations in the soil can disrupt osmotic balance in plants and inhibit growth.
4. Sodicity: Sodic soils have high levels of sodium, which can lead to soil structure deterioration and reduced permeability.
5. Heavy Metal Toxicity: Excessive levels of heavy metals in the soil can be toxic to plants and may contaminate food crops.

Biological Stresses: These relate to the living components of the soil ecosystem and include:

1. Loss of Soil Organic Matter: Reduced organic matter levels diminish soil fertility and water-holding capacity.
2. Diminished Microbial Activities: Soil microorganisms play a vital role in nutrient cycling and organic matter decomposition; their decline can impact soil health.
3. Loss of Soil Biodiversity: A reduction in soil biodiversity can disrupt ecological balance and the functioning of the soil ecosystem.

In India, these soil stresses have significant implications for agricultural land. For example, a substantial portion of land is affected by salt stress, with areas categorized as sodic or saline. Additionally, acidic soils are distributed throughout the country. Addressing these soil stresses through appropriate soil management practices and amendments are crucial for sustaining agricultural productivity and ensuring food security. In India, soil stress is a significant concern, with approximately 6.72 million hectares of salt-affected land, including 3.77 million hectares of sodic soil and 2.96 million hectares of saline soil (Arora and Sharma 2017). Furthermore, around 0.93 million hectares of Indian soils are acidic and distributed across the country (Maji et al. 2012). Addressing these soil stresses through appropriate soil management practices and amendments is vital for sustaining agricultural productivity and ensuring food security."

Atmospheric stress

"Atmospheric stress" is not a commonly recognized scientific term or concept. It refers to various environmental or atmospheric factors that can have stress-inducing effects on living organisms (Greaves, 1996). These factors can include:

1. Air Pollution: Elevated levels of air pollutants, such as particulate matter, ozone, sulfur dioxide, nitrogen oxides, and volatile organic compounds, can stress plants, animals, and humans. Air pollution can damage plant leaves, impair respiratory functions in animals, and have adverse health effects on humans.
2. Climate Change: The ongoing changes in global climate patterns, including rising temperatures, altered precipitation patterns, and extreme weather events, can create stress for ecosystems, agriculture, and communities. Climate change can disrupt

ecosystems, impact crop yields, and increase the frequency and intensity of extreme weather events.

3. Heat Stress: High temperatures, particularly during heatwaves, can lead to heat stress in humans, animals, and even plants. Prolonged exposure to extreme heat can cause heat-related illnesses, reduce crop yields, and harm wildlife.
4. Drought: Extended periods of water scarcity due to reduced precipitation or increased evaporation can lead to drought stress. Drought affects agriculture, water resources, and ecosystems, causing water shortages and environmental damage.
5. Extreme Weather: Events like hurricanes, tornadoes, and severe storms can subject communities and ecosystems to stress. These events can result in property damage, loss of life, and environmental disruptions.
6. Airborne Allergens: Certain atmospheric conditions can increase the concentration of airborne allergens, such as pollen and mould spores. This can trigger allergies and respiratory issues in susceptible individuals.
7. Natural Disasters: Atmospheric conditions play a significant role in natural disasters like wildfires and dust storms. These events can have catastrophic effects on the environment and communities.

It's important to note that these atmospheric stressors can have wide-ranging impacts on both natural ecosystems and human societies. Efforts to mitigate and adapt to these stressors are essential for the well-being of the planet and its inhabitants.

Abiotic stresses in Indian agriculture

India's agricultural landscape faces a multitude of challenges and complexities (Pathak and Kakade, 2021). Here is a breakdown of the key points from the provided text:

1. Land Distribution and Usage: India has a total geographical area of 328 million hectares (Mha), with reported land under forest covering 70 Mha, and 43 Mha that is unsuitable for cultivation. The net sown area is 140 Mha, of which only 43 Mha is fully irrigated, 23 Mha is partially irrigated, and 50 Mha is unirrigated.
2. Drought Vulnerability: Approximately 68% of the cultivated area in India is susceptible to drought, highlighting the significant risk posed by water scarcity to agriculture.
3. Land Degradation: About 36% (121 Mha) of India's total geographical area is degraded due to soil erosion, salinity, alkalinity, acidity, water logging, and other edaphic stresses. This degradation adversely affects agricultural productivity.
4. Limited Suitable Land for Crop Production: A mere 9% of the world's land area is considered suitable for crop production, and India faces the challenge of sustaining agriculture in the majority of the remaining 91% that is affected by various stressors.

5. Urbanization and Industrialization: Expanding urbanization and industrialization contribute to pollution of land, water, and air, and result in increased competition for agricultural land and water resources.
6. Climate Change: Climate change compounds agricultural challenges with extreme heat, intense rainfall, frequent droughts, melting glaciers, and rising sea levels, threatening all sectors of agriculture.
7. Sustainable Development Goals: Despite progress toward achieving Sustainable Development Goals (SDGs), India still faces significant gaps in overcoming poverty, hunger, and malnutrition.
8. Resource Base Decline: India's resource base for agriculture, including soil, water, and air, is shrinking despite growing population and income levels, which has led to increasing demand for food.
9. Farmer Demographics: More than 60% of Indian farmers are over 50 years of age, and approximately 40% are willing to leave agriculture if alternative occupations are available.
10. Productivity Stagnation: Productivity growth rates for many crops have plateaued, affecting the profitability of agriculture.
11. Unsustainability: Indian agriculture faces challenges such as low and volatile wages, degraded natural resources, rising labour and energy shortages, and the looming threats of climate change, making it unsustainable.
12. Vulnerable Small-Holders: More than 85% of Indian farmers are smallholders and are particularly vulnerable to these challenges.

Impacts of abiotic stresses on crops

Abiotic stresses pose a significant and nearly inevitable challenge to crop growth and productivity on a global scale. These stressors have a profound negative impact on agricultural production, often leading to a substantial reduction in crop yields. Research by Wang et al. in 2007 demonstrated that abiotic stressors can cause a yield reduction of over 50% compared to the potential yield.

Abiotic stress encompasses a wide array of adverse conditions, including heat (40% of cases), salinity (20%), drought (17%), cold (15%), and various other stress factors. Remarkably, only 9% of the Earth's land surface is deemed suitable for agriculture, while the remaining 91% is affected by diverse stressors, as indicated by the Vision 2050 report from NIASM (Vision 2050, NIASM).

Unpredictable and heavy rainfall, especially during unseasonal times, can inflict severe damage to standing crops, leading to significant losses for farmers. Recent instances in different states of India illustrate this problem. In Punjab and Haryana, heavy rains during the harvest season damaged ripe wheat crops. Similarly, maize, litchi, and mango crops in Bihar and West Bengal faced ruin due to unseasonal rain, resulting in moisture-related issues, discolouration, increased susceptibility to storage diseases, and delayed procurement due to the need for drying before sale.

Unseasonal rainfall doesn't spare perennial and hardy crops either. For instance, the December 2021 rainfall in some regions, accompanied by fog and dew, negatively impacted commercial fruit crops like grapes, papaya, mango, and pomegranates by creating favourable conditions for diseases and pests. Additionally, unseasonal rain can disrupt crucial controlled water stress periods in fruit crops, such as pomegranates, guavas, and custard apples, leading to excessive vegetative growth instead of desired flowering. This often forces farmers to resort to artificial stress-inducing chemicals, increasing cultivation costs and reducing net income (Minhas et al. 2015).

Furthermore, waterlogging in fields, especially in larger farming areas, complicates operations like pesticide spraying and can result in the washout of applied chemicals, subsequently leading to outbreaks of diseases and pests following unseasonal rains. These challenges underscore the need for innovative agricultural practices and strategies to mitigate the impacts of abiotic stresses and enhance crop resilience in the face of unpredictable weather events (Brussaard et al. 2007)

Beneficial effect of abiotic stresses

Abiotic stresses can have varying effects on organisms, and these effects can sometimes be beneficial, depending on the context, location, and the specific organisms involved (Roelofs et al. 2008). Here are some examples of how abiotic stresses can have both positive and negative impacts:

Flooding: Flooding is detrimental to most non-aquatic plants in a particular area as it can lead to oxygen deprivation in the soil. However, aquatic plants such as rice are adapted to thrive in flooded conditions. In some cases, flooding can also have positive effects, such as recharging groundwater and depositing nutrient-rich sediments onto floodplains, as seen in regions like the Indo-Gangetic belt.

Elevated Temperature: An increase in temperature can negatively affect some organisms, such as phytoplankton. However, thermophilic zooplankton can benefit from warmer conditions and thrive under elevated temperatures.

Natural Wildfires: While wildfires can be destructive, they are a natural part of some ecosystems and can be beneficial. These fires can clear out old vegetation, allowing new organisms to grow and thrive. They also play a role in natural selection and the evolution of species.

Controlled Water Stress: Controlled water stress is a practice used in agriculture, particularly in fruit crops like pomegranates, guavas, custard apples, and mangoes. It involves intentionally subjecting crops to limited water availability for specific periods. This practice can have several benefits, including reducing the crop cycle to one season, promoting bumper flowering and fruiting, managing issues like water shortages, pests, and diseases, and preventing market glutes. However, the timing and duration of water stress must be carefully managed to avoid negative impacts on the crops.

Unseasonal Rains: While unseasonal rains can damage crops and cause various challenges, they can also have positive effects. For some farmers, unseasonal rains can make field preparation easier, provide life-saving irrigation for rain-fed agriculture, and benefit newly planted or sown crops. Additionally, such rains can lower temperatures, which may be beneficial in certain situations.

Conclusions

The projected scenario of abiotic stress-prone areas becoming the home to more than half of the global population by 2050 raises serious concerns about the future of agricultural production. Abiotic stress, driven in part by climate change and various environmental factors, is emerging as a major threat to agriculture, with potential consequences for crop yields, ecosystems, and the global economy.

The negative consequences of climate change are already evident, and they are expected to intensify in the coming decades. This challenge is not limited to any specific region or country; it affects emerging and developing nations alike. These countries face a complex web of social and technological constraints, which may hinder or facilitate the transition toward long-term sustainable agricultural production.

However, in regions that are particularly vulnerable to climate change and its associated abiotic stresses, a coordinated adaptive approach is imperative. This approach should be politically relevant, addressing the concerns of policymakers and governments; socially feasible, considering the needs and aspirations of local communities; culturally acceptable, respecting the traditions and values of the populations affected; and environmentally sustainable, ensuring the responsible use of natural resources and minimizing ecological impact.

In essence, addressing the challenges posed by abiotic stress in the context of a changing climate requires a holistic and inclusive strategy that transcends borders, engages diverse stakeholders, and prioritizes the well-being of both current and future generations. It calls for innovation, resilience, and a shared commitment to safeguarding our agricultural systems and the livelihoods they support.

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Climate Change and Extreme Weather Events of India

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What Is Climate Change?

Climate change refers to a discernible alteration in the state of the climate system, supported by statistical tests, involving changes in its mean or variability, which persists for an extended period, typically decades or longer. This definition emphasizes the importance of detecting measurable changes in the climate. Climate change can result from natural processes, human activities, or a combination of both. Its consequences are far-reaching, affecting various environmental, social, and economic aspects. These include rising global temperatures, altered weather patterns, and sea-level rise, among others.

Since 1880, scientists have maintained thermometer-based records of global surface temperatures. These records have consistently shown a warming trend, indicating that the planet is becoming warmer. This upward trend in global temperatures is a critical aspect of climate change. It signifies a long-term shift in climate conditions, resulting in various environmental and societal impacts. This warming leads to consequences such as the melting of ice caps, more frequent and severe heat waves, and altered weather patterns. These effects extend beyond just temperature changes and impact ecosystems, sea levels, and weather events. Understanding these trends and their implications is essential for addressing the challenges posed by climate change and taking action to mitigate its impacts and adapt to a changing world.

Why is Climate Change a Problem?

Climate change presents a multifaceted problem with serious consequences for the planet and its inhabitants. The core issues contributing to the problem are:

1. **Warming Temperatures:** As previously discussed, global temperatures are rising. This warming leads to several issues:
    - **Melting Ice Caps and Rising Sea Levels:** Warming temperatures cause polar ice caps and glaciers to melt, contributing to rising sea levels. This, in turn, threatens coastal communities and ecosystems.
    - **Extreme Weather Events:** Increasing temperatures result in more frequent and severe weather events such as hurricanes, droughts, and floods. These events can have devastating impacts on communities and economies.
2. **Ecosystem Disruption:** Climate change disrupts ecosystems and biodiversity:
    - **Shifts in Habitats:** Rising temperatures force shifts in habitats, impacting species' survival.

- **Loss of Biodiversity:** Many species may become extinct due to habitat loss and an inability to adapt to rapidly changing conditions.

3. **Ocean Acidification:** Increased levels of carbon dioxide in the atmosphere are absorbed by the oceans, causing ocean acidification. This threatens marine life, particularly coral reefs and shellfish.

4. **Economic Consequences:** The economic ramifications of climate change are substantial:

   - **Agricultural Disruption:** Changing weather patterns can disrupt agriculture, leading to food shortages and increased prices.

   - **Infrastructure Damage:** Rising sea levels and extreme weather events can damage infrastructure, resulting in costly repairs and relocations.

5. **Social and Political Implications:** Climate change exacerbates social and political challenges:

   - **Climate-Induced Migration:** As some areas become uninhabitable due to climate impacts, there will be increased migration, which can strain resources and lead to conflicts.

   - **Resource Scarcity:** Climate change can exacerbate resource scarcity, leading to conflicts over water, arable land, and energy sources.

6. **Global Health Issues:** Climate change can have direct and indirect effects on human health:

   - **Heat-Related Illnesses:** More frequent and intense heatwaves can lead to heat-related illnesses and deaths.

   - **Spread of Diseases:** Climate change can alter the geographic distribution of diseases and disease-carrying vectors, impacting public health.

Additionally, rising global temperatures contribute to a reduction in sea ice, causing problems for animals that depend on the ice for hunting, mating, and rest. The bright surface of ice reflects 80% of sunlight, helping to cool polar regions and moderate the global climate. However, reduced sea ice means less sunlight is reflected, leading to more ocean warming and further sea ice reduction. This feedback loop accelerates climate change. Moreover, even with swift action, global temperatures are expected to continue rising due to greenhouse gases already in the atmosphere. This necessitates urgent efforts to minimize temperature increases for the well-being of both humans and wildlife.

Population and Food requirement

The world's population has experienced significant growth, increasing from around 5.3 billion in 1990 to over 7.8 billion in 2021. Future projections suggest this trend will continue, with estimates ranging from 9.7 billion to over 11 billion by 2100. This growing population naturally leads to increased food demand, exacerbated by changing dietary patterns that favour more resource-intensive diets.

However, the challenge extends beyond sheer numbers. The combined effects of a rising global population and changing diets place enormous stress on crucial resources like arable land, freshwater, and forests. Climate change further compounds these challenges. It brings about more frequent extreme weather events, prolonged droughts, and shifts in suitable agricultural regions. Rising temperatures and changing precipitation patterns can lead to greater variability in crop yields, affecting food production. This variability threatens food security by reducing the predictability and stability of food production, increasing the risk of food shortages and price volatility. Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts and related losses and damages to nature, as reported by the IPCC in 2023.

Increasing weather and climate extreme events have exposed millions of people to acute food insecurity and reduced water security, with the largest adverse impacts observed in many locations, particularly in Asia and among small-scale food producers, as highlighted by the same IPCC report.

In this context, addressing the complex interaction between population growth, food requirements, and climate change is imperative. Sustainable agricultural practices, efficient resource management, and strategies to adapt to changing conditions are essential components of a holistic approach to ensure food security and environmental sustainability in a growing world.

Causes Climate Change: The Greenhouse Effect

Climate change is primarily driven by the greenhouse effect, a natural phenomenon that maintains Earth's habitable temperature. It involves the balance of short-wave and long-wave radiation in the atmosphere. The Sun emits short-wave solar radiation, which includes visible light and ultraviolet rays. Earth's atmosphere permits this short-wave radiation to pass through and warm the surface when it is absorbed. In turn, the Earth emits long-wave, infrared radiation as part of its cooling process.

The greenhouse effect is essential for sustaining the planet's temperature, as it allows outgoing long-wave radiation to escape into space. However, greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4), and water vapour (H_2O) play a crucial role in this process. They absorb some of the outgoing long-wave radiation, preventing it from escaping, which, in turn, maintains the Earth's temperature within a habitable range.

Climate change can be caused gradually by natural processes or suddenly by large events, such as a massive meteorite strike or volcanic activity. However, the rapid climate change experienced today is primarily attributable to three main human activities. Burning fossil fuels for heating, cooking, generating electricity, and powering vehicles releases carbon dioxide into the atmosphere. Simultaneously, deforestation, the destruction of forests, releases carbon dioxide and reduces the number of trees capable of capturing carbon dioxide from the atmosphere. Furthermore, the reduction of biodiversity contributes to an unstable ecosystem, resulting in nature loss that makes ecosystems less capable of capturing carbon from the atmosphere and less resilient to rising temperatures. This disrupts the natural balance, trapping more heat and leading to global warming, which is at the core of climate change. This warming has far-reaching consequences, impacting ecosystems, weather patterns, and sea levels, emphasizing the urgent need for global efforts to mitigate and adapt to these changes.

Extreme Weather Events

Extreme weather events are occurrences that are rare within their statistical reference distribution for a specific location. They are as rare as, or even rarer than, events falling within the 10^{th} or 90^{th} percentile of a probability density function that's estimated from historical observations. These events can include, but are not limited to, intense heatwaves, powerful hurricanes, devastating floods, or severe droughts. Extreme weather events are characterized by their exceptional nature, standing out from the typical weather patterns of a region.

When an extreme weather event persists for an extended period, such as an entire season, it may be classified as an extreme climate event. An extreme climate event is especially notable if it results in an average or total that is itself extreme. For instance, a prolonged period of drought or exceptionally heavy rainfall throughout a season can be considered extreme climate events. These events have far-reaching impacts, affecting ecosystems, agriculture, and human societies, and are closely connected to the broader context of climate change and its consequences. Understanding and monitoring these occurrences is vital for preparedness, mitigation, and adaptation in the face of a changing climate.

Heat Waves and Cold Waves: Understanding Extreme Temperature Events

Heat Waves

Heat waves are climatic phenomena that signify a prolonged period of exceptionally hot weather, typically exceeding a region-specific threshold temperature. Often, these episodes are accompanied by high humidity levels, making the experience even more uncomfortable and, in some cases, life-threatening. The Indian Meteorological Department (IMD) characterizes a heat wave as a continuous spell of abnormally hot weather. These extended periods of extreme heat are more than just a passing inconvenience. They can have profound consequences for society and the environment.

Heat waves can lead to heat-related illnesses, including heatstroke and heat exhaustion, with vulnerable populations such as the elderly and young children being particularly at risk. Additionally, they put a strain on energy resources as people increase their use of air conditioning and cooling systems. Moreover, the impact of heat waves extends to ecosystems, often causing damage to agriculture, wildlife, and even infrastructure. Understanding, monitoring, and preparing for heat waves are essential for safeguarding public health and infrastructure.

Cold Waves

In contrast to heat waves, cold waves are characterized by rapid and substantial drops in temperature within 24 hours. These temperature decreases are significant enough to necessitate increased protection for various sectors, including agriculture, industry, commerce, and social activities, according to the Indian Meteorological Department (IMD) definition. Cold waves have their own set of consequences, often associated with the sudden onset of freezing conditions. These events can result in frost damage to crops and vegetation, leading to substantial losses for the agricultural sector. They can also disrupt transportation systems, including road, rail, and air travel, as icy conditions make travel hazardous. Additionally, cold waves can lead to increased energy consumption as people rely on heating systems to stay warm, potentially causing stress on energy resources.

Both heat waves and cold waves are notable extreme weather events, each with its unique set of challenges and impacts. Being prepared and having strategies in place to mitigate their effects is crucial to protecting the well-being of communities and critical infrastructure during these temperature extremes.

Criteria for Heat Wave and cold wave (IMD)

Heat waves are defined based on specific temperature criteria. For plains, a heat wave is not considered until the maximum temperature of a station reaches at least 40°C. In hilly regions, this threshold is lower, with a minimum requirement of at least 30°C.

The categorization of heat waves is based on the departure from normal maximum temperatures. When the actual maximum temperature exceeds normal by:

- +4°C to +5°C, it is classified as a Heat Wave (HW).
- +5°C to +6°C, it is considered a Severe Heat Wave (SHW).
- If the actual maximum temperature remains 45°C or higher, a heat wave is declared, irrespective of the normal maximum temperature.

Cold Waves are also defined based on similar specific temperature criteria. The classification is determined by the departure from normal minimum temperatures, taking into account the specific threshold for normal Tmin. The criteria for declaring cold waves are as follows:

When the minimum temperature falls to:

- -4°C to -5°C for normal Tmin > 10°C, it is classified as a Cold Wave (CW).
- -5°C to -6°C, it is considered a Severe Cold Wave (SCW).
- If the Wind Chill Temperature (WCT_n) reaches 0°C, a Cold Wave is declared, with an exception for stations where normal Tmin is 0°C, in which case this criteria is not applicable.

These criteria provide a systematic method for classifying and declaring heat waves and cold waves, helping to monitor and respond to extreme temperature events in different regions.

Drought: A Complex and Slow-Onset Natural Hazard

Drought is a climatic phenomenon characterized by its slow onset, cumulative impact, and the absence of a universal definition. It stands as one of the most complex and least understood of all natural hazards. Droughts are marked by several distinctive features:

- **Slow Onset:** Droughts have a creeping nature, and their onset and termination are often challenging to discern. They develop gradually over an extended period, making it difficult to pinpoint their exact beginnings.
- **Duration and Intensity:** Droughts vary in duration, with some spanning from months to years. Their intensity can also fluctuate over time, posing challenges in both prediction and response.
- **Frequency:** Droughts may occur intermittently, and their core area or epicentre can shift and evolve, affecting different regions in various ways.
- **Non-Structural Impact:** Unlike many natural hazards, droughts primarily exert non-structural impacts, making them difficult to quantify. These effects can extend to agriculture, water resources, ecosystems, and human livelihoods.
- **Cumulative Impact:** The cumulative impact of droughts is pronounced when these events persist from one season or year to the next. This accumulation of impacts further complicates the provision of relief and recovery efforts.
- **No Universal Definition:** There is no universally accepted definition of drought. It is understood and classified differently across regions and scientific disciplines.
- **Absence of Single Indicator:** Droughts have no single indicator or index that unequivocally marks their onset or determines their severity. Understanding and monitoring droughts typically involve a combination of indicators and data sources.

Droughts are significant natural events that require comprehensive assessment and monitoring. The intricate and evolving nature of drought makes them a challenging phenomenon to study and address, making it essential to develop strategies and responses that consider their multifaceted and region-specific characteristics.

Drought Definitions:

1. **Meteorological Drought:** Meteorological drought is defined by the departure of precipitation from the long-term average over a specific period. The assessment periods may vary from monthly to seasonal or yearly, and these definitions are typically region-specific. Meteorological drought relies on a deep understanding of the region's climatology, often serving as an early warning sign, preceding other types of drought.
2. **Agricultural / Vegetation Drought:** Agricultural or vegetation drought is characterized by the availability of soil moisture to support crop growth. For instance, it may occur when the root zone of a crop contains less than 30% of the available soil moisture. The onset and severity of this type of drought depend on factors such as soil water-holding capacity and soil infiltration characteristics, which can vary with soil type, slope, and other factors. There is usually a lag of several weeks between precipitation deficits and the onset of agricultural drought.
3. **Hydrological Drought:** Hydrological drought is closely tied to the impact of precipitation shortfalls on surface or subsurface water supplies. It affects features like streamflow, reservoir and lake levels, and groundwater. Unlike meteorological drought, hydrological drought has a considerable time lag concerning precipitation departures. Recovery from hydrological drought is typically slow and can extend over a prolonged period.
4. **Socio-Economic Drought:** Socio-economic drought focuses on the relationship between the supply and demand for economic goods and services, particularly in the context of water resources. It addresses the economic impacts of water shortages and their consequences for various sectors, including agriculture, industry, and society at large.

Understanding Drought in Multiple Dimensions

Drought is a multifaceted natural phenomenon, and its comprehension varies across different disciplines. Meteorological drought, for instance, is rooted in the departure of precipitation from historical norms. It often serves as an early indicator, allowing communities to prepare for potential water shortages. Agricultural or vegetation drought takes a more practical approach, looking at the availability of soil moisture to sustain crop growth. This kind of drought is sensitive to factors like soil water-holding capacity and infiltration rates, making it closely tied to the agricultural sector. There is typically a lag between precipitation deficits and the onset of agricultural drought, giving farmers a brief window to adapt.

Hydrological drought delves into the actual impact of precipitation shortfalls on water supplies, including surface water sources like rivers and lakes, as well as subsurface resources such as groundwater. Unlike meteorological drought, hydrological drought is characterized by its slow response to changing precipitation patterns, and its recovery period can extend over an extended duration. Socio-economic drought addresses the broader consequences of water scarcity on economic activities, from agriculture to industry and beyond. It underlines the interdependence between the supply and demand for economic goods and services, emphasizing that drought's impacts extend far beyond the natural environment. These disciplinary definitions of drought, each focusing on specific aspects, highlight the intricate and interconnected nature of drought. Understanding and integrating these different dimensions of drought is essential for developing comprehensive strategies for drought management and response.

Heavy rainfall

Heavy rainfall is defined based on the amount of precipitation received over a specified time period, typically 24 hours. The criteria for heavy rainfall, as established by the World Meteorological Organization (WMO), are characterized by rainfall equal to or greater than 50 millimetres (mm) in the past 24 hours. This amount of rainfall is considered substantial and can have significant impacts on the environment and human activities.

Descriptive Intensity of Rainfall:

Rainfall intensity is often described using terms that categorize the amount of precipitation within a given time frame. These descriptive terms are used to communicate the magnitude of rainfall events. Here is a breakdown of the terms along with the corresponding rainfall amounts in millimetres (mm) received in a day:

- **No Rain:** 0.0 mm
- **Very Light Rain:** 0.1 to 2.4 mm
- **Light Rain:** 2.5 to 7.5 mm
- **Moderate Rain:** 7.6 to 35.5 mm
- **Rather Heavy Rain:** 35.6 to 64.4 mm
- **Heavy Rain:** 64.5 to 124.4 mm
- **Very Heavy Rain:** 124.5 to 244.4 mm
- **Extremely Heavy Rain:** More than 244.5 mm

These definitions and descriptive terms provide a standardized way to communicate the intensity of rainfall events, assisting meteorologists, emergency responders, and the public in understanding and responding to precipitation-related challenges.

Causes of Heavy Rainfall

Heavy rainfall events can be triggered by various natural and environmental factors. Here are some of the key causes of heavy rainfall:

1. **Cumulonimbus Clouds:** Heavy rainfall is often associated with cumulonimbus clouds, which are large, towering clouds that can extend to high altitudes. These clouds are capable of producing intense precipitation, often in the form of heavy rain, thunderstorms, and even severe weather events.
2. **Windward Side in Mountain Regions:** Orographic lift, which occurs when moist air is forced to rise over mountain ranges, is a common cause of heavy rainfall on the windward side of mountains. As the air rises and cools, it can release significant amounts of moisture in the form of heavy rain.
3. **Tropical Cyclones:** Heavy rainfall is a prominent feature of tropical cyclones, including hurricanes and typhoons. These intense storms can carry large amounts of moisture and release it as heavy rain when they make landfall, leading to widespread flooding.
4. **Global Warming and Pollution:** Climate change, driven by global warming and exacerbated by pollution, can influence weather patterns and lead to more intense rainfall events. Warmer air can hold more moisture, potentially resulting in heavier rainfall when the conditions are right. Pollution, in the form of aerosols, can affect cloud formation and precipitation processes.

Heavy rainfall events can have significant impacts on local ecosystems, agriculture, and communities. Understanding the causes of heavy rainfall is crucial for both preparedness and mitigation efforts to minimize the adverse consequences associated with these events.

Cloudburst

A cloudburst is an extraordinary and intense rainfall event that stands out for its unique characteristics. It is defined by several key features, notably its unparalleled rainfall intensity. Cloudbursts are characterized by rainfall rates on the order of 100 millimeters per hour (mm/hr), which equates to over 4 inches of rainfall in just one hour. This high precipitation rate sets cloudbursts apart from typical rainfall events, making them a significant meteorological phenomenon. In addition to their exceptional rainfall intensity, cloudbursts are often accompanied by other meteorological elements, such as strong winds and lightning. These factors contribute to the intensity and impact of the event. The combination of intense rainfall, strong winds, and lightning can have severe consequences, particularly in regions prone to cloudbursts.

Cloudbursts are highly localized events, impacting a relatively small area. The affected region typically does not extend beyond 20 to 30 square kilometers. This localized nature distinguishes cloudbursts from more widespread and less intense rainfall events, which can cover larger geographic areas. Certain geographic regions are more susceptible to cloudbursts. In India, for instance, cloudbursts are relatively common during the monsoon season, particularly in areas with steep orographic features like the Himalayan region, northeastern states, and the Western Ghats. The topography in these areas contributes to the unique conditions that lead to cloudbursts, including heavy downpours and flash flooding. The western Himalayan region in India, in particular, occasionally witnesses cloudbursts with heavy downpours, especially during active monsoon conditions. These events can have profound and rapid consequences, including flash floods and landslides. Understanding the characteristics, regional prevalence, and potential impacts of cloudbursts is crucial for monitoring and responding to these extreme weather events effectively.

Tropical Cyclones

Tropical cyclones are among the most powerful and destructive meteorological events on Earth. They can bring heavy rainfall, storm surges, and devastating winds, leading to severe damage to infrastructure, coastal areas, and communities. Understanding these defining characteristics is essential for monitoring, forecasting, and responding to tropical cyclones effectively. These tropical cyclones, known by different names depending on their location, are powerful meteorological phenomena characterized by several key attributes:

1. **Rotational Low-Pressure System:** A tropical cyclone is essentially a massive, rotating low-pressure weather system. It exhibits counterclockwise rotation in the Northern Hemisphere and clockwise rotation in the Southern Hemisphere, driven by the Coriolis effect.

2. **Central Pressure Drop:** A distinctive feature of a tropical cyclone is the rapid drop in central pressure within the storm. This drop can be as much as 5 to 6 hectopascals (hPa) in a short period. A lower central pressure is often associated with a more intense and potentially destructive cyclone.

3. **Wind Speed Threshold:** Tropical cyclones are characterized by strong winds. The wind speed required for a weather system to be classified as a tropical cyclone is typically 34 knots, equivalent to about 62 kilometres per hour (km/h). However, as a tropical cyclone intensifies, its wind speeds can far exceed this threshold.

4. **Vast, Violent Whirl:** Tropical cyclones are vast and violent whirlwinds that can cover a considerable expanse. Their size can range from 150 to 800 kilometres (km) in diameter. The storm's winds spiral around a central point, and the entire system progresses along the surface of the sea at a rate of 300 to 500 km per day.
5. **Regional Nomenclature:** Tropical cyclones are known by different names in various ocean basins. In the Atlantic Ocean, they are called hurricanes, while in the Pacific Ocean, they are referred to as typhoons.

Unseasonal Rainfall and Floods

Unseasonal rainfall, as the term suggests, occurs when there is precipitation outside the established periods for these monsoons. It can manifest as rainfall during the dry season or at any time other than the traditional monsoon seasons. Unseasonal rainfall can have various consequences, including disruption of agriculture, waterlogging, and the potential for floods. In India, the traditional rainfall patterns are divided into two primary monsoon seasons:

- **Southwest Monsoon (June to September):** This is the main monsoon season, bringing substantial rainfall to most of India. It plays a critical role in supporting agriculture and water resources.
- **Northeast Monsoon (October to December):** This season primarily affects the southern peninsula of India, particularly Tamil Nadu. While it is less significant than the southwest monsoon, it is important for specific regions.

Floods:

A flood is characterized by a significant flow of water, often resulting in the inundation of land that is typically dry. The European Union (EU) Floods Directive provides a specific definition of a flood, characterizing it as the covering of land by water that is not typically submerged or inundated. This definition emphasizes the temporary and unusual nature of flooding, where water extends over areas that are usually dry. Flooding can occur due to various factors, including heavy rainfall, snowmelt, storm surges, or even dam failures. Floods can cause extensive damage to infrastructure, displace communities, disrupt transportation, and have adverse impacts on agriculture and the environment.

Causes of Flood

Floods can occur due to a variety of natural and anthropogenic factors. Here are some of the primary causes of floods:

Natural Causes:

1. **Heavy Rainfall:** One of the most common natural causes of floods is heavy rainfall. When there is an exceptionally large amount of precipitation in a short time, rivers

and drainage systems may not be able to handle the increased water volume, leading to flooding.

2. **Cloud Burst:** A cloudburst, which is characterized by extremely intense rainfall over a short period, can overwhelm drainage systems and contribute to flash floods.
3. **La Niña:** La Niña, a climate phenomenon characterized by cooler-than-average sea surface temperatures in the equatorial Pacific Ocean, can affect weather patterns and lead to increased rainfall in some regions, potentially causing flooding.
4. **Bad Drainage:** Poorly designed or inadequate drainage systems, especially in low-lying areas like the Tarai region, can contribute to water accumulation and flooding during heavy rainfall.
5. **Basin Topography:** The topography of a river basin, as seen in regions like Punjab and Haryana (PB HR), can influence how water flows. Flat or sloping terrain can lead to water stagnation and flooding.
6. **Narrow River Valleys:** Narrow river valleys, such as those found along the Brahmaputra River, can restrict the flow of water, increasing the risk of flooding during heavy rains or snowmelt.
7. **Siltation:** The deposition of silt and sediment in rivers and waterways over time can reduce their capacity to carry water, leading to increased flood risk.

Anthropogenic Causes:

1. **Global Warming:** Climate change, driven by global warming and the greenhouse effect, can alter weather patterns and increase the intensity and frequency of extreme rainfall events, potentially leading to more floods.
2. **Deforestation:** The removal of forests can disrupt local ecosystems and reduce the ability of vegetation to absorb and slow down rainfall, increasing surface runoff and the risk of flooding.
3. **Dams and Canals:** The construction of dams and canals can alter natural river flows and exacerbate flooding downstream if not managed properly.
4. **Flood Gates:** Inadequate operation of flood gates in response to rising water levels can lead to uncontrolled releases of water and downstream flooding.
5. **Poor Settlement Practices:** Unplanned urban development and construction in flood-prone areas can increase vulnerability to flooding.

Thunderstorm:

A thunderstorm is a meteorological phenomenon defined by specific characteristics. It typically involves one or more sudden electrical discharges, which are manifested by a flash of light (lightning) and a sharp rumbling sound (thunder). Thunderstorms often occur in association with clouds of vertical development. The process leading to a thunderstorm includes the buildup of moist, unstable air, the ascent of this air, and the condensation of water vapour, which releases heat and creates powerful updrafts and downdrafts within the storm cloud.

Severe Thunderstorm

Severe thunderstorms are a subset of thunderstorms that exhibit more extreme or dangerous features. These are defined as thunderstorms with at least one of the following characteristics:

1. **Tornado:** A tornado is a rapidly rotating column of air that extends from a thunderstorm to the ground. It is capable of causing significant damage and poses a considerable threat to life and property.

2. **Wind Speed Greater Than 58 Knots:** Severe thunderstorms can generate high wind speeds exceeding 58 knots (approximately 66.7 miles per hour or 107.4 km/hr). These strong winds can lead to damage, especially when associated with downbursts or straight-line winds.

3. **Hail Larger Than 0.75 Inch:** Hail is precipitation in the form of balls or lumps of ice. Severe thunderstorms can produce hailstones larger than 0.75 inch (about 19 mm) in diameter. Larger hailstones can cause damage to crops, vehicles, and structures.

Severe thunderstorms pose a significant risk to life, property, and the environment. They can lead to hazards such as tornadoes, damaging winds, large hail, and heavy rainfall that may result in flash flooding. Understanding and monitoring severe thunderstorms is crucial for issuing timely warnings and ensuring public safety.

Formation of Thunderstorms

Thunderstorms are complex meteorological phenomena that require specific conditions to develop. These conditions are typically characterized by three essential ingredients:

1. **Moisture:** The presence of humid air carrying a significant amount of water vapour is a critical component for the formation of thunderstorms. This moisture often becomes visible as low clouds or haziness in the atmosphere. The high moisture content provides the necessary fuel for the storm.

2. **Lifting Mechanism:** To trigger the development of thunderstorms, a lifting mechanism is required. This force is responsible for rapidly lifting the moist air, initiating the storm-building process. Several lifting mechanisms can contribute to thunderstorm formation:

- **Advancing Cold Front:** Thunderstorms can be generated when a colder, denser air mass advances and pushes under the warmer, moister air ahead of it, lifting the warmer air.
- **Orographic Lift:** As air is forced to move upward while passing over rising terrain, such as mountains, it can trigger the lifting of moist air, leading to thunderstorm development.
- **Sea Breeze Convergence:** The movement of cooler winds from the sea inland can cause the lifting of the warmer air present over the land, creating conditions conducive to thunderstorms.
- **Thermal Lift:** During the day, the sun's heating of the Earth's surface can warm the air near the ground, causing it to rise. This thermal lift is another mechanism that can initiate thunderstorms.

3. **Atmospheric Instability:** Atmospheric instability plays a crucial role in thunderstorm formation. When warm, moist air rises into a layer of cooler air above, it continues to ascend as long as it remains warmer than its surroundings. The rising air cools as it ascends, and when it cools enough, the moisture in the air condenses, forming clouds. This process of condensation is essential for thunderstorm development, as it releases heat and helps to intensify the storm.

Understanding Lightning

Lightning is a natural atmospheric phenomenon characterized by the sudden discharge of electrical energy. It occurs when there is a buildup of static electricity in the atmosphere, typically between thunderclouds or between a thundercloud and the ground. Lightning is a remarkable natural occurrence, and it is defined by the following key characteristics:

- **Electrostatic Discharge:** Lightning is fundamentally an electrostatic discharge, representing the rapid release of electrical energy. This discharge can bridge the gap between areas of opposing electrical charge, leading to a sudden equalization of charge.
- **Emission of Visible Light:** Lightning is accompanied by the emission of visible light, which is why it is visible to the human eye. The bright flashes of light produced by lightning bolts are a result of the rapid movement of electrical charges.
- **Other Electromagnetic Radiation:** In addition to visible light, lightning generates various forms of electromagnetic radiation, including radio waves and X-rays. These emissions are detected through various scientific instruments and can provide valuable data for research.

- **Extreme Heat:** The energy released during a lightning strike is immense. It heats the surrounding air dramatically, with temperatures reaching anywhere from approximately 9,822.2 degrees Celsius (17,732 degrees Fahrenheit) to as high as 33,315.6 degrees Celsius (60,000 degrees Fahrenheit). This intense heat can lead to the rapid expansion of air, which produces the characteristic thunder associated with lightning.

Conclusion

A profound understanding of extreme weather events, including heatwaves, cold waves, droughts, and floods, is of paramount importance for effective disaster preparedness, response, and mitigation strategies. These meteorological phenomena have the potential to unleash significant and far-reaching consequences, extending their impact across ecosystems, critical infrastructure, and the very fabric of human communities. From immediate threats to long-term repercussions, extreme weather events demand our attention and comprehensive preparedness. In the realm of agriculture, the role of extreme weather events in managing abiotic stress cannot be understated. In the face of such climatic unpredictability, they must not only withstand but also thrive. This calls for the implementation of innovative, resilient agricultural practices and strategies that safeguard food security and enable the sustainable management of natural resources. In essence, the agricultural sector must evolve in response to the challenges posed by extreme weather, ensuring its capacity to meet the world's growing food demands.

As the world grapples with shifting climate patterns and the escalating frequency and severity of extreme weather events, there is a pressing need for ongoing research and proactive measures. Understanding the intricate dynamics of these events and their interaction with broader climate change is essential for reducing vulnerability and enhancing resilience. It is through this collective effort that societies can fortify themselves against the meteorological challenges that threaten the well-being of people, the health of the planet, and the future of agriculture. In this pursuit, research, technology, and policy must converge to chart a sustainable course through a climate-altered world.

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Abiotic Stress Tolerant Crop Varieties

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Introduction

Abiotic stresses in agriculture can arise from a variety of environmental factors, including extreme moisture conditions (drought and floods), extreme temperatures (heat and cold/chilling/frost), radiation (UV, ionizing radiation), chemical factors (nutrient deficiencies, excessive soluble salts, salinity, alkalinity, low pH/acidic conditions, high P and anion retention, calcareous conditions, low redox, chemical contaminants of both natural and human-made origin), physical factors (high susceptibility to erosion, steep slopes, shallow soils, surface crusting and sealing low water-holding capacity, poor drainage, low structural stability, root-restricting layers, high swell/shrink potential), and biological components (low or high organic contents) (Minhas et al., 2017). Among these stressors, extreme moisture and temperature conditions are particularly prevalent and have significant impacts on agricultural production, including crop yields. To mitigate the adverse effects of these abiotic stressors on crop production, several strategies can be employed, including Water-saving Technologies, Residue Incorporation, Tolerant Crop Varieties, Conservation Agriculture, Site-specific Nutrient Management, Promoting and cultivating crop varieties that are well-suited to withstand abiotic stresses is particularly important, as it can provide a sustainable and effective solution for enhancing agricultural productivity in the face of challenging environmental conditions.

Understanding the intricate mechanisms governing traits associated with abiotic stress tolerance and harnessing the genetic diversity present in plant germplasm is pivotal in the pursuit of developing crops with increased resilience to abiotic stressors. Some progress has already been made in deciphering the basis of crop tolerance to abiotic stresses. For instance, the identification of abscisic acid (ABA) receptors, such as ABA-responsive element (ABRE) binding proteins or ABRE binding factors (AREB/ABF) transcription factors, and the study of other regulons like WRKYs, MYB/MYCs, NACs, HSFs, bZIPs, and nuclear factor-Y, hold significant promise in enhancing plant tolerance to abiotic stresses. Additionally, molecular research into the post-transcriptional regulation of stress-responsive genes has opened up new avenues for understanding how plants respond to stress at the cellular level (Onaga and Wydra, 2016). These insights have the potential to be applied in crop improvement and breeding programs.

Furthermore, the identification of promising genotypes that exhibit tolerance to various abiotic stresses, along with their registration and incorporation into breeding programs, is a crucial step. In India, the National Agricultural Research System (NARS), including various ICAR (Indian Council of Agricultural Research) institutes and state agricultural universities, has been actively engaged in developing improved crop varieties and livestock breeds that can withstand multiple abiotic stresses. These varieties and breeds can be invaluable for farming communities facing extreme weather conditions.

The utilization of abiotic stress-tolerant crop varieties, both traditional and improved livestock and fish breeds, in conjunction with adaptation and mitigation strategies, is essential to mitigate the adverse impacts of abiotic stresses on crop, livestock, and fisheries productivity. This approach not only contributes to food security but also promotes sustainable and self-sufficient food production, even in the face of changing climate scenarios.

Drought

Drought, characterized by a deficit in moisture levels, poses a significant and recurring challenge in many regions of India, particularly in arid and semiarid areas. Under drought conditions, plants experience a range of detrimental effects on their growth and yield. To cope with such conditions, plants have evolved various adaptive mechanisms encompassing morphological, biochemical, physiological responses, and molecular mechanisms. These adaptive strategies are critical for plant survival and persistence in the face of drought stress. Plants employ diverse strategies such as escape, avoidance, and tolerance to adapt and thrive even in drought-prone environments. Numerous adaptive traits have been extensively researched and harnessed to enhance drought tolerance. These traits include early vigour, shortened growth duration, osmotic adjustment, delayed leaf senescence, and the maintenance of a "stay green" phenotype. The "stay green" trait in plants, specifically, denotes the capacity to withstand drought-induced post-flowering senescence, thereby extending the period of active photosynthesis.

Roots also play a pivotal role in plant adaptation to drought stress, as they are essential for water uptake and nutrient absorption under water-deficient conditions. Plant breeders at various ICAR institutes and state agricultural universities have harnessed these adaptive traits over the years to develop high-yielding varieties of different crops with enhanced drought tolerance. These drought-tolerant varieties hold the potential to significantly benefit farming communities grappling with water scarcity. Various Institutes/Universities in India have released drought-tolerant varieties of major field and horticultural crops, encompassing cereals, pulses, oilseeds, fibre crops, forages, vegetables, fruits, plantation crops, medicinal plants, and spices. These varieties represent a valuable resource for sustainable agriculture in drought-prone regions.

Waterlogging/Flooding/Submergence

In recent decades, the increasing duration and frequency of heavy rainfall events, driven by climate change, have led to waterlogging conditions in crop fields. These conditions can have detrimental effects on plant growth and, if flooding persists, can ultimately result in plant death. Except for sorghum, most food crops are highly sensitive to flooding, resulting in substantial yield losses (Singh et al., 2011). While research related to waterlogging has primarily focused on maize, barley, and soybean, there has been extensive study of the physiological and molecular responses of rice to flooding (Colmer et al., 2014). These studies have identified several traits associated with submergence tolerance that could enhance crop resilience to flooding.

Improving crop tolerance to flooding is essential for maintaining agricultural productivity in regions prone to waterlogging. Promising traits and strategies for enhancing flood tolerance in crops include Anatomical adaptations, barriers against Radial Oxygen Loss, growth of adventitious roots, Genomics and Genome-wide Association Studies (GWA) and exploring flood tolerant relatives and ancestral cultivars. By leveraging these traits and employing genetic and breeding strategies, it is possible to develop crop varieties that can thrive in waterlogged conditions, ultimately ensuring more reliable agricultural production in areas susceptible to flooding (Mustroph, 2018).

Despite the complex challenges posed by flooded soils, progress has been made in developing flood-tolerant cereal varieties. A significant breakthrough was the discovery and deployment of the SUBMERGENCE 1 (SUB1) locus in rice, which confers tolerance to complete inundation (submergence). Subsequently, various organizations, including NRRI in Cuttack and IRRI in Hyderabad, have developed several submergence-tolerant rice varieties (Pathak et al., 2019). In response to the increasing frequency of floods over the last two decades, various ICAR institutes and state agricultural universities have initiated breeding programs to develop flood-tolerant varieties in different crops. These efforts aim to provide valuable resources to different stakeholders, including farmers, who face the challenges posed by waterlogging and flooding in agriculture.

High Temperature and Crop Performance

Climate change has brought about extreme temperatures that are adversely affecting crop performance in many regions worldwide. High temperatures impact plants at various organizational levels, primarily by hastening phenological events, reducing biomass production, and shortening the reproductive phase, resulting in substantial yield losses. Beyond these visible effects, high temperatures disrupt cellular metabolism and gene expression, leading to a cascade of morphological, physiological, and biochemical changes in plants. High temperatures, particularly during the reproductive growth stage, including flowering, anthesis, pollination, fertilization, and seed formation, have a detrimental impact on seed set and ultimately reduce yields in various crops. To mitigate the adverse effects of heat stress, the development of thermo-tolerant crop varieties through genetic improvement is essential.

Enhancing heat tolerance in crop plants is crucial to mitigate the negative impacts of rising temperatures on agriculture. Heat-tolerant genotypes typically exhibit a range of adaptive traits related to thermotolerance in various plant parts and at the molecular level. Heat-tolerant plants often possess leaves with enhanced membrane thermostability, allowing them to maintain cell membrane integrity even under high temperatures. They may also maintain better photosynthetic efficiency, chlorophyll content, chlorophyll fluorescence, and stomatal activity, enabling them to continue photosynthesis and CO_2 uptake in heat-stressed conditions. Heat-tolerant genotypes exhibit adaptive traits in their flowers, such as improved pollen viability, pollen germination, fertilization success, and ovule viability. These traits are essential for maintaining reproductive processes under high-temperature conditions (Chaudhary et al., 2020). The root architecture of heat-tolerant plants may be adapted to optimize nutrient and water uptake, even in hot environments. Efficient root systems help plants better withstand heat stress. Heat-tolerant plants often contain higher levels of antioxidants, osmolytes, phytohormones, heat-shock proteins, and other stress-related proteins. These biomolecules play a crucial role in protecting plant cells and maintaining cellular functions under heat stress.

While conventional breeding methods have seen some success in improving crop plants with heat tolerance, the most effective approach involves an integrated strategy that combines traditional breeding techniques with modern molecular tools. Molecular breeding allows for the precise identification of genes associated with heat tolerance and their incorporation into high-yielding but heat-sensitive crop varieties. This integrated approach holds the key to developing resilient and heat-tolerant crops that can thrive in a changing climate.

There are several examples of high-temperature stress tolerant varieties in crop plants. Rice crop varieties such as DRR Dhan 47 and DRR Dhan 52 are the best examples for both drought and heat stress tolerance. Similarly in Lok-1, WH 1124, DBW 107, DBW 173, DBW73 are tolerant varieties in wheat crop. In Bajra GHB-558, GHB-732 and GHB-538 are reported for tolerance to high-temperature stress (Boraiah et al., 2021)

Salinity stress in crop plants

Salinity is a significant threat to crop production, particularly in arid and semi-arid regions where water scarcity and inadequate drainage of irrigated lands prevail. The increasing salinization of arable lands is expected to have severe repercussions on agricultural production in numerous countries, including India. High salinity levels impose both hyper-ionic and hyperosmotic stress on plants and can ultimately lead to plant death (Munns and Tester, 2008). Sodicity is a secondary consequence of salinity in clayey soils. Leaching can wash soluble salts into the subsoil, leaving sodium bound to the negative charges of the clay (Wang et al., 2003).

Plants have evolved two primary mechanisms to cope with salt stress:

Limiting Entry of salts: Few plants restrict the uptake of salts through their roots. They employ mechanisms to reduce the influx of sodium and chloride ions from the soil into the plant.

Controlling Salt Concentration and Distribution: Others control the concentration and distribution of salt within their tissues. They transport excess salt to specific compartments or tissues where it has less impact on critical cellular functions.

Understanding how plants regulate sodium accumulation and studying the genes involved in these transport processes offer promising avenues to improve salinity tolerance in crops, especially in regions where food security is threatened by arid conditions. This deeper understanding of tolerance mechanisms can be applied to breeding programs to develop crop varieties that exhibit improved yield performance under salinity stress (Hanin et al., 2016). This is crucial for ensuring agricultural productivity and food security in regions prone to salinity-related challenges. The best examples of salinity tolerant varieties in Rice are Vikas, Basmati CSR 30 and DRR Dhan 9, CSR 27, CSR 36 etc. which are released from CSSRI, Karnal, NRRI Cuttack and ICAR-IIRR, Hyderabad.

The important varieties tolerant to various abiotic stresses in different crop plants are given below.

Stress tolerant crop varieties for climate resilience

Crop	Stress	Tolerant varieties
Rice	Drought	Birsa Vikas Dhan 111, Sahbhagi Dhan, CR Dhan 209, CR Dhan 210
	Submergence	Swarna sub1, Jalamani, Samba sub-1, Ksheera
	Salinity	CSR 46, CSR 60, CSR 56, CSR 52, CSR 56, Panvel 3, CARI Dhan 5
	Low temperature	Kalinga 1, Tellahamsa, Pant Dhan 11, Varun Dhan, Gizza-14, K-448, NE Megha Rice-1 & 2
	Drought + submergence	CR Dhan 801, CR Dhan 802, DRR Dhan 50
	Drought + high temperature	DRR Dhan 47, DRR Dhan 52
	Submergence + salinity	CSR 43
Wheat	Drought	HD 2987, HD 3043, PBW 644, Sabour Nirjal, HUW 669, DBW 252, Netravati, WH 1142

	High temperature	Lok-1, WH 1124, DBW 107, DBW 173, DBW73
	Low temperature	Buland Mansarovar, Shalimar wheat-1, RSP 561
	Drought + alkalinity	KRL-213
	Waterlogging + salinity	KRL 19, KRL 210, KRL 283
Barley	Drought	PL419,JB-58, RD 2660, RD-2592
	Low temperature	BHS352
Maize	Drought	Pratap Makka-5, HQPM-1, Bajauramakka, HQPM-, NAH-1147, PEHM-1
	Waterlogging	Jawahar Maize 218, Pusa Jawahar Hybrid Maize-1, Pragati
	High temperature	Suwan, PMH-7, RCRMH2
Pearl millet	Drought	CZP 9802, Pusa Composite 443, Pusa Hybrid 415, HHB-234, PBH 306, Balwan, NBH 4903
	High temperature	GHB-558, GHB-732, GHB-538
Sorghum	Drought	M35-1, Phule Panchami, DSV-2, Phule Vasudha, Parbanimoti, PS-4, SIA-326
Pigeonpea	Drought	Pragati (ICPL 87), BRG-1, BRG-2, PRG-158, BDN-711, BDN-716, GT-102, GRG 811, BDN-708, BRG 5
	Waterlogging	ICPL 84023
	High temperature	Rajeev Lochan
	Drought + waterlogging	Maruti, Asha
	Drought + salinity	Jagriti
	High temperature + salinity	UPAS-120
	Drought + waterlogging + salinity	MAL 13
	High & low temperature + salinity	Bahar
Blackgram	Drought	Shekhar-2, Azad-3, Pratap Urd-1, BDU-1, Pant Urd-35
Greengram	Drought	Pusa Vishal, GM-4, Co (Gg) 8, Yadadri, VBN 4, BM-2003-2
Chickpea	Drought	Vijay (Phule G-81-1-1), Akash (BDNG 797), BGD 103, PKV Harita (AKG 9303-12), JG 36, Pant Kabuli gram-2, Nandyal Gram 49, JG 16, JG-315, JAKI 9218
	Waterlogging	Pusa 240, GNG 1581, DCP 92-3, GNG16

	Salinity	Karnal chana-1
	Low temperature	PDG 4
	Drought + high temp	JG -6, JG-11, JG 14, Indira Chana 1, Pant G 186
Cowpea	Drought	C 519 (Himachal Lobiya 11), IT-38956-1, UPC 628, Hidrudaya
	Salinity	Hissar Cowpea-46, (HC 98-46)
Field bean	Drought	H-4
Moth bean	Drought	CAZRI Moth -3 (CZM-99), RMO-257, RMO-423
	High temperature	RMO-225, CAZRI MOTH-1 (CZM-79)
Horsegram	Drought	PHG-9 CRIDA-18R, Indira Kulthi-1 (IKGH-01-01), CRIDALATHA (CRHG-4), VL Gahat-19 (VLG-19), GHG-5, Bilasa Kulthi (BSP 15-1), Dapoli Kulthi-1
Lentil	Drought	L 4729
	Drought + high temperature	Kota Masoor 3 (RKL 605-03)
Groundnut	Drought	TAG-24, S-230, ICGV-91114 (Anantha Jyothi), Abhaya (TPT-25), Narayani (TCGS-29), Ajeya (R-2001-3), Kadiri Haritandhra (K-1319), Girnar-3 (PBS-12160), Vijetha (R-2001-2), RARS-T-1, RARS-T-2, Divya (CSMG-2003-19), Raj Mongfali-1 (RG-510), Dharani (TCGS 1043), Birsa Groundnut 4 (BAU - 25), Dheeraj (TCGS 1073), DH-257, Dh 256, Kadiri Lepakshi
	High temperature	Kadiri-6
	Drought + high temp	Vemana (K-134)
Soybean	Drought	JS 71-05, MACS-450, Parbhani Sona (MAUS-47), MAU-71, JS-9305, JS-95-60, PS-1225, Pratap Soya-2(RKS-18), RKS-24, Pratap Soya 45 (RKS 45)
	Waterlogging	Jawahar Soybean 97-52 (JS 97-52)
	Drought + waterlogging	Ahilya-4 (NRC-37)
	Drought + high temp	JS-335
Sunflower	Drought	KBSH-44, JWALAMUKHI (PSCL-5015), KBSH-41, KBSH-42, DRSF-108, Bhanu, KBSH-53, Bhaskar
	High temperature	DRSF-113, PSFH-118
Safflower	Drought	Phule Kusum (JLSF-414), Bhima, Malviya Kusum 305, JSI-7, Parbhani Kusum (PBNS-12), PBNS-40, ISF-764

Niger	Drought	JNC-9, KBN-1, Phule Karala (IGPN 2004-1), Brisa Niger-1 (BNS-10), Birsa Niger-3 (BNS-11)
Castor	Drought	GCH-5 Kranthi (PCS-4), Kiran (PCS-136), Jwala
Linseed	Drought	Binwa (KL-210), Himani (KL-214), JLS-67 (Shival), JLS-73 (SLS-73), Mau Azad Alsi-2 (LMS - 149-4), Jawahar Linseed-165 (PKDL-165
	Salinity	PSL-9, PDL-1
	Drought + high temperature	Indira Alsi-32 (RLC-81), Deepika (RLC-78), RLC 92
Sesame	Drought	Jawahar Til PKDS-11, TKG-306, Amrit TKG-308, RJ Til -346, G Til-4, RJ Til 351, RT 372
	Drought + high temperature	Suprava (CUMS-17)
Rape seed and mustard	Drought	Pusa Bold, Rohini, Karan Tara, CR Sarson, Pusa Mustard-21, Pant Rai 20, RH 761, DRMR 150-35 (Bharat Sarson 7)
	High temperature	Vasundhara, Pusa Mustard 26 (NPJ-113)
	Low temperature	RGN 73, RH-9801 (SWARNA)
	Salinity	CS 58, CS 60, Narendra Rai (NDR-8501), Giriraj (DRMRIJ 31)
	Drought + high temp	Puas Tarak
	Drought + low temp	RGN 48
	High temperature + salinity	Pusa Vijay, NRCDR 601 (DMR 601), RGN 229, RGN 236, Pusa mustard 29 (LET - 36), Pusa Mustard 30 (LES-43), RH 0406

Source: Boraiah et al., (2021)

Conclusion

In the current era of climate change and the growing global population, the adoption of abiotic stress-tolerant crop varieties, as well as resilient livestock and fish breeds, has emerged as a critical strategy for both adaptation and mitigation. These strategies are essential to ensure food security. Many of these stress-tolerant crop varieties have traditionally been developed through conventional breeding methods and, in some instances, have arisen serendipitously. However, recent advancements in molecular breeding techniques have significantly expedited the process of developing climate-smart varieties in many crop plants. Within this context, the National Agricultural Research System (NARS) has played a pivotal role in advancing the development of climate-resilient varieties across various crops. This progress has been achieved through the exploration of phenological, morphological, and adaptive traits that enable these plants and animals to thrive under adverse environmental conditions.

Nonetheless, it is important to underscore the critical role that access to high-quality seeds of these climate-resilient varieties plays in mitigating the adverse effects of climate change, including droughts, floods, salinity, and cold spells. Accessible and dependable sources of quality seeds are instrumental in safeguarding agricultural production and ensuring food security, especially in the face of climate-induced challenges. Therefore, the adoption of abiotic stress-tolerant crop varieties, as well as resilient livestock and fish breeds, represents a vital component of our response to climate change and the imperative to sustainably feed a burgeoning global population. While traditional and molecular breeding techniques have enabled the development of these varieties and breeds, equitable access to quality seeds remains a linchpin in our efforts to address the adverse impacts of climate change on agriculture and food production.

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Management of Soil and Water Stress in Horticultural Crops: A Watershed Perspective

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Introduction

Watersheds, often referred to as hydrological units, are fundamental components of the Earth's natural functioning and serve as primary planning units in the field of natural resource management. These hydrological units provide a structured framework for conducting surveys and investigations to assess and manage our natural resources and guide the development of various approaches for sustainable development. Watersheds offer a scientifically sound and appropriate foundation for conducting surveys and investigations. By delineating watershed boundaries, we can better understand the intricate interactions between water resources, land, and ecosystems. Hydrologic unit maps are invaluable tools for a wide range of water resource studies. These studies encompass flood assessments, water-quality sampling, water-use reporting, watershed protection, conservation planning, and broader resource management efforts. Watershed boundaries define the geographical area from which rainwater and runoff flow into a specific drain, channel, stream, or river at a given point. This delineation helps us understand the origin and paths of water flows, critical for managing water resources effectively. Watershed boundaries are primarily determined by the terrain's topography. The boundary between two adjacent watersheds is known as the drainage divide line. At the lowest point of elevation along these boundaries or drainage lines lies the pour point, where water exits the watershed. Watersheds can be quite complex, varying in size and topography. They often contain numerous tributaries, such as streams and ditches, as well as ponding areas like detention structures, natural ponds, and wetlands. These elements contribute to the overall hydrological balance. Watershed boundaries are critical because they define the geographical extent within which hydrologic processes operate. This demarcation allows us to describe, control, and manage these processes to some extent. These are scalable, meaning we can adjust them to accommodate the specific ecological processes of interest. Watersheds can be delineated in various sizes, from smaller sub-watersheds to larger regional or continental ones. This scalability enables the study and management of water resources at different scales, depending on the scope and objectives of the research or conservation efforts.

Watershed management offers a multitude of benefits for soil and water conservation. By strategically managing the flow of water within a given watershed, it significantly reduces soil erosion, helping to preserve the topsoil and maintain soil fertility. It also acts as a natural barrier to prevent sediment from entering water bodies, which ultimately leads to better water quality. In addition to this, watershed management aids in flood control by regulating the flow of water during heavy rainfall, reducing the risk of devastating floods and safeguarding communities. It plays a pivotal role in recharging aquifers and maintaining groundwater resources, ensuring a sustainable and reliable supply of freshwater for agriculture and domestic use. Moreover, it fosters biodiversity conservation, as healthy watersheds create habitats for various plant and animal species, contributing to the overall ecological balance and sustainability.

Furthermore, watershed management practices like terracing and contour farming support sustainable agriculture by conserving soil, reducing runoff, and enhancing water availability for crops. By mitigating both flooding and drought impacts, watershed management helps communities withstand extreme weather events, fostering resilience. Lastly, the long-term focus of watershed management ensures the preservation of natural landscapes, which provides recreational opportunities and supports local economies. In essence, watershed management is a holistic and proactive strategy that not only safeguards soil and water resources but also contributes to the overall well-being of ecosystems, communities, and the environment.

Abiotic stresses in semi-arid regions

Semi-arid regions are characterized by limited and unreliable precipitation, making them susceptible to various abiotic stresses that can affect both natural ecosystems and agriculture. Addressing abiotic stresses in semi-arid regions often requires a combination of sustainable water management, soil conservation, drought-resistant crop varieties, and adaptive agricultural practices. Furthermore, improving water efficiency, implementing reforestation and afforestation efforts, and developing sustainable land management strategies are crucial for mitigating the adverse effects of these stresses in semi-arid environments. Some of the key abiotic stresses in semi-arid regions include:

- **Drought:** Drought is one of the most prominent abiotic stresses in semi-arid regions. It occurs when there is an extended period of insufficient rainfall, leading to water scarcity. Drought can have severe consequences for agriculture, natural ecosystems, and water resources.
- **Water Scarcity:** Even in the absence of drought, semi-arid regions often face chronic water scarcity. Insufficient water availability can limit agricultural productivity and make it challenging to meet the water needs of both humans and ecosystems.

- **Heat Stress:** High temperatures and heat waves are common in semi-arid regions. Excessive heat can stress crops and natural vegetation, leading to reduced yields, increased evaporation, and adverse effects on ecosystems.
- **Salinity and Soil Degradation**: In semi-arid areas, the combination of low rainfall and high evaporation can lead to the accumulation of salts in the soil, causing salinity issues. Soil degradation, including desertification and erosion, can also be exacerbated by these conditions, making it difficult to sustain agriculture.
- **Nutrient Deficiency**: Limited water availability can affect nutrient uptake by plants, leading to nutrient deficiencies. This can reduce crop yields and the overall health of natural vegetation.

Horticulture Component in Watershed Development

Watershed development projects play a crucial role in managing water resources, enhancing agricultural productivity, and improving the livelihoods of communities living in diverse climates. One vital component of these projects is horticulture, which offers a range of opportunities, although its potential benefits have not always been fully realized. This article will discuss the horticulture component in watershed development, focusing on its significance in diversified climates, cost-intensive farming activities, production systems, and challenges related to perennial plants. A Wider Crop Choice One of the key advantages of integrating horticulture into watershed development is the ability to diversify crop choices. Diverse climatic conditions within a watershed can support a wide range of horticultural crops. Unlike traditional mono-cropping, horticulture allows for the cultivation of various fruits, vegetables, herbs, and ornamental plants. This diversity can help communities adapt to changing weather patterns and market demands, ultimately reducing vulnerability. Watershed-based horticulture aligns with the Common Guidelines of 2011, which allocate 10% of the project budget to horticultural activities. This allocation enables communities to establish and maintain horticultural production systems and micro-enterprises. By providing funds and technical support for horticulture, watershed projects empower local communities to engage in income-generating activities, contributing to their economic well-being.

In watershed development initiatives, entry point activities are crucial for laying the foundation of sustainable growth. With a focus on horticulture, these activities play a pivotal role in improving food security, income generation, and community cohesion. Three such activities that form the bedrock of watershed-based horticulture development are the distribution of vegetable seeds for establishing nutrition gardens, planting perennial fruit trees on field bunds, and setting up post-harvest processing cottage industries. These initiatives not only serve practical purposes but also strengthen community bonds, raise awareness about horticulture, and boost employment and income for resource-poor farmers.

The distribution of vegetable seeds to local households serves a dual purpose. Firstly, it promotes the establishment of nutrition gardens, enabling families to grow a variety of fresh vegetables. These gardens help meet the nutritional needs of households and enhance food security. Secondly, they act as a practical entry point for introducing communities to horticultural practices. As families nurture these gardens, they learn about crop care, irrigation, and pest control, which can be extended to larger horticultural endeavors. By integrating nutrition gardens into the watershed development plan, awareness about the importance of diversified diets and the value of horticulture is raised.

Field bunds, which are common features in watershed development, provide an excellent opportunity for planting perennial fruit trees. Fruit trees, such as mangoes, guavas, and citrus, can serve multiple purposes. They not only produce a source of nutritious food but also provide fodder for livestock and wood for fuel. This multi-functional approach aligns with sustainability goals by utilizing available resources more efficiently. Furthermore, the presence of fruit trees on field bunds beautifies the landscape and fosters a sense of pride and stewardship among the community members. The collaborative planting of these trees can strengthen the social fabric within watershed user groups.

Post-harvest processing cottage industries are essential components of a holistic horticultural strategy. These industries add value to the produce, reduce post-harvest losses, and generate employment and income. In a watershed context, they also provide a framework for collaboration among community members. Farmers can collectively engage in activities such as sorting, grading, and processing fruits and vegetables. This not only promotes income generation but also enhances the collective spirit of the community. These industries encourage resource-poor farmers to view horticulture as a viable source of income, fostering awareness and buy-in for horticultural activities within the watershed.

Despite the opportunities, realizing the potential benefits of horticulture within watershed projects can be challenging (Fig. 1). Several factors can hinder success, including inadequate technical knowledge, insufficient resources, and limited access to markets. Addressing these challenges requires continuous capacity building and improved market linkages. Special Crop Management for Perennial Plants Perennial horticultural crops, such as fruit trees and perennial herbs, have unique requirements from establishment to harvesting. They demand a long-term commitment and specialized care. Watershed development projects must provide support and training to farmers for proper management of these crops, ensuring they reach their full yield potential.

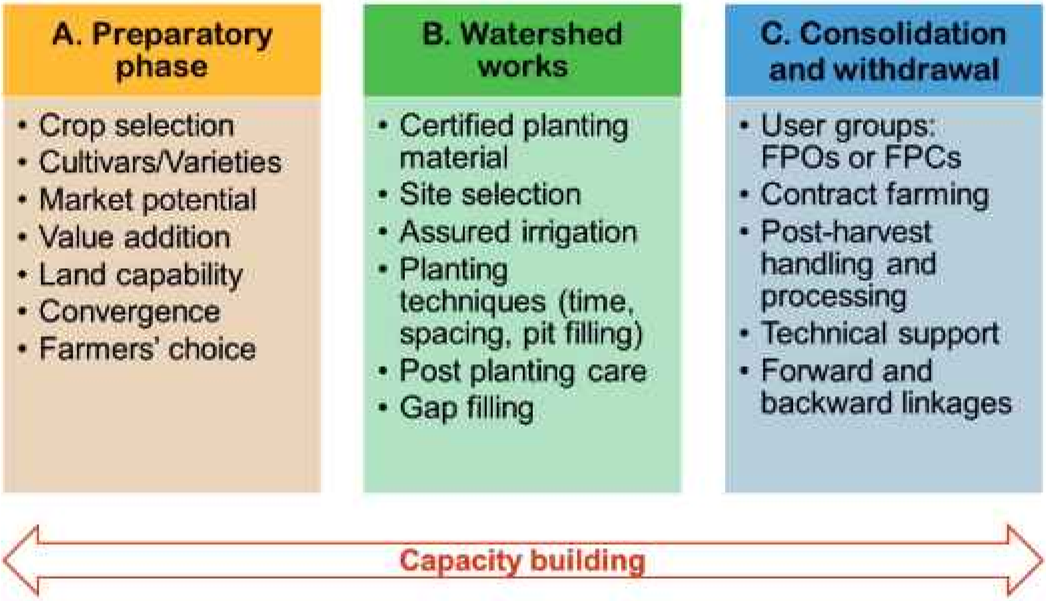

Fig. 1: Watershed project and issues in Horticultural component

Interventions to mitigate soil and water stress through watershed approach

1. Use of land resources inventory for site selection and crop planning

The proper utilization of land resources is critical for sustainable development, especially in rural areas. To achieve this, a comprehensive land resources inventory (LRI) is an essential tool. An LRI involves surveying, defining, and mapping various land units along with collecting descriptive data on land characteristics and resources (Fig. 2). This inventory serves as a scientific foundation for informed land use planning, facilitating the successful implementation of rural development projects and the sustainable management of natural resources. Land Resources Inventory (LRI) plays a pivotal role in modern agriculture, providing invaluable information for precision farming and sustainable land use LRI offers a fine-grained view of land parcels, making it possible to plan crop activities at the farm level. This level of detail allows farmers to optimize their land use, minimizing waste and maximizing productivity. At the heart of LRI is the in-depth analysis of soil fertility and land capability attributes. Information is collected at a granular 250 m^2 grid interval, enabling precise recommendations for land management and crop selection. LRI provides insights into the suitability of a given land parcel for different crops. By considering soil characteristics, topography, and climate, it helps in identifying which crops are likely to thrive, ensuring the best possible yield. The information generated through LRI is designed to be user-friendly. Both PIAs and farmers can easily interpret the findings, making it accessible and practical for decision-makers at all levels of agriculture. LRI doesn't just focus on a single crop but offers a wide array of crop recommendations. This diversity allows farmers to explore alternative crops, reducing risks associated with mono-cropping and market volatility. To further simplify decision-making, LRI classifies crop suitability into four levels, each with specific limiting factors. This helps in understanding the constraints and opportunities for each crop. Nutrient management is crucial for sustainable agriculture. LRI provides site-specific recommendations for soil nutrient management, enabling farmers to optimize fertilization, reduce waste, and protect the environment. Effective water management is essential in agriculture. LRI also suggests suitable soil-water conservation measures, such as contour farming, drip irrigation, or rainwater harvesting, based on the land's characteristics.

By tailoring crop choices to the specific characteristics of the land, LRI significantly enhances agricultural productivity. By identifying the most suitable locations for planting perennial fruit plants, farmers can effectively utilize specific land parcels. Understanding the nutrient or fertility status of the soil provides enhanced options for managing nutrients, ensuring sustainable yields. Additionally, selecting appropriate soil-water conservation practices helps mitigate issues like soil erosion and alleviates the impact of drought stress. LRI promotes sustainable land use and nutrient management, reducing environmental impacts and conserving natural resources. Through diverse crop recommendations and site-specific information, LRI helps farmers mitigate risks associated with weather, market fluctuations, and unforeseen challenges. Improved crop selection and nutrient management practices lead to increased profits for farmers, contributing to rural economic development. LRI fosters responsible land and resource management, supporting the preservation of the environment and biodiversity.

Fig. 2: Land suitability map based on LRI in macro-Watershed project gives suitable sites for planting

2. Integrated cropping systems

The implementation of integrated cropping systems, coconut-based intercropping systems, and the use of poly-lining for farm pond management has brought about a remarkable transformation in agricultural practices. These sustainable initiatives not only extended the availability of water resources but also led to the cultivation of a diverse range of horticultural crops and the development of pisciculture. The farmer can harness the potential of their land to the fullest extent. The landscape is a vibrant tapestry of productivity, featuring an impressive array of crops and activities. Fruit trees, including mango, banana, and guava, grace the land, providing a bountiful harvest of delicious and nutritious fruits. In addition to the fruit orchards, the farmer can venture into vegetable cultivation, growing a variety of greens and vegetables, enriching the local diet and income. Furthermore, the integration of forestry species like bamboo, silver oak, and Melia showcases a forward-thinking approach to sustainable agroforestry, with the promise of valuable timber and non-timber forest products in the future. To meet the fodder requirements for livestock, the farmer can wisely intercrop Napier grass, ensuring a consistent and high-quality feed source. The strategic blend of crop varieties enriches the land, optimizing the use of available resources. The establishment of a vermicompost unit is a significant step in recycling farm waste. This eco-friendly practice not only minimizes waste but also produces nutrient-rich compost, which, when applied to the fields, leads to increased crop yields. Simultaneously, the improved soil properties resulting from the use of compost enhance the overall health and fertility of the land, ensuring the sustainability of the farming.

Fig. 3: More than 20 plant species of fruits, vegetables, forestry, flower and fodder species grown in Harve-I micro-watershed, Chamrajnagar, Karnataka.

3. Water harvesting

The availability of high-quality irrigation water stands as the single most critical factor for the prosperity of commercial horticulture within a watershed development program. Water plays a multifaceted role in the success of horticultural endeavours. Its importance spans from ensuring the early establishment and minimal mortality of fruit trees to promoting robust vegetative growth, timely flowering, and successful fruit set. Furthermore, the adequacy of water resources during critical stages, particularly during fruit development, is instrumental in securing superior fruit yield and quality. Indeed, water is the lifeblood of horticultural productivity.

Fig. 5: Water harvesting structures: Poly-lined water pond for spring-water harvesting (left) and farm pond for rainwater harvesting (right).

However, the capricious nature of climatic conditions, characterized by recurrent droughts and insufficient rainfall, casts a looming shadow over the reliability of water sources for horticultural crops. These fluctuations in water availability pose substantial challenges and risks to the sector. The creation of supplementary water resources is a beacon of hope, offering the promise of resilience and sustainability. Among the viable options, the implementation of springwater harvesting, the construction of rainwater harvesting farm ponds, and the establishment of percolation tanks for groundwater recharge are worth emphasizing. Springwater harvesting strategies allow for the harnessing of natural springs to bolster the water supply for horticultural activities. This technique captures and channels spring water, ensuring a consistent and reliable source of irrigation water, thus reducing dependence on unpredictable rainfall. The construction of rainwater harvesting farm ponds offers a strategic approach to water resource management. These ponds serve as reservoirs for storing rainwater runoff during monsoons, providing an invaluable resource during dry spells. The utilization of rainwater in this manner not only mitigates water scarcity but also enhances its efficient use. Percolation tanks play a pivotal role in recharging groundwater, contributing to the sustainable availability of water. By allowing rainwater to percolate into the ground, these tanks help replenish underground aquifers, bolstering the overall groundwater supply.

This approach not only benefits horticulture but also contributes to the holistic management of water resources within the watershed.

4. Space utilization around soil water conservation structures

In the case study of Mr. Channayaa from Kalkere, located in the Tumkur district of Karnataka, we delve into his innovative approach to horticultural and forestry plantations alongside the implementation of water harvesting structures and trench-cum-bunding techniques. Mr. Channayaa has taken the initiative to construct a farm pond measuring 12.0 × 12.0 × 3.0 meters. This pond incorporates a trench-cum-bund (TCB) system and strategically integrates horticultural and forestry plantations based on the recommendations derived from the Land Resources Inventory (LRI). Within the scope of the watershed development project, a variety of plant species, including *Simarouba*, castor, custard apple, drumstick (Moringa), acid lime, and guava, have been introduced. These plantings serve a dual purpose by optimizing the space surrounding the farm pond and stabilizing the bunds of the pond (see Figure 4). This creative use of land allows for the allocation of 96 square meters for kitchen gardening alongside each farm pond of this size.

Furthermore, Mr. Channayaa has ventured into cultivating vegetables such as dill, bottle gourd, and cluster beans as intercrops, primarily intended for household consumption. The spaces along the berms, nestled between the trench and bunds, have been effectively utilized for the planting of forestry species like silver oak, Melia dubia, and teak, all along the field borders. Notably, bottle gourds have been planted on the bunds, serving not only to stabilize these earthworks but also to provide an additional source of income to the farmer. One of the notable benefits of the bunding system is the positive impact it has on soil moisture within the profile, ultimately leading to increased crop yields. Mr. Channayaa's innovative approach demonstrates how land use and sustainable farming practices can lead to a harmonious coexistence of agriculture, horticulture, and forestry, while also addressing water management effectively.

Fig. 4: Space utilization around water harvesting farm pond and trench cum bunding

5. Soil water conservation systems in horticultural crops

The sustainable cultivation of horticultural crops relies heavily on efficient soil water conservation systems. These techniques not only preserve precious water resources but also contribute to the overall health of the soil and the prosperity of crops.

- **Trench Cum Bunding:** Trench cum bunding is a method that involves creating a series of trenches and bunds or embankments within the agricultural landscape. These structures are strategically designed to capture and hold rainwater, allowing it to percolate into the soil. Trenches prevent surface runoff and soil erosion, while bunds effectively trap water, creating moist micro-environments for horticultural crops. This method not only conserves water but also prevents soil degradation.
- **Micro Catchments for Rainwater Harvesting:** Micro catchments are designed to collect and store rainwater effectively. They comprise depressions or low areas in the field, often shaped to channel water into storage structures. These systems enhance water availability for horticultural crops during dry spells, improving overall crop productivity. By capturing and conserving rainwater, micro catchments contribute to reducing irrigation needs and enhancing water use efficiency.
- **Use of Vegetative Barriers:** Vegetative barriers, such as hedgerows and grass strips, serve multiple purposes in soil water conservation. These barriers break the force of rainwater, preventing soil erosion and surface runoff. This technique helps maintain soil moisture and prevents waterlogging in low-lying areas, creating a more favorable environment for horticultural crops.
- **Mulching:** Mulching is an essential practice in soil water conservation. It involves covering the soil surface around horticultural crops with organic or synthetic materials. Mulch acts as a protective shield, reducing water evaporation, minimizing weed growth, and maintaining soil temperature. By retaining soil moisture, mulching enables crops to access a more consistent water supply, which is especially critical during dry periods. This practice contributes to both water conservation and the prevention of soil degradation.

Fig. 5: micro-catchment for rain water harvesting for better establishment of guava planation (left) and trench-cum-bunding in coconut orchard (right)

Conclusion

The watershed management strategy represents a pivotal approach in the realm of natural resource management, encompassing the careful stewardship of soil and water resources while simultaneously addressing the holistic development of the community. It integrates various facets of agriculture, including the social, economic, and environmental dimensions. Within this multifaceted framework, horticulture emerges as a crucial component of watershed development initiatives, offering a spectrum of activities aimed at optimizing agricultural practices and ensuring sustainability

Nonetheless, horticulture faces its share of abiotic stresses that can jeopardize its success. Water shortages, stemming from either rainwater deficits or soil moisture deficits, pose significant challenges. Soil erosion, driven by factors such as rain and wind, and compounded by human activities, leads to the loss of valuable soil and essential nutrients. It is, therefore, imperative to employ a watershed approach to mitigate these abiotic stresses, ensuring the sustainable growth of horticultural endeavours. To address soil-related stress factors, such as soil moisture deficits, water-logging, and nutrient deficiencies resulting from low carbon and nutrient content, proactive measures must be taken. These measures include adopting a land resource inventory approach, creating additional water resources through methods like spring and rainwater harvesting, and constructing soil water conservation structures on both arable and non-arable lands. Implementing proper orchard floor management practices, such as micro-catchments, mulching, precise planting techniques, and vegetative barriers, is instrumental in mitigating soil and water-related stresses. Additionally, integrated nutrient management techniques further enhance the resilience and productivity of horticultural crops within the watershed.

By implementing these multifaceted approaches and embracing sustainable agricultural practices, horticulture can thrive within the framework of watershed development. It ensures not only the efficient use of soil and water resources but also the long-term welfare and prosperity of the communities it serves. As a result, the watershed management strategy stands as a model for harmoniously balancing the ecological, social, and economic dimensions of agriculture.

Soil Health Management for Degraded and Nutrient Stressed Soils

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Introduction

Soil degradation and nutrient stresses are one of the most challenging global problems and have a direct impact on global food security. Soil degradation is defined as a change in soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries (FAO, 2020). Soil degradation encompasses biological, chemical, and physical deterioration, manifesting as the loss of organic matter, decline in soil fertility, structural degradation, erosion (including sheet, rill, and gully erosion), adverse alterations in salinity, acidity or alkalinity, and the impacts of toxic chemicals, pollutants, or excessive flooding. Presently, approximately 33% of global soils exhibit a moderate to high degree of degradation, with 40% of these compromised soils concentrated in Africa, while the remainder predominantly resides in regions grappling with poverty and food insecurity. Given the profound correlation between soil health and food security, there is an exigent need for strategic and immediate interventions, particularly at the local level, to counteract soil degradation. Such efforts are imperative to bolster food production and mitigate food insecurity, particularly in regions most susceptible, all within the contextual framework of climate change (FAO, 2015).

It is vital to recognize the various manifestations of soil degradation, ranging from water and wind erosion to salinity, loss of organic matter, fertility decline, soil acidity or alkalinity, structural decline (including soil compaction and surface sealing), mass movement, and soil contamination (NSW Department of Planning, Industry and Environment, 2019). As we confront the multifaceted challenges of soil degradation, a comprehensive understanding of these diverse facets is indispensable for formulating effective strategies to reverse this phenomenon and ensure sustainable soil management practices.

Status of soil degradation and nutrient stress in India

In India, about 147 million hectares of land are facing soil problems. This includes 94 million hectares affected by water erosion, 23 million hectares dealing with issues like salinity, alkalinity, or acidification, 14 million hectares struggling with water-logging or flooding, 9 million hectares impacted by wind erosion, and 7 million hectares facing a mix of problems from different sources. To tackle this, the Indian government aims to restore 26 million hectares of degraded lands, including those with salt issues, by the year 2030. This effort is crucial to make sure there's enough food for everyone. Currently, around 6.74 million hectares of land in the country have salt-related problems. What's concerning is that each year, about 10% more land is getting affected by salt, and if this continues, by 2050, half of the land used for farming could have salt problems (Chaudhary et al., 2022).

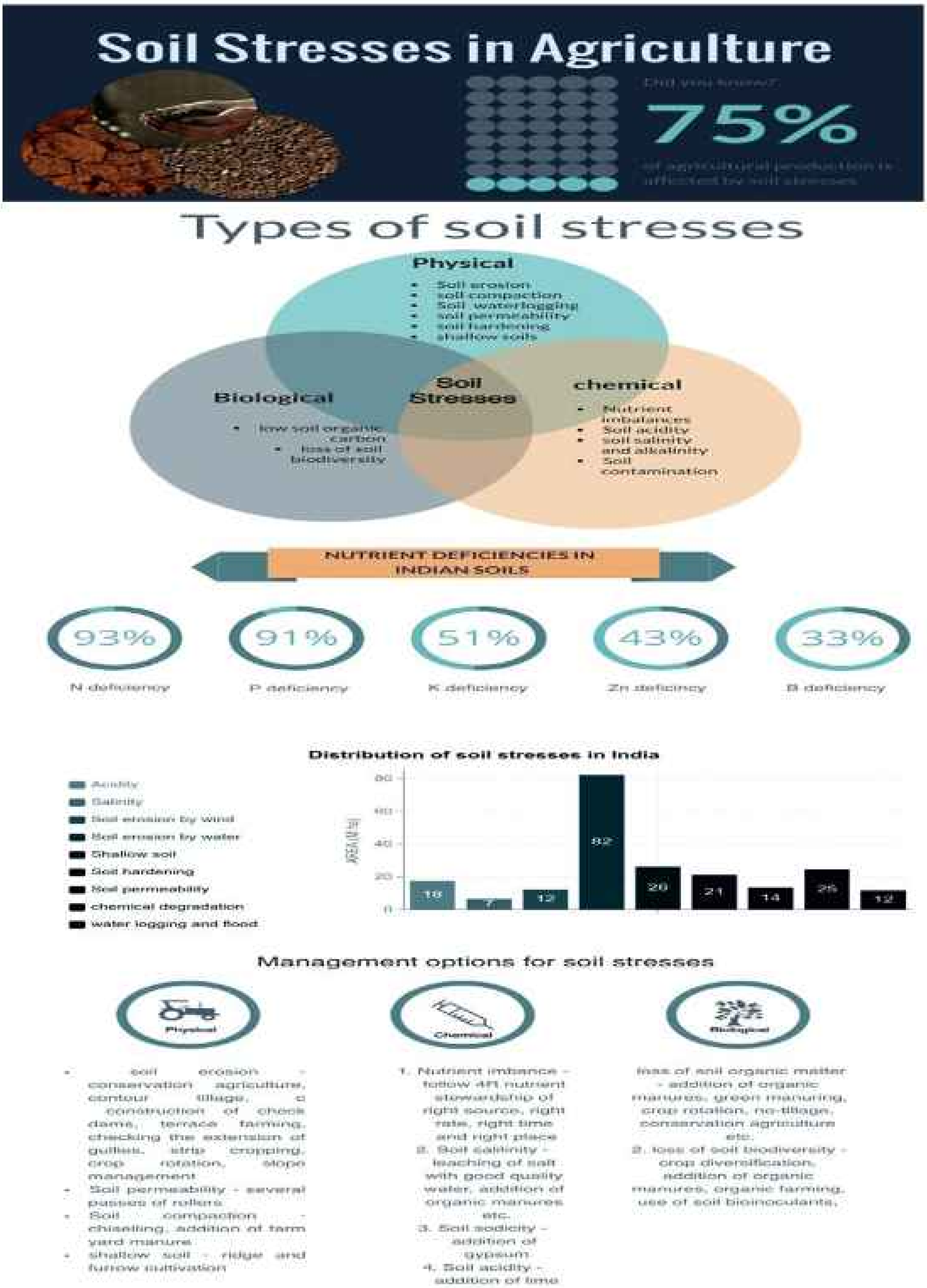

Figure 1. Depiction of different soil stresses in India and their management strategies

Out of the affected areas, 44% are impacted by saline soils in 12 states and one Union Territory. Additionally, sodic soils cover 47% of the land area across 11 states. This highlights the need for urgent actions to protect our land and ensure we have enough food in the future. The soil fertility status of Indian soil is also very poor. About 93, 91, and 51% of deficiency of N, P and K is reported in Indian soil. Besides this, micronutrient such Zn and B is also deficient in many parts of the country (Minhas et al., 2017; Chaudhary et al., 2022).

Management options for soil degradation

1. Increasing Soil Organic Carbon and Organic Matter: Leaving crop residues and composting, Crop rotation and diversification and judicious use of fertilizers
2. Soil Conservation and Erosion Control Measures: Cover cropping, Contour lines and Terracing
3. Rehabilitating Degraded Soils:
4. Curbing Deforestation:
5. Climate-Smart Agroforestry Practices:
6. Irrigation for Improved Crop Production:
7. Establishing/Equipping Soil Testing Laboratories:
8. Building Farmers' Capacity: Training programs and Educational resources
9. Supporting National Extension Services:
10. Legislation and Policy Guidelines: Framework for sustainable soil management
11. Enhancing Technical Capacities: Training workshops, Research and development initiatives

Management of soil physical stresses

1. **Importance of Soil Physical Properties:**
    - Soil physical properties regulate water movement, nutrient transformations, root absorption, microbial activities, and heat movement.
    - Efficient crop production requires understanding the soil environment to identify limitations and improve conditions without harming soil health.
2. **Impact of Soil Compaction:**
    - Soil compaction is a significant issue in modern agriculture, affecting root penetration, water, and gas exchange.
    - It is exacerbated by intensive tillage, heavy machinery use, short-duration crop rotations, intensive grazing, and improper soil management practices.
3. **Effects of Soil Compaction:**
    - Compacted soils have higher strength, increased draft power for tillage, poor fertility, reduced water and nutrient supply, and discourage root growth.
    - Soil compaction leads to decreased water and nutrient uptake, poor crop growth, reduced nutrient mineralization, microbial activities, and overall yield.

- Compacted soils increase mechanical impedance for root growth, alter soil structure, reduce pore spaces, and impede water, nutrient, and gas movement.
- The development of compact layers restricts root penetration, causing surface runoff, soil erosion, and oxygen stress in the root zone.

Management of Soil Compaction:

1. Managing soil compaction involves various strategies:
    - Subsoiling, controlling farm traffic, contour farming, and subsurface drainage.
    - Application of organic matter to improve soil hydro-physical properties and increase crop yield.
    - Avoiding retracing the same path by farm vehicles to minimize overall field compaction.
    - Implementing reduced soil disturbance, farm traffic, and enhanced residue incorporation for improved soil quality and crop performance.
    - Deep tillage is recommended for breaking up plough pans, especially in dry conditions after crop harvest.
    - Further research is needed to explore the relationship between tillage, crop
2. **Soil Crusting Overview:**
    - Soil crusting is the development of a thin, dense, and hard layer on the soil surface.
    - Characteristics include higher density, shear strength, narrower pores, and poor saturated hydraulic conductivity compared to the underlying soil.
3. **Crust Appearance:**
    - Soil crusts appear more even and smooth than freshly exposed or cultivated soils.
    - Considerably more compacted than the layer beneath.
4. **Moisture Content Influence:**
    - Soils with 2-3% moisture content (depending on texture) are more prone to crust development than oven-dried or excessively wet soils.
5. **Texture and Crust Strength:**
    - The strength of the crust increases with the fineness of texture.
6. **Wetting Methods and Crust Strength:**
    - Flooding as a wetting method results in higher values of the module of rupture compared to other methods like sprinkler or capillary saturation.

- The higher module of rupture yields higher crust strength.

7. **Control Measures:**
    - The primary control measure is to reduce the force of raindrop impact.
    - Application of straw mulch hampers direct contact of raindrops with bare soil surfaces, decreasing crust strength.

8. **Additional Measures:**
    - Application of farmyard manure (FYM) can improve seedling emergence in various crops.
    - Studies show that FYM on seed lines with mulch significantly increases seedling emergence, particularly in pearl millet and cotton crops.
    - Improved yield and fibre quality in cotton have been observed with this approach.
    - residue, controlled traffic, productivity, and the environment

Overview of Soil Erosion:

- Soil erosion occurs via water, wind, or tillage, removing soil from the ground surface.
- Overland flow creates channels like rills or gullies, while wind erosion occurs when loose soil is exposed to high winds.
- Tillage erosion involves soil redistribution within a field due to tillage instruments.
- Human activities often expedite or exacerbate natural erosion processes.

Principles of Erosion Control:

- **Land Use Classification:** Land use should align with capability classification.
- **Cover Cropping:** Growing plants or using organic/non-organic waste cover protects the soil surface.
- **Runoff Control:** Manage runoff before it develops erosive force.
- **Soil Erosion Control Classes:** Divided into three classes:
- **Management of Soil Erosion:** Key to sustainable soil management involves selecting suitable methods to control erosion.
- **Agronomic Measures:** Maintain plant cover to reduce wind and water erosion. Includes mulching, minimum tillage, no-till, cover crops, agro-ecological approaches, and more.
- **Physical Measures:** Limit runoff velocity and depth using physical barriers like terraces, strip cropping, contour planting, agroforestry, and grass strips. Methods

to minimize runoff also retain silt, including riparian buffers, check dams, sediment ponds, and wetlands.

Overview of Soil Salinity and Sodicity:

Global issues in arid and semi-arid areas, causing agricultural productivity loss. Soil salinity affects 20% of all cultivated land and 33% of irrigated agricultural land globally. Salt-affected soils cover 954 million hectares in 120 countries, resulting in a 7–8% loss in productivity.

Classification of Soil Salinization and Sodification: Based on pH, electrical conductivity, and exchangeable sodium percentage (ESP). It is classified as saline soil, sodic soil, and saline-sodic soil.

Management of Soil Salinization:

- **Leaching:** Continuous or intermittent ponding with good quality water for downward movement and salt flushing.
- **Drainage:** Horizontal and vertical subsurface drainage systems. Installation of subsurface drainage pipes to lower the water table and accrete salt.
- **Salt-Tolerant Plants:** Essential for maintaining production in salt-affected regions. Tolerance mechanisms include ion accumulation selectivity and enhanced ion partitioning in plant cells.

Management of Soil Sodification:

Chemical Amendments:

- Easily soluble source of Ca2+: Gypsum, Calcium chloride.
- Sparingly soluble source of Ca2+: Calcite.
- Acid and acid formers: Sulphur, Sulphuric acid, Sulphates of iron and aluminium, pyrites, and lime-sulphur.

Specific Amendments:

Gypsum: Most effective for restoring sodic soil. It replaces Na+ with Ca2+, leading to leaching of NaSO4 deeper into the soil profile.

Phospho-Gypsum: it is a by-product of phosphate fertilizer production, used as a replacement for gypsum. It may also contain trace amounts of potentially toxic elements.

Compost: Green waste, sugarcane compost, and gypsum used to rehabilitate saline soils. It enhances microbial activity and displaces excess Na^{+} with Ca^{2+}.

Organic Supplements: Biochar, municipal solid waste compost, inorganic amendments rich in calcium, and zeolites used to restore sodic soils. Improve soil properties, decrease pH, electrical conductivity, and exchangeable sodium percentage.

Overview of Soil pH and Acid Soil :

- Reduction in soil pH due to increased H+ and Al3+ ion activity.
- Loss of basic cations (Ca2+, Mg2+, K+, Na+) contributes to acidity.
- Growth-restricting factors include Al and Mn toxicity, deficiencies in Ca, Mg, P, B, and Mo.
- Approximately 67% of total soil areas face significant agricultural production restrictions due to acid fertility issues.

Acid Soil Management:

- Liming of Acid Soils:
- Lime sources include calcite, dolomite, marl, slag, fire dust, and other industrial by products.
- **Integrated Nutrient Management (INM):**
- Synergistic effects of lime, organic manure, and inorganic fertilizers.
- Improved maize productivity documented with INM practices on acidic soils in Meghalaya.

Waterlogged Soil: Pore oxygen depletion due to excessive moisture, leading to harmful gas build up (CO_2, ethylene). It generally occurs in soils with restricted drainage, causing oxidation-reduction processes.

***Management of Waterlogged Soils*:**

- **Raised Bed Farming:**
  - Elevated flat beds create aerobic conditions for plant roots.
  - Enhances hydraulic conductivity, reduces soil density, and promotes effective drainage.
- **Surface Drainage:**
  - Traditional drainage systems like hands, subheads, and collectors.
  - Farmers' direct operation and monitoring of surface drainage systems.
- **Sub-surface Drainage:**
  - Effective in areas with higher water tables.
  - Open and pipe drains of different depths and spacing.
  - Bio-drainage using fast-growing tree species.
- **Adaptive Nutrient Management:**

- Influences N absorption, losses, and Nitrogen Use Efficiency (NUE).
- Synchronizing N availability with crop N demand is crucial.
- Optimal N source, treatment rate, and timing are critical for poorly drained soils.
- Efficient N management decisions are vital for maximizing fertilizer value and crop yields.

***Management of nutrient Stresses*:**

Decrease in Soil Organic Matter (SOM) is primary cause for nutrient stress in soils. Healthy soils store more carbon than the atmosphere and vegetation combined. Cultivated soils globally have lost 25-75% of original carbon stock, contributing to climate change. Conservation agriculture, crop diversification, integrated nutrient management, and agroforestry enhance carbon sequestration potential. Human activities like recurrent tillage, monoculture, residue burning, and unsuitable cropping systems contribute to soil organic carbon loss.

***Critical Management Measures to Boost SOM*:**

a. **Conservation Tillage:**

   i. Reduces tillage passes, minimizes soil disturbance, and covers 30% of the soil surface with residues.

   ii. No-till protects SOM better than conventional tillage, enhancing aggregate stability.

b. **Residue Retention:**

   i. Crop straw retention improves soil fertility, structure, water retention, and reduces erosion risk.

   ii. SOC content influenced by C: N ratio of crop residues and various factors.

c. **Cover Crops:**

   i. Planted to protect soil from erosion, cover crops improve soil physical, chemical, and biological characteristics.

   ii. Canopy reduces raindrop impact, conserves moisture, and increases soil moisture availability.

d. **Deep Tillage:**

   i. Ploughing below usual depth to improve soil physical and chemical properties, alleviate compaction, and enhance root development.

   ii. Deep ploughing and subsoiling can improve subsurface carbon sequestration.

e. **Crop Rotation or Diversification:**

   i. Planting multiple crops on the same plot to enhance soil health, nutrient maximization, and pest/weed reduction.

   ii. Optimized agricultural diversification improves soil chemical nutrients and microorganisms.

f. **Conservation Agriculture:**

   i. Based on no-tillage, residue retention, and crop diversity principles.

   ii. Enhances soil health, reduces soil erosion, lowers production costs, and sequesters carbon.

g. **Integrated Nutrient Management:**

   i. Maintains soil fertility through organic, inorganic, and biological components.

   ii. Combined application of FYM with recommended fertilizers enhances SOC storage.

h. **Biochar:**

   i. Carbonized biomass stored in soils to improve agricultural and environmental value.

   ii. Porous substance aiding water and nutrient retention in the soil.

   iii. Produced from various feedstocks through pyrolysis, stabilizing organic C.

Conclusion

Maintaining the health of our soils is critical for sustainable agriculture and environmental well-being. The soil degradation and nutrient stresses poses a global challenge, with cultivated soils losing a substantial portion of their carbon stock. Promising strategies to address this include conservation agriculture practices like reduced tillage, residue retention, and crop diversification. These methods enhance soil structure, protect against SOM loss, and promote carbon sequestration. Integrated approaches such as nutrient management cover cropping, and biochar incorporation offer synergistic benefits for soil health and carbon storage. Furthermore, preserving soil biodiversity is crucial for ecosystem functioning, and human-induced activities like deforestation and intensive agriculture threaten this diversity. Sustainable land use practices are essential to mitigate these impacts.

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Plant Phenotyping for Abiotic Stress Assessment and Crop Improvement Through Plant Breeding

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Introduction

Plants modify their morphology, anatomy, phenology, and cellular metabolism in response to varied external stimuli. In light of this, crops' growth, development and productivity may enhance or decrease based on environmental conditions. A significant portion of the progress made thus far in enhancing crop productivity is due to per se selection for yield and yield attributes. This was more noticeable in favourable growing environments than those adversely influenced by various abiotic stress factors. As a result, traits associated with tolerance to abiotic stresses are receiving more attention. Genes governing such traits are crucial to further improvement. Therefore, it is essential to understand genotype and phenotype components to establish the association between genes and traits, while the power of prediction of association is primarily governed by several genotypes characterized (Basavaraj et al. 2023a). In recent years, tremendous progress has been made in understanding plant responses at the molecular level with the advent of next-generation sequencing and other molecular biology tools. However, the primary constraint is the absence of advancements in understanding the phenotypic characteristics and large-scale plant response characterization. Thus, the science of plant phenomics has evolved, aiming to accurately and quickly characterise how plants react to their surroundings using non-destructive techniques that enable widespread genotype screening.

Phenotype and Phenotyping

The term phenotype refers to srt of observable characteristics or traits of an organism. The term covers the organism's morphology, developmental processes, biochemical and physiological properties, behaviour, and products of behaviour (Basavaraj et al. 2023a). Phenotyping is measuring a trait of its component trait. Phenotyping started with human civilization when man started selecting for a superior phenotype.

Features of Plant Phenomics in a Controlled Environment (Rane et al. 2016)

- Automated control of the growth environment, including soil moisture, temperature, and humidity.
- The required level of stress is maintained and monitored with greater precision.
- A controlled environment allows screening for multiple stresses simultaneously.
- Image acquisition, processing and analysis to assess plant response to given stress or stresses

- Large-scale phenotyping of several hundred to thousands of germplasm accessions in a robust and non-destructive way.
- Plant responses are captured through images obtained from different electromagnetic radiation in a non-invasive manner.
- Images from the visible range reveal changes in morphology and developmental stages.
- Images from the infra-red range reveal variations in plant temperature
- Images from near-infrared range reveal plant water status

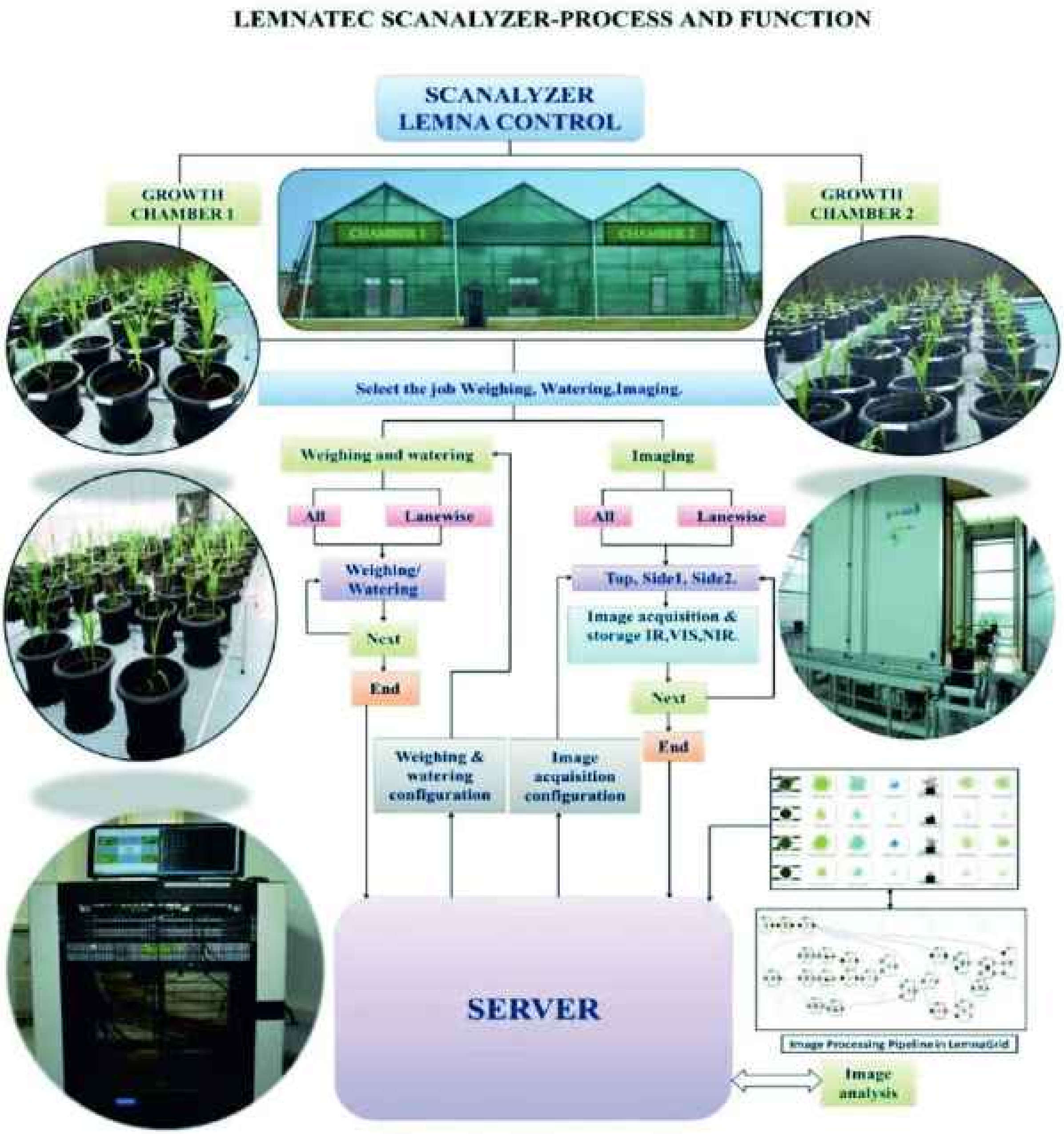


Figure: 1 Plant Phenomics facility at ICAR-National Institute of Abiotic Stress Management, Baramati

Necessity of Phenomics or phenotyping platforms

- The conventional way of phenotyping is tedious, subjective, and error-prone.
- Since yield is a complex quantitative trait with low heritability, selection for yield per se under an abiotic stress environment will not be rewarding.
- Trait-based selection is essential for diverse agroecosystems vulnerable to climate change.
- To dissect the underlying tolerance mechanism and identify gene (s), it is necessary to phenotype a large number of individuals or populations of the particular crop (Basavaraj and Rane 2020).
- To minimize the Genotype x environment x management error.

What does plant phenomics involve?

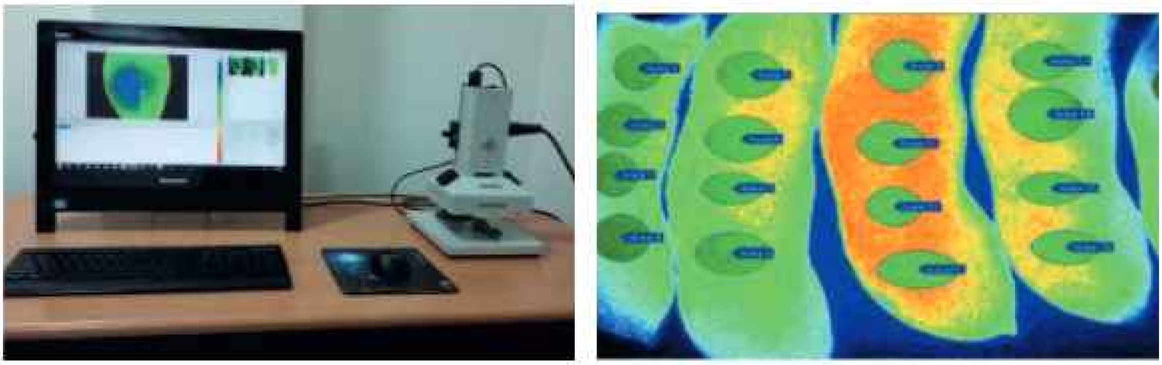
Phenomics borrows medical imaging techniques to allow researchers to study the inner workings of leaves, roots or whole plants. Some phenomics techniques are,

3D imaging: Pots of plants move on a conveyor belt through an imaging chamber. The 3D models are automatically generated by a computer program. The TrayScansystem holds a mini-conveyor belt that cycles trays of plants through a high-tech array of cameras. Each tray is labelled with a barcode so plants can be easily identified.

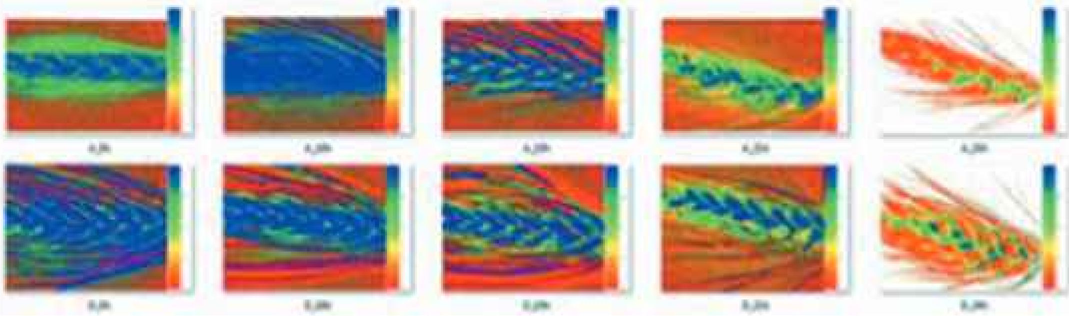
Figure:2 3D imaging facility at ICAR-NIASM

Infrared imaging: IR cameras are used to study temperature. They use light in the IR region of the spectrum (15–1000 μμm). Temperature differences can be used to study salinity tolerance, water usage, and photosynthesis efficiency.

Fluorescence imaging: Fluorescence occurs when an object absorbs light of one wavelength and gives off light of a different wavelength. Chlorophyll fluorescence is used to study the effect of different genes or environmental conditions on the efficiency of photosynthesis (Rane et al. 2021b).



Model image of Chlorophyll fluorescence imaging



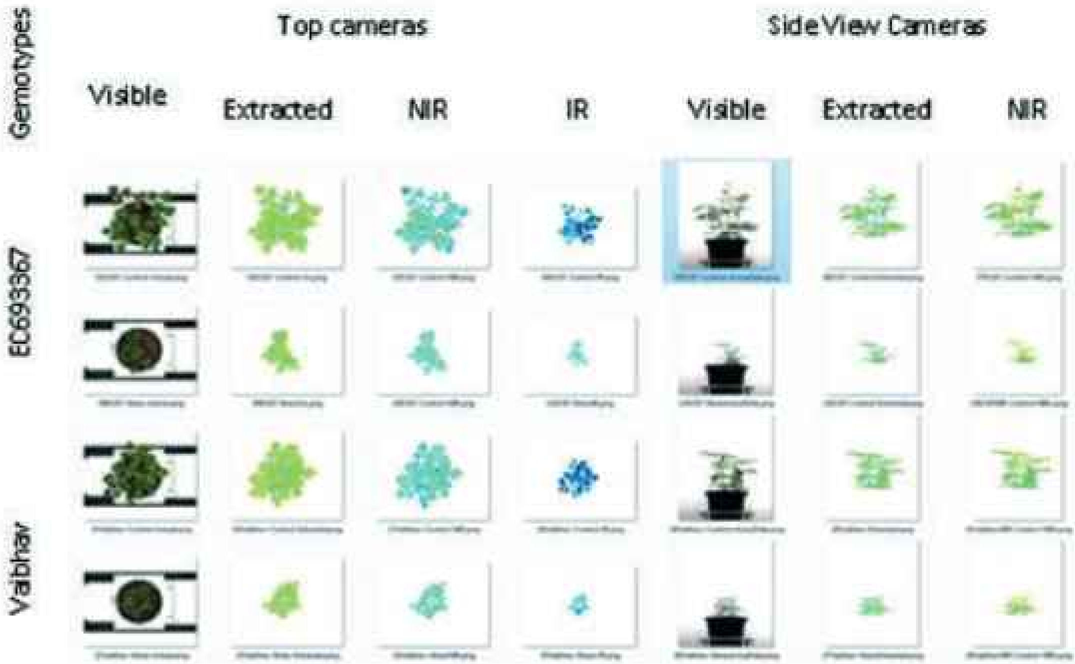
Chlorophyll fluorescence imaging to assess desiccation tolerance

Magnetic resonance imaging: Magnetic resonance imaging (MRI) is used to study plant roots (Rane et al. 2023). MRI uses a magnetic field and radio waves to take images of roots like imaging body organs in medicine. MRI allows the 3D geometry of roots to be viewed just as if the plant was growing in the soil.

Spectral reflectance: Spectral reflectance is the fraction of light reflected by a non-transparent surface. Researchers can use spectral reflectance to tell if a plant is stressed by saline soil or drought, well before it can be seen by eye (Jones et al. 2010). A hyperspectral camera measures all wavelengths of light that are either reflected or absorbed by a plant.

Optimisation of phenomics protocol

In order to phenotype efficiently, for each crops protocols and imaging configurations need to be standardised. This involves several preliminary experiments. At NIASM, protocols for screening of mungbean, chickpea, soybean, maize and wheat for water stress tolerance were optimised. Based on this method, biomass can be predicted and effective water use of each accessions or germplasm can be obtained (Rane et al. 2021a; Basavaraj et al. 2023b).



Plant phenomics in the field

Most of the time it is difficult to extrapolate controlled experimental results to field, therefore, field based phenotyping tools emerged to address this issues. Field based Phenomics remote sensing technology allows researchers to study plants in the field. Measurements can be taken on many plants at once, and over a whole growing season rapidly and non-destructively.

Some examples of phenomics field technology are:


Phenonet sensor network

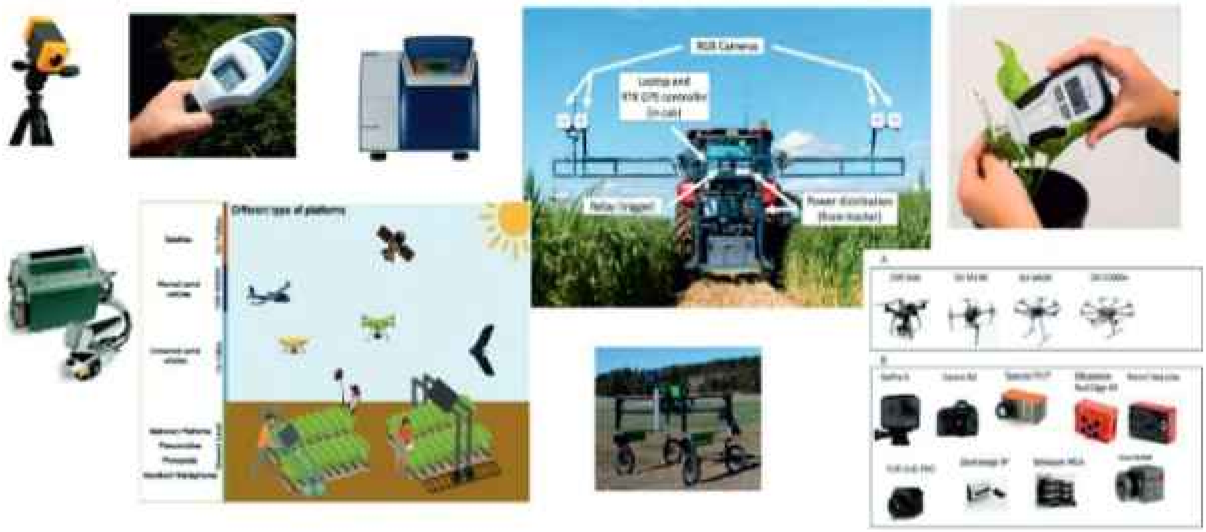

Phenomobile


Phenotower


Multicopter


Phenomobile

Field Phenotyping tools



Phenonet sensor network: A network of data loggers collects information from a field of crops and sends it through the mobile phone network to researchers at the lab. Sensors include: far infrared thermometer, weather station, soil moisture sensor, thermistor for measuring soil temperature (Reynolds et al. 2020).

Phenomobile: It characterize precisely and not ambiguously, the micro-plots of land. The main components are viz., 3Sick LMS400Lidars, 2 RGB Cameras, 5 Flashs LUMIX FR60, 2 RTK GPS, 2 IMU (SBG Ellipse), 1Windsonic Anemomete. It mainly measures the leaf greenness and ground cover, canopy temperature, volume (biomass) of plants, plant height and plant density and crop chemical composition (Deery et al. 2020).

Phenotower: The phenotower is a cherry picker used to take images of crops 15 m above the ground. It mainly used for capturing visible and IR images to study canopy cover, greeness and canopy temperature using different cameras (Deery et al. 2020).

Multicopter: The Multicopter can take infrared and colour images of a field from just a few centimetres above the ground to a height of up to 100 metres. It is deployed to measure canopy temperature of the crops and spectral signature of the crop to deroive meaningful inferences.

Phenomics facilities at global level (Rane et al. 2016**).**

Country	Phenomics faclity
India	ICAR-NIASM, Natiaonl Plant Phenomics facility Baramati- Works on Pulses ICAR-IARI, Nanaji Deshmukh Plant Phenomics facility, New Delhi,Works on Rice ICAR-IIHR, Bangalore-Works on Vegetable crops

	ICAR-CRIDA, Hyderabad, Works on dryland cerelas
China	CAAS, Beijing, Harbin Agripheno, Pudong, Shanghai
Australia	Victoria laboratory, Horsham, ACPGF, Adelaide
Germany	IPK Gaterlaben Plant Science Research Centre, Julich
France	INRA science and impact, Dijon INRA Montpellier
Netherland	Keygene
Italy	Metaponto (ITALY)
United Kingdom	Rothamsted Research Station Aberysstwyth University
Canada	McGill Phenomics Platform, Canada
USA	Donald Danfroth Plant Science Center Arkansas State University

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Innovative Concepts in Watershed Management- New Paradigm for Climate Change Mitigation

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Introduction

In recent years, the concept of watershed development has emerged as a promising new perspective in the realm of sustainable resource management. As human activities continue to impact the environment and disrupt delicate ecosystems, a more comprehensive approach is needed to address these challenges effectively. Watershed development offers a holistic strategy that considers the interconnectedness of land, water, and communities within a specific geographic area, known as a watershed. By recognizing the intricate relationships between these elements, this approach aims to achieve not only environmental conservation but also social and economic upliftment for local communities.

Unlike traditional development paradigms, which often focus on isolated sectors, watershed development takes a more integrated and participatory approach. It seeks to harmonize human interventions with nature's processes, acknowledging that the health of ecosystems and the well-being of communities are intricately linked. By involving local stakeholders in decision-making and implementation, watershed development empowers communities to take ownership of their natural resources, ensuring that their unique knowledge and needs are respected and incorporated into the planning process. Through soil and water conservation, afforestation, sustainable agriculture, and the establishment of watershed institutions, this approach strives to create resilient ecosystems and sustainable livelihoods while mitigating the adverse effects of environmental degradation. Ultimately, watershed development offers a transformative path towards a more balanced and interconnected relationship between humans and the environment they depend upon.

Advanced Technologies in Watershed Development

Advanced technologies such as Remote Sensing (RS) and Geographic Information Systems (GIS) have revolutionized watershed development by providing valuable tools for planning, analysis, and monitoring of natural resources and ecosystems. These technologies offer a comprehensive and data-driven approach, enabling informed decision-making and effective management strategies for sustainable development.

The integration of Remote Sensing and GIS in watershed development has streamlined and enhanced the planning and implementation of projects. These technologies offer a powerful synergy, enabling a deeper understanding of complex environmental processes and supporting evidence-based management decisions. As we continue to face the challenges of sustainable resource management, RS and GIS remain indispensable tools in fostering a new era of watershed development that is efficient, ecologically sensitive, and socially beneficial.

Estimation of losses from the watershed

Soil Loss: Soil loss refers to the erosion and detachment of fertile topsoil due to natural processes like rainfall and wind, as well as human activities like deforestation and improper land use. It can lead to reduced agricultural productivity, degraded ecosystems, and increased sedimentation in water bodies.

Sediment Loss: Sediment loss is the transport of eroded soil particles by water or wind, leading to sediment deposition in rivers, lakes, and reservoirs. Excessive sedimentation can harm aquatic habitats, reduce water quality, and impact hydropower generation and irrigation infrastructure.

Runoff: Runoff is the flow of water over the land surface, often occurring after rainfall or snowmelt. Excessive runoff can cause soil erosion, carry pollutants into water bodies, and contribute to flooding in low-lying areas, affecting both the environment and human settlements.

Carbon Loss: Carbon loss refers to the loss of soil carbon and the release of carbon dioxide (CO2) and other greenhouse gases from soils due to various processes, including land-use changes, deforestation, and soil degradation. Such losses contribute to climate change, as carbon dioxide is a significant driver of global warming.

Watershed Prioritization

Watershed prioritization using remote sensing is a data-driven approach that leverages satellite imagery and other remote sensing technologies to identify and prioritize areas within a watershed that require immediate attention and intervention. By analyzing various spatial data layers, such as land cover, soil erosion, vegetation health, and hydrological patterns, this technique helps stakeholders focus their efforts on the most critical and vulnerable regions.

Concept of Carbon Neutral Watershed

The concept of a carbon-neutral watershed involves balancing the amount of carbon dioxide emitted with an equivalent amount of carbon dioxide removed or offset, resulting in a net-zero carbon footprint within the watershed. Achieving a carbon-neutral watershed requires implementing sustainable land management practices, afforestation, reforestation, and promoting renewable energy sources to reduce carbon emissions and enhance carbon sequestration.

Carbon Sequestration

Carbon sequestration plays a vital role in climate change mitigation within watersheds. By capturing and storing carbon dioxide from the atmosphere, natural ecosystems like forests, wetlands, and grasslands act as carbon sinks. Restoring and conserving these habitats, along with adopting sustainable land use practices, enhances their ability to sequester carbon. This process helps offset greenhouse gas emissions, contributing to the overall goal of combating climate change and promoting environmental resilience within the watershed.

Innovative Conservation Measures

Curved Check Dam: By implementing a curved design for check dams, construction costs can be reduced by up to 50% while maintaining equivalent structural stability and water storage capacity.

Scrap Tyre Check Dam: Utilizing scrap tyres for check dams not only reduces environmental hazards posed by discarded tyres but also provides an economically viable solution for water storage and conservation.

Deep CCT (Continuous Contour Trench): Employing a deep continuous contour trench allows for spacing optimization, leading to cost savings, while still providing similar benefits in terms of water retention and soil conservation within the watershed.

Constraints in New Paradigm

Trained Man Power: The lack of adequately trained personnel with expertise in the new paradigm may hinder its effective implementation and success.

Policy Restrictions: Existing policies and regulations may not align with the principles of the new paradigm, impeding its adoption and integration into mainstream practices.

Professional Outlook: Resistance or reluctance from professionals to embrace new approaches and deviate from conventional methods can slow down the adoption of the new paradigm.

Visionary Leadership: A lack of visionary leaders who can champion the cause and drive transformative change might hinder the widespread acceptance and implementation of the new paradigm.

Passion and Perseverance: The success of the new paradigm depends on the passion and perseverance of individuals and communities in overcoming challenges and persisting with its implementation.

Out of Box Thinking: Embracing out-of-the-box thinking is crucial to effectively innovate and adapt the new paradigm to unique and diverse watershed contexts, ensuring its scalability and sustainability.

Innovative Methods for Establishing Fruit Orchards in Shallow basaltic terrains

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Introduction

Over the past four decades, Indian horticulture has experienced remarkable growth, resulting in fruit production reaching approximately 269 million tons (Mt), surpassing total food production, which stands at around 260 Mt. Maharashtra, the leading state in fruit production, contributes the most with 56 Mt (15%), followed by Andhra Pradesh (12%). Despite these achievements, there are significant challenges in the agricultural landscape. In Maharashtra, a substantial portion of the state, about 96.4 percent, is affected by various degrees of erosion. The soil profile analysis indicates that severe erosion is most prevalent in the Western Ghats region (53.1%), followed by lower Maharashtra (11.5%).

The soil composition in Maharashtra primarily consists of residual soil derived from underlying basalts. In the semi-dry plateau regions, there is regular or black-cotton soil, which is clayey, rich in iron, and has good moisture retention properties but is deficient in nitrogen and organic matter. Along river valleys, kali soils are found, which are deeper and heavier, making them suitable for Rabi crops. Moving farther with a better lime mixture, morand soils become prevalent, ideal for Kharif crops. The higher plateau areas have panther soils that contain more gravel. In the states of Maharashtra and Andhra Pradesh, which are major contributors to fruit production, approximately 40% of the soils are shallow basaltic/red soils. These soils are predominantly used for rainfed farming, as only about one-fifth of the area is under irrigation. These soils also suffer from inherent deficiencies, such as low organic carbon content, leading to multiple nutrient deficiencies. Additionally, the impact of climate change is further exacerbating challenges in the farming systems of these regions.

Research efforts have significantly advanced our understanding of the biology and management of horticultural plantations, especially in environments characterized by abiotic stresses. In addressing the challenges posed by such conditions, various on-site and off-site soil and water conservation techniques have been advocated.

On-site Techniques: These include strategies implemented directly in the orchards or fields:

1. Trenching: Creating trenches can help improve water infiltration and retention in the soil, which is particularly valuable in areas with limited rainfall.
2. Contour/Strip Planting: Planting in contour lines or strips helps to reduce soil erosion and conserve water by preventing runoff.
3. Graded Farrows/Ridges: Constructing graded furrows or ridges can enhance water distribution and retention, supporting crop or tree growth.

Off-site Techniques: These methods focus on water management beyond the immediate planting area:

1. Run-off Storage: Storing rainwater runoff in reservoirs or ponds can provide a supplementary water source for irrigation.
2. Canal/Water Transport: Using multi-stage pumping, water tankers, or other means to transport canal or drain water can ensure a more reliable water supply.
3. Drip Irrigation: Switching to drip irrigation systems from flood irrigation system can optimize water and nutrient delivery to plants, reducing waste and improving efficiency.

Fruit trees, in particular, face significant challenges due to limited root proliferation in shallow soils with hard murrum pans or stones beneath. This restricts their access to sufficient soil volume, water, and nutrients. As a result, it is widely acknowledged that the successful cultivation of fruit trees requires a substantial shift in planting techniques, site preparation, and post-planting management. The initial establishment and growth of fruit tree saplings are critical phases in orchard development, and efforts should be directed towards creating favorable conditions for their roots. Based on research conducted at NIASM in Baramati, it has been demonstrated that, with appropriate changes in planting techniques and site management, the initial growth of orchards can be significantly improved even in shallow basaltic soils. Consequently, a wealth of information has been compiled from these experiences to benefit growers facing similar challenges in establishing orchard crops on rocky basaltic terrain. This knowledge can guide growers in making informed decisions and implementing practices that enhance the success of their fruit tree plantations.

Soil and weather conditions at ICAR-NIASM

Large expanses of barren and uncultivable terrain, primarily resulting from the presence of superficially subdued basalt igneous rocks, are prevalent across many regions of India, particularly in Peninsular India. These lands typically exhibit characteristics such as porosity, shallow depth (10-30 cm), gravelly texture, low organic matter content, high bulk density, and poor water retention capacity.

The location of NIASM (National Institute of Abiotic Stress Management) is situated at coordinates 18° 09' 30.62''N latitude and 74° 30' 03.08''E longitude, with an elevation of 570 meters above sea level. It is situated in Malegaon Khurd, Baramati, in the Pune district of Maharashtra state. This region falls within the agro-ecological region known as the Deccan Plateau, characterized by a hot and semi-arid climate (AER-6). It also belongs to agro-climatic zone AZ-95, which is classified as a scarcity zone in Maharashtra. The site experiences an average annual rainfall of 560mm, primarily concentrated during the south-west and retreating monsoon seasons.

Establishing a research farm for orchards at this location presented significant challenges. The site itself reflected multiple soil-related stresses, including the presence of shallow murrum soil layers ranging from 0.1 to 0.3 m. Additionally, the region was susceptible to frequent droughts and vulnerable to the impacts of climate change. This undulating rocky (basalt) terrain had no natural vegetation, creating a rain-shadow environment, making it a formidable undertaking to develop a research farm suitable for orchards.

Development steps for shallow basaltic terrain

The development process described involves a combination of physical (mechanical) and chemical weathering processes to accelerate soil development. Here are the steps involved:

1. **Utilizing Physical (Mechanical) and Chemical Weathering**: The development process begins by employing both physical and chemical weathering principles to facilitate the breakdown of the parent rock material and promote soil formation.
2. **Ripping and Chaining with Heavy Machinery**: Heavy machinery is used to carry out ripping and chaining activities. These machines target the larger parental rock blocks and break them down into smaller-sized boulders and gravels. This mechanical disintegration process is crucial for creating a suitable environment for soil development.
3. **Repetitive Ripping, Chaining, and Leveling**: The process of ripping, chaining, and pushing the soil is repeated multiple times in each of the fields until the terrain becomes almost level. This repeated action ensures the thorough disintegration of the parent rock material and helps in levelling the land for agricultural use.
4. **Utilizing Distillery Raw Spent Wash**: In the region where this development process is implemented, distillery raw spent wash, which is a by-product of the sugar industry, is abundantly available. This substance is characterized by its low pH (approximately 4.0), high organic carbon content (around 44 g/L), and the presence of macro and micro-nutrients.
5. **Chemical Reaction with Parental Zeolites and Rocky Materials/Murrum**: The distillery raw spent wash is used as a reactant with the parental zeolites and other rocky materials, including murrum, found in the area. This chemical interaction serves

to further enhance the process of soil development by promoting chemical disintegration of the parent materials.

Several possible alternative planting methods being tried to overcome edaphic stresses are given below:

1. Sub-surface Water Harvesting (SSWH) along with Larger Pits/Trenches

Planting fruit seedlings is a common agricultural practice, often involving the excavation of pits measuring 0.45 m×0.45 m×0.45 m. These pits are typically filled with a mixture of the original soil, sand, and Farm Yard Manure (FYM). However, in regions with shallow soils, orchards established using this method frequently underperform due to factors such as irregular rainfall, recurring droughts, and the presence of shallow, gravelly rhizosphere conditions. These conditions expose the fruit trees to significant moisture stress.

To address these challenges and enhance water accessibility for the plants, it is recommended to adopt a different approach, particularly when dealing with shallow-rooted fruit trees like pomegranates. For crops like grapes, which are planted at close intervals, longer trenches are preferable. However, for deep-rooted plants like sapota, ber, and guava, even larger pits or trenches may not be sufficient. The presence of murrum or rock layers beneath the planting sites can impede the growth of these deep-rooted trees.

To create more substantial and deeper soil volumes for root development, a technique involving controlled micro-blasting specific to the site was introduced. This method involves shattering and fragmenting approximately 1.0 cubic meter of murrum below 1 m depth at the planting site. The micro-blasting releases energy, resulting in the fragmentation of the rock into smaller pieces and displacing it. Since these soils are highly porous, rainwater infiltrates rapidly and reaches the blasted site. However, due to the impervious nature of the surrounding murrum or rock layers, the water is unable to percolate further.

The presence of these crushed and fragmented murrum or rock pieces in the soil not only facilitates subsurface water harvesting (SSWH) but also allows fruit trees to access water during critical periods, such as the dry summer months and droughts. This technique offers advantages over conventional methods like storing harvested runoff water in farm ponds, where significant losses occur due to evaporation and seepage, leading to lower water use efficiency. This approach overcome the challenges of shallow and gravelly soils by utilizing larger pits or trenches and employing controlled micro-blasting to promote deeper root penetration and enhance water access for fruit trees. This innovative method aims to increase water storage capacity and minimize water loss, ultimately improving water utilization efficiency in fruit orchards.

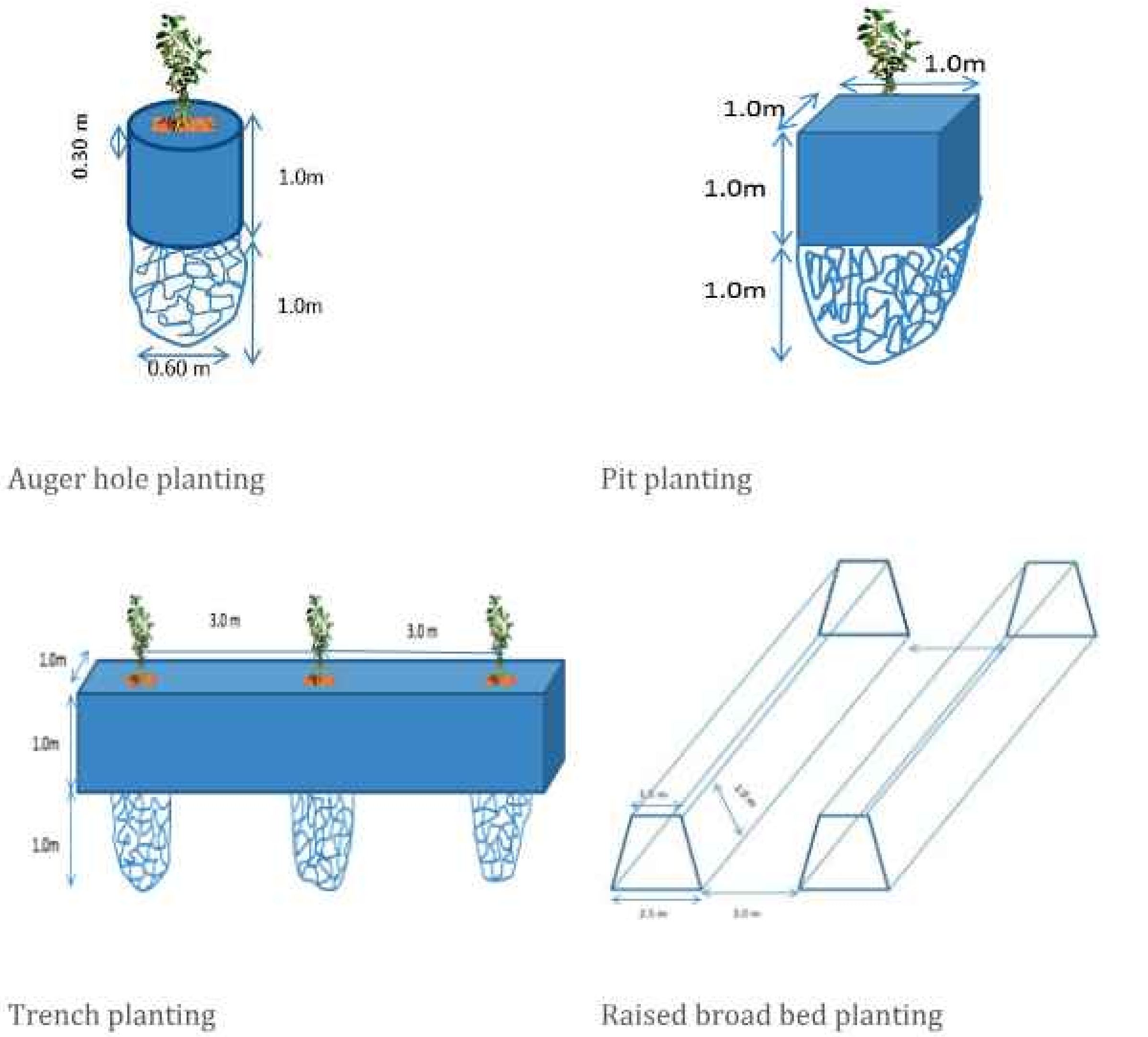

Fig. 1. Schematic diagram of various planting methods adapted for establishing orchards

All of the previously mentioned approaches, including the use of auger bore holes (0.6m in diameter and 1.0m deep), larger pits (1.0m x 1.0m x 1.0m), and trenches (1.0m x 1.0m x the length of the planting row), have been implemented in conjunction with subsurface water harvesting (SSWH) involving controlled blasting below the planting sites. These methods have been tested with three different types of fruit trees, each with varying root patterns—pomegranate, guava, and sapota. To further enhance soil moisture and nutrient conditions, two different approaches have been employed. One method involves refilling the planting sites with a blend of native soil and Farm Yard Manure (FYM) in accordance with recommended guidelines. The other approach utilizes equal proportions of native soil, black soil, and FYM. Observations regarding soil water storage have demonstrated significant advantages associated with the SSWH system. This innovative technique has effectively created favorable micro environments characterized by improved water retention and increased soil volume for robust root proliferation.

Consequently, the transplanted fruit seedlings have exhibited superior establishment and growth.

Notably, the most favorable outcomes have been observed when the planting sites were refilled with a mixture containing both native and black soils. This particular approach has the potential to substantially enhance soil quality, better water-holding capacity, and contribute to the successful cultivation of fruit trees. This is especially valuable in regions where challenging soil and water conditions pose significant obstacles to successful orchard establishment and growth.

2. Raised Bed Planting/Mounding with Stone Pitching

An alternative method for expanding the root volume in shallow soils is to create raised beds by scraping the surface soil. The typical raised beds for planting fruit trees have a height of about 0.5 meters. Whereas in arid basaltic conditions, it is recommended to use broader raised beds with a width of 1.5 m and a minimum height of 0.8 to 1.0 m. These larger raised beds provide a sufficient amount of loose and friable soil, ideal for root growth.

To increase the soil volume for constructing these ridges, the process of scraping can be preceded by ripping the soil. The wide furrows formed in between the two raised beds can be effectively utilized for the in situ conservation of runoff rainwater. This structure is particularly well-suited for fruit trees like mandarins and limes, which have surface feeder roots that extend to a depth of about 1.0 meter. One of the advantages of these raised beds is that they eliminate the need for heavy machinery to penetrate the underlying murrum or basaltic rock and its fragmentation, which is often required for cumbersome trenching or deeper pits. However, one drawback of raised beds is the larger exposed surface area, which can lead to increased water losses through evaporation and runoff.

To mitigate these water losses and promote soil health, mulch can be applied. Although crop residues may not be readily available, an alternative approach involves spreading gravel and covering it with a thin black polythene sheet. This has shown promising results, as demonstrated by the vigorous growth of mandarin trees transplanted using this method about a year ago. In summary, creating wider raised beds with sufficient height in arid basaltic conditions provides loose and friable soil for fruit tree root growth. These beds are advantageous in terms of ease of construction compared to deeper pits but may require water-saving measures such as mulch to minimize evaporation and runoff. Overall, this approach appears to be a promising solution for improving fruit tree cultivation in shallow and arid soils.

Cost of development

Cost of Cultivation Lakh Rs/ha	With Blast (With filling mixures)			Without blast (with filling mixtures)		
	100 % Black soil	50 % Black soil	100 % Native murrum soil	100 % Black soil	50 % Black soil	100 % Native murrum soil
Auger Planting (60 cm iameter)	3.25	3.00	2.50	2.25	2.00	1.75
Pit Planting (1x1x1 m)	4.25	3.50	2.75	3.50	2.75	2.00
Trench planting 0.75 m x 1m	7.25	5.50	3.75	6.50	4.75	3.00

Ripping and chaining with heavy machineries

Making pits with Pokhlain/JCB

Making pits with post hole digger

Preparing for microblast

Inserting catridges for microblast

Micro blasting in pits

Depth of auger pit after blasting

Depth of normal pit after blasting

Filling pits with different soil mixtures

Performance of pomegranate orchard

Nagpur mandrain established on raised beds

Nagpur mandrain established on raised beds

Fig. 2. Photos showing different steps in establsihemnt of orchards

Conclusion

The innovative techniques developed for establishing orchards in shallow basaltic soils hold great potential and should indeed be evaluated on a larger scale in the shallow basaltic regions of Maharashtra and other states across India. Scaling up and implementing this technology can have a significant positive impact by expanding the cultivation of horticultural crops and delivering substantial benefits to farmers.

Here are some key points to consider for the evaluation and implementation of these techniques on a larger scale:

1. Field Trials and Demonstrations: Conduct extensive field trials and demonstrations in various regions with shallow basaltic soils to validate the effectiveness of these innovative techniques under diverse climatic and soil conditions.
2. Knowledge Transfer: Share the knowledge and best practices gained from these trials with local farmers through workshops, training programs, and agricultural extension services to ensure widespread adoption.
3. Customization: Tailor the techniques to suit specific regional requirements and crop preferences, as different areas may have unique soil profiles and cropping patterns.
4. Government Support: Seek support and collaboration from government agricultural departments and agencies to promote the adoption of these methods through subsidies, incentives, and policy initiatives.
5. Research Collaboration: Collaborate with agricultural research institutions and universities to further refine the techniques and gather scientific data on their performance.
6. Monitoring and Evaluation: Continuously monitor and evaluate the outcomes of orchards established using these methods, including factors like crop yield, water savings, and economic benefits.
7. Awareness Campaigns: Launch awareness campaigns to educate farmers about the advantages of these techniques in terms of water conservation, soil improvement, and increased crop productivity.
8. Sustainability: Emphasize sustainable practices in orchard management to ensure the long-term health of the soil and environment.
9. Scaling Up Production: Encourage the production of necessary inputs such as planting materials, organic matter, and soil amendments to meet the increased demand resulting from the expansion of horticultural cultivation.
10. Market Access: Facilitate market access for the increased horticultural produce, possibly through the establishment of cooperatives or improved transportation and distribution networks.

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Quantification of ecosystem services from agroforestry systems

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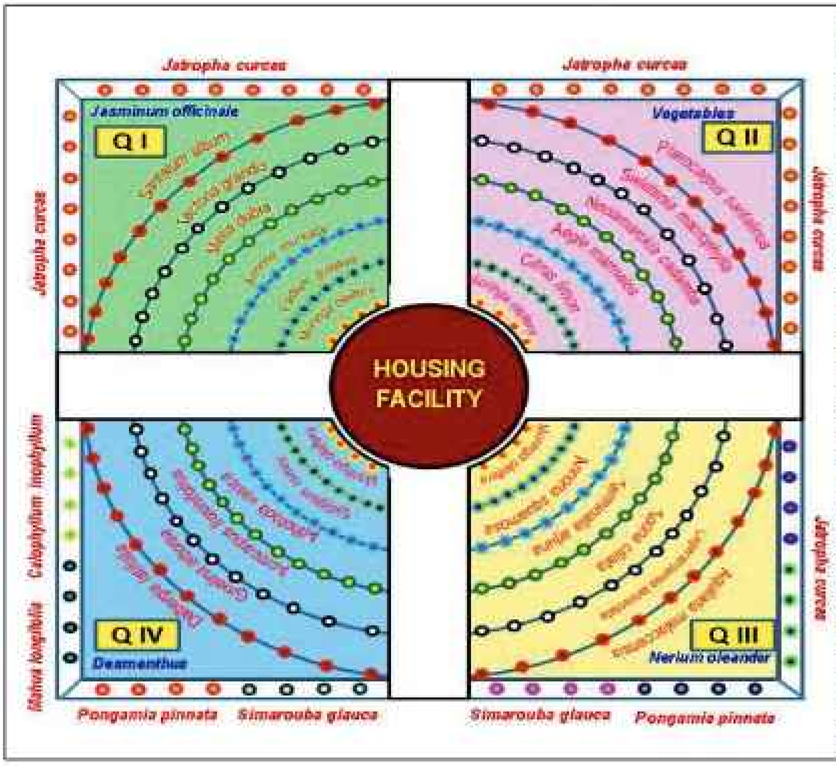
Introduction

Ecosystem services are defined as *'the set of diverse ecological functions that are essential to human welfare'* or *'Conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfill human life'* (Daily, 1997). In other words, it is the '*direct and indirect contributions of an ecosystem to the human well-being* (TEEB, 2009). The Millennium Ecosystem Assessment (MEA) has highlighted that approximately 60 percent, or 15 out of 24 ecosystem services, are facing degradation or unsustainable use due to agricultural management and various other human activities. This assessment has introduced a globally recognized classification that underscores the connection between ecosystem services and human well-being, categorizing them into four types: i) Provisioning services, ii) Regulating services, iii) Supporting services, and iv)Cultural services (Haines-Young and Potschin, 2009). Despite the demonstrated role of agroforestry in generating these ecosystem services, economic analyses pertaining to non-market services and potential trade-offs are either limited or absent (Jose, 2009).

Agroforestry systems serve as a prime example of agroecological land-use systems and are characterized as landscape units that integrate elements of both agriculture and forestry. This includes the deliberate cultivation and utilization of trees in agricultural settings (Van Noordwijk, 2019). The diverse array of benefits and services provided by various agroforestry systems has been acknowledged as a valuable means of enhancing the livelihoods of people worldwide (Chavan *et al.,* 2015). Moreover, the concept of agroforestry has attained changes in each and every decade since 1970's. At present, agroforestry is seen as a multidimensional tool for transforming lives and landscapes in terms of improving income and food security (Parthiban *et al.*, 2021). The term 'Multifunctionality' was first introduced at Rio Earth Summit, 1992 and further it was developed in 1998. Multifunctionality means the simultaneous provision of diverse outputs and its benefits to society. In other words, it is the ability of an ecosystem to deliver multiple functions or services simultaneously.

On a global scale, agroforestry is practiced by approximately 1.2 billion people, as reported by the World Bank (2004). These practices cover about 10 percent of the total agricultural lands, which amounts to more than 1 billion hectares, as indicated by Zomer et al. (2016). The diversity of agroforestry systems that has evolved over time in various ecological zones is a testament to the accumulated knowledge and adaptive strategies of countless smallholder farmers, especially in the face of changing climate scenarios. The most prominent example of multifunctional agroforestry is 'home gardens' that promote food security and diversity, production of wood and food crops, carbon stocks, bio drainage plantations, domestication of local fruit trees, conserving biodiversity, providing employment opportunities and income generation through value addition and sustaining the livelihood of people (Dagar and Yadav, 2017). Therefore, in the twenty-first century, multifunctional agroforestry systems are essential and at the same time developing new multifunctional agroforestry models are necessary to maximize food production and also to serve as a host for various ecosystem services. Therefore, studies on ecosystem services from multifunctional agroforestry system were carried out at Forest College and Research Institute between 2018 and 2021. The circular shaped multifunctional agroforestry comprises of 25 different tree species and 8 intercrops covering an area of 0.75 acre divided into four equal quadrats was established and deployed for the current study (Fig 1). The main objective of the study is to quantify ecosystem services *viz*., provisioning, regulating, cultural and supporting services from multifunctional agroforestry.



Tree species	Number of trees
Quadrat I	
Moringa oleifera	4
Psidium guajava	10
Annona muricata	11
Melia dubia	11
Tectona grandis	12
Santalum album	12
Intercrops (Flowers)	
Jasminum officinale	72
Jasminum grandiflorum	104
Quadrat II	
Moringa oleifera	4
Citrus lemon	6
Aegle marmelos	11
Neolamarckia cadamba	11
Swietenia macrophylla	11
Pterocarpus santalinus	12
Intercrops (Vegetables)	
Quadrat III	
Moringa oleifera	4
Annona squamosa	10
Terminalia arjuna	10
Toona ciliata	11
Lagerstroemia lanceolata	12
Aquilaria malaccensis	12
Intercrops	
Nerium oleander	28
Murraya koenigii	250
Quadrat IV	
Moringa oleifera	4
Syzygium cumini	11
Adhatoda vasica	12
Artocarpus heterophyllus	13
Gmelina arborea	12
Dalbergia latifolia	12
Intercrops	
CO 1 Guinea grass	301
Desmanthus	
Bunds	
Jatropha curcas	30
Calophyllum inophyllum	5
Simarouba glauca	10
Pongamia pinnata	10
Madhuca longifolia	5
Total plants	1174

Fig 1: Field view of multifunctional agroforestry

Provisioning services were quantified in kilograms or tonnes by the market price method. Under **regulating services**, micro-climatic regulation was monitored using a micro-climatic senor kit and climatic regulation *via* the non-destructive method of carbon sequestration. **Socio-cultural services** were done through a set of questionnaires and the willingness to pay method. In **support services**, litter decomposition studies were carried out through the litter bag technique and butterfly diversity was estimated using the pollard walk method. The economic valuation of ecosystem services for present and future projections was also calculated.

Multifunctional agroforestry recognizes agroforestry as a synergestic association of several diversified production systems, characterized by intensive, integrated, integrative and intentional means of a sustainable land-use system for maximizing the provision of ecosystem services. (Sahoo *et al.*, 2020; Doddabasawa and Chittapur, 2021). The results revealed that the provisioning services delivered multiple outputs timber/wood, food, fodder, flowers, fruits, fodders, medicinal plants and tree borne oil seeds) and also generated more income at the end of the study period. Concerning on-farm benefits in the current study, among 12 timber species, 20 per cent of the biomass was contributed from *Neolamarckia cadamba*, 18 per cent of biomass from *Melia dubia*, 12 per cent from *Lagerstroemia lanceolata* and 10 per cent from *Tectona grandis.* Within three to six months of development, the annual crop components begin to yield income, and after one year, the entire model becomes fully operational, generating income on a monthly basis for the growers. This approach produces multiple outputs, providing resilience even in unfavourable climatic conditions. Diversified cropping systems are the sustainable options that can benefit the soil and also supply organic matter; however the amount and delivery of nutrients vary with cropping pattern and mixtures grown in a field. The available N,P,K varied significantly among different quadrats of multifunctional agroforestry. Nevertheless, the values obtained for NPK varied among different depths which may be due to the presence of different tree and cropping mixtures followed in the study. The available nitrogen was high in quadrat II and III at 0-20 cm depth and this is attributed to the application of fertilizers. In the present study, the air temperature in different circles of multifunctional agroforestry shows a reduction of- 1 to 2^{o}C which was prominent in summer when compared to an open area. The temperature variation was found to be moderated by the presence of trees in multifunctional agroforestry. Higher light intensity (lux) was recorded in the open area when compared to different circles of multifunctional agroforestry. Significantly higher biomass and carbon stock followed the order of *Neolamarckia cadamba* > *Melia dubia* > *Lagerstroemia lanceoalata* > *Dalbergia latifolia* > *Tectona grandis.* The total change in soil organic carbon stock over three years (2018-2021) was 32.05 Mg ha^{-1} and 11.55 Mg $quadrat^{-1}$ respectively.

Among different indicators of socio-cultural services, education and scientific knowledge ranked foremost followed by relaxation and walking. The willingness to pay depicted an average of Rs.33 per visit per respondent. The multiple linear regression analysis indicated that multifunctional agroforestry is a good fit (R^2 = 0.79) for studying cultural services. Under support services, the worked-out decay constant (k) in litter decomposition followed the order of *Neolamarckia cadamba* < *Tectona grandis* < *Annona muricata* < *Moringa oleifera* < *Lagerstroemia lanceolata* < *Terminalia arjuna*. The results from correlation analysis indicated that the initial negative correlation with leaf litter lignin content and lignin: nitrogen ratio was a good predictor for the decomposition process. A total of 37 butterfly species were sighted during the entire study period belonging to three families *viz.*, Nymphalidae, Pieridae and Papilionidae indicating the supporting services of multifunctional agroforestry.

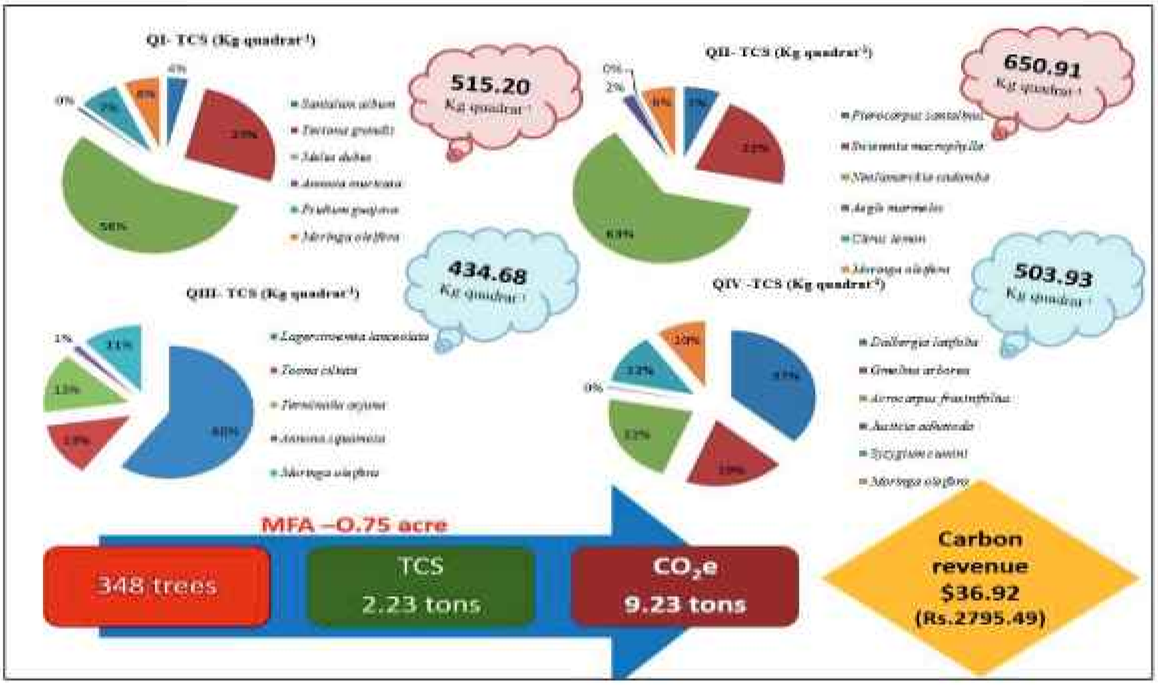


Fig 2: Quadrat wise carbon stock in multifunctional agroforestry

Holistically, in three years (2018-2021), the monetary value of ecosystem services from multifunctional agroforestry was INR 374211.42/-. In a holistic analysis, the multifunctional agroforestry model designed and evaluated through the current study indicated a significant impact in extending provisional, regulating, cultural and supporting services. The study identified that the positive impact was due to the species diversity coupled with enhanced productivity and improved soil health. The study recommends the promotion of this multifunctional agroforestry model across different land-use systems in the country to create sustainable income and employment generation activities, particularly in small and marginal land-use systems. The protocol and procedures established in the current study for quantification of various ecosystem services will help the agroforestry researchers to replicate in other agroforestry systems; thereby the study extends greater scope of adoption and replication across the country.

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Climate resilient integrated farming system in scarcity regions

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Introduction

The division of land resources and the reduction in the total cultivated area pose a serious threat to the future sustainability and food security of Indian agriculture (Siddeswaran et al. 2012). Various factors like increasing input costs, diminishing water resources, soil degradation, imbalanced fertilizer usage, excessive pesticide application, and the impact of climate change all contribute to challenges within the agricultural production system (Paroda 2012). Marginal and small-scale Indian farmers who primarily engage in monoculture face heightened vulnerability to climate fluctuations, including floods, droughts, and hailstorms. The global implications of climate change are dire, as it jeopardizes agriculture, food security, and the livelihoods of countless individuals. This shift in climate patterns, characterized by erratic rainfall, water scarcity in arid regions, rising temperatures, and alterations in the frequency and severity of extreme weather events such as floods and droughts, will significantly affect worldwide agriculture. This will result in reduced productivity, profitability, and employment opportunities (Kakamoukas et al. 2021). Consequently, farmers must adapt to the changing climate by developing innovative and sustainable farming practices. The term "climate-smart agriculture," as defined by Lipper et al. in 2014, refers to agricultural strategies that enhance productivity, bolster adaptability, reduce greenhouse gas emissions, and facilitate the achievement of national food security and development objectives.

Integrated farming systems are pivotal in sustainable agriculture because they minimize waste and the byproducts of one component can serve as inputs for another. This holistic approach to farming diversifies production, leading to increased income for farmers, improved quality and quantity of food production, the utilization of underutilized resources, and support for small-scale farmers with limited land for crop cultivation (Gupta et al., 2012). Integrated Farming Systems (IFS) strive to meet the needs of farmers while coexisting harmoniously with the environment, maintaining ecological and socioeconomic equilibrium, achieving high productivity with efficient recycling of organic wastes and residues, and enhancing nutrient management (Solaiappan et al., 2007).

Methodology for development of Climate smart IFS (CIFS) model

The methodology for developing Climate-Resilient Integrated Farming Systems (CIFS) involves a systematic approach to enhance agricultural sustainability and resilience to climate change. The following are the steps involved in this methodology:

1. **Survey of Local Area**:

   Begin by conducting a comprehensive survey of the local agricultural area to understand the prevailing conditions, including climate, soil types, and existing farming practices.

2. **Characterization of Existing Farming Systems:**

   Analyse and characterize the existing farming systems in the area to identify their strengths, weaknesses, and resource utilization.

3. **Assessment of Resources Available with Farmers:**

   Evaluate the resources available to local farmers, such as land, water, labor, and capital, to determine the potential for integrated farming.

4. **Identification of Production Gaps:**

   Identify component-wise production gaps within the existing farming systems, pinpointing areas where improvements are needed.

5. **Constraints Analysis:**

   Analyse the constraints and challenges that hinder achieving optimum production levels, including biotic and abiotic stress factors.

6. **Selection of Resilient Components:**

   Choose farming components (crops, livestock, aquaculture, etc.) based on their ability to tolerate abiotic stresses and adapt to local conditions, aiming for climate resilience.

7. **Diversification:**

   Promote diversification in the components and within the components to reduce risk and enhance overall sustainability.

8. **Optimization of Component Sizes:**

   Determine the ideal sizes of different components to maximize resource efficiency and reduce dependence on external inputs from the market.

9. **Sustainable Resource Management:**

   Emphasize the efficient recycling of available resources within the farming system, minimizing external inputs, and adopting sustainable management practices.

10. **Climate-Smart Technologies and Indigenous Traditional Knowledge (ITKs):**

    Incorporate proven climate-smart technologies and indigenous traditional knowledge to manage the various components effectively.

11. **Continuous Assessment:**

Continuously monitor and assess the performance of individual components within the integrated farming system. Modify component sizes and practices for higher productivity and income based on performance data.

Fig. 1. Selection of crop and cropping systems in CIFS model.

Selections of components

First, there is need of thorough understanding on existing farming systems of a particular region by surveying the local area and also with the help of available secondary agriculture data related to their socio-economic status of farmers, production status of components, existing constraints and production gaps of crop, livestock, horticulture components and other allied components. Selection of abiotic stress tolerant crops, crop varieties, livestock and their species, horticulture crops varieties is one of the crucial steps for ensuring optimum productivity in climate smart integrated farming system. The primary objective of selection of components should be climate resilience and achieving sustainable productivity under abiotic stress regions. The selection of enterprises must be based on the fundamental principal of minimizing the competition and promoting complementarity between the enterprises (Mynavathi et al., 2015).

Optimizing the size of CIFS components

Optimizing the size of components within a Climate-Resilient Integrated Farming System (CIFS) is crucial for ensuring minimal competition and maximizing complementary effects among the selected components. The size of individual components should be designed to meet the nutritional requirements of the farm household. This includes producing enough food for the family's consumption and ensuring an adequate supply of fodder for livestock. It's important to generate cash income from the farming system to cover personal expenses and other financial needs of the family. This cash income can come from selling surplus produce in the market. The primary objective is to increase sustainable agricultural income for the farm household.

This involves optimizing resource allocation to maximize overall income while maintaining environmental sustainability. To achieve these objectives and make informed decisions about component sizes, linear programming techniques can be employed. Linear programming is a mathematical approach that helps in finding the best allocation of resources to achieve specific goals while adhering to constraints. Linear programming determines the optimal mix and size of crops, livestock, and other components within the farming system. Maximize overall income while considering resource limitations and constraints. Balance the production of food, fodder, and cash crops to meet household needs.

Diversification of components and within components

The diversification of components and within components should be done to minimize the risk of crop failure and increase the chances of sustainable income for the farmers. Crop diversification with livestock mitigates the effect of aberrant weather conditions such as early or late season drought, dry spells, moisture stress and provides stable and sustainable production system. Crop diversification helps in fulfilling the requirements of farm family such as food, nutrition and economic stability. In the same way rearing diversified livestock species and horticultural crops will help in getting income from livestock component in CIFS. For example, if diversified rearing of livestock species such as dairy animals, goat and poultry are carried out then due to any problems, if there is loss in dairy animals, income from goat and poultry can be obtained, if there is loss in poultry component, income from dairy animals and goat can be obtained. If, there is loss in goat component income from dairy animals and poultry can be obtained by the farmers.

Adoption of climate smart technologies for mitigation of climate change

Scientifically proven technologies and innovative approaches must be embraced to counteract the adverse impacts of abiotic stresses on individual components or entire systems, thereby promoting sustainable productivity and profitability. Various strategies, such as enhancing plant resilience to heat, drought, and nutrient stress, improving nutrient and water efficiency in crops, and employing high-yielding, dwarf varieties rather than traditional crops, can effectively alleviate the repercussions of climate change. Additionally, a combination of agro-forestry, alley cropping, intercropping, and perennial forages offers diverse options for reducing climate change's impact by enhancing carbon sequestration and nutrient availability (Bell et al., 2014). The adoption of micro-irrigation, renewable energy sources, bio-fertilizers, bio-pesticides, integrated pest management (IPM) techniques, and organic farming practices within the context of Climate-Resilient Agriculture (CIFS) can mitigate the detrimental effects of climate change.

Fig. 2. Micro-irrigation in crop component in CIFS model.

Sustainable income through IFS

Indeed, integrated farming systems (IFS) offer several advantages, including sustainable and higher net income, and can significantly benefit small and marginal farmers. IFS promotes the efficient use of resources by recycling byproducts and residues within the system. This reduces input costs, especially for critical inputs like fertilizers, pesticides, and herbicides. It contributes to sustainability by minimizing waste and environmental impact. IFS encourages the flow of resources within the farming system, optimizing resource utilization. Integrated pest management (IPM) practices within IFS reduce the reliance on chemical pesticides, promoting environmentally friendly and cost-effective pest control. IFS incorporates various components, including crops, livestock, fruits, vegetables, and forage. This diversification of income sources ensures that farmers have alternative income streams, which can provide financial stability during times of crop failure or market fluctuations. IFS is a sustainable approach that not only enhances economic returns but also helps maintain the long-term health of the farm ecosystem. It contributes to soil health, biodiversity, and overall farm resilience. For small and marginal farmers, IFS can serve as a major livelihood option. It enables them to make the most of their limited resources and land, thereby improving their economic prospects and reducing their vulnerability to income fluctuations. In the Indian context, where the goal is to double farmers' income, IFS plays a pivotal role. By optimizing resource utilization and income generation, IFS aligns with the government's initiatives to improve the economic well-being of farmers.

Crop+ Dairy is the predominant farming system in India. Integration of livestock with crop will provide higher income than single crop component. Kadian et al. (1992) reported that the net return from IFS was higher with integration of buffalo, cow and cropland enterprises. Deoghare and Bhattacharya (1993) reported that, in semi-arid tropics the most important source of income was selling of goat and sheep and contributed to 30% of total farm income in India. Goat rearing alone contributed 59% share in total income obtained through IFS. Cropping system including sorghum and cowpea is more beneficial if integrated with buffaloes for obtaining milk yield. Crop+ fish+ cattle integration was found maximum beneficial in terms of productivity (Jayanthi et al., 2003). Vinodakumar et al. (2017), reported that Crop+ Goat+ Cow+ Poultry+ Fishery IFS model gave higher net returns than conventional cotton alone which may be due to livestock component generating regular income for the farmer. Fishery based farming system provides more profit because of its market demand. Jagadeeshwara et al. (2011), stated that 26.3% higher productivity can be obtained from IFS than conventional system. Integration of stress tolerant breeds of cattle, goat and poultry, innovative fish production system, improved feed and fodder production, silage making at field level, improved shelters for preventing heat stress in livestock and preventive vaccinations on time are the major factors for obtaining sustainable income through livestock (Gulshan Kumar and Hem Chander, 2018).

One of the major advantage of livestock rearing in IFS is that they can be feed with the crop residues generated in farm itself reducing the cost of their feeding. Introduction of improved forage species enhances sustainability of system species. Forage not only provide feed to the livestock but also increases soil fertility by enhancing nutrient and organic matter levels. The byproducts of livestock can be used for aquaculture supplementation reducing the cost of rearing. Manure from 5-6 cows is sufficient for 1 ha of pond and in addition to 9000 kg milk, about 3000-4000 kg fish $ha^{-1}year^{-1}$ can also be harvested (IFM, 2015) and thus provides additional and sustainable income to farmer.

To achieve food and income security, it is necessary to grow drought and stress tolerant crops such as millets, short-duration pulses, vegetables and root crops (Rufino et al., 2013). For dryland areas, the crop varieties should be of short duration and can produce good yield under limited soil moisture conditions. As crops and related enterprises are intensified under IFS, the yield and productivity per unit area can be increased. The yield of different cropping systems maximizes under IFS when applied with recycled poultry manure, goat manure, cattle dung and vermicompost.

Climate resilient integrated farming system model was developed at ICAR-NIASM. The model consists of crop, livestock, fisheries, horticulture and agro-forestry components. The overall cost of cultivation, gross income and net income in CIFS were

Rs.227395, Rs.369265 and Rs.141870 respectively. The B:C ratio was 1.62 in second year (2021-22) of experiment.

Table 1: Economics of different components in CIFS

CIFS Components	Cost of Cultivation (Rs.)	Gross Income (Rs.)	Net Income (Rs.)	B:C Ratio
Crop	38913.05	50720	11806.95	1.28
Livestock	173627	293787.4	120160.4	1.82
Fishery	14855	24758.5	9903.5	1.67
Total	227395.05	369265.9	141870.85	1.62

Resource use efficiency in IFS

Resource use efficiency is using the limited resources in a sustainable manner while minimizing the impacts on the environment. At farm level some resources may be under-utilized or over-utilized but the best use of available resources defines and improves the system's resource use efficiency and increases sustainability (Archana et al., 2022). In IFS, recycling of farm wastes into nutrient rich manures reduces near about 36% use of chemical fertilizers and in addition it also improves soil organic carbon, macro and micronutrient contents in soil (Singh et al., 2012). According to Reddy et al. (2020), there was an increase in organic carbon, available nitrogen (N), available phosphorus (P), and available potassium (K) by 0.06%, 4 kg/ha, 1 kg/ha, and 4 kg/ha, respectively, after three years of implementing Integrated Farming System (IFS) practices compared to the initial values. Manure, poultry waste, crop stubbles, compost generated through waste recycling of farm residues increases the soil health by improving soil aggregation, soil structure, nutrient availability and microbial growth. Agroforestry system, biomass of fruit crops and green manuring improves carbon stock and soil quality (Paramesh et al., 2019). Excreta from farm animals can be used for the production of biogas and energy and this fuel can replace charcoal and wood (Singh et al., 2022). In IFS, the waste product of one enterprise can be a best input to other enterprise, hence the cost of production as well as the cost of maintenance is lower as compared to conventional farming. This reduces the dependency of farmer on external inputs and thereby also increases resources efficiency within the system. Poultry raising not only provide meat and eggs but also their excreta can be used to fertilize the fishpond. IFS utilizes every part of land. The land which is not suitable for crop production can be utilized for livestock rearing, border of cropping systems can be used for fodder and trees plantation which will not only provide fodder but also enriches soil by fixing atmospheric nitrogen.

Fig. 3. Nutrient recycling through vermicomposting in CIFS model.

The long-term sustainability of the resource base is negatively impacted by excessive and unbalanced use of input which also lowers system net gain. Resource use efficiency in IFS is enhanced through the synergistic use of natural and man-made resources, reducing competition and stress within the system (Sing et al., 2020). It's noteworthy that around 58% of the total production cost can be offset by the farm itself through the systematic recycling of resources generated on the farm, further improving resource use efficiency (Singh et al., 2018). Maximum utilization of land with Agro-horti and Agro-forestry system, use of farm by-products for preparation of vermicompost and manure and efficient use of labor and employment generation. The various components of IFS have potential for employment generation. 400-man days were employed by crop production alone whereas, in an integrated farming system with six buffaloes 904-man days were employed (Pandey and Bhogal, 1980). Under rainfed vertisols, the IFS with crop + goat provide additional employment to about 314 man-days ha^{-1} $year^{-1}$ (Radhamani et al., 2001). A herd of 200 goats gave a year-round full-time employment for 2 persons under IFS (Ramasamy et al., 2007). The use efficiency of water can be increased by in-situ moisture conservation, rainwater harvesting and recycling for further irrigation, conservation tillage, mulching and cover crops to reduce evapotranspiration rate (Gulshan Kumar and Hem Chander, 2018). Each enterprise in IFS is complementary to the others, hence there is increase in the resource use efficiency with a minimum amount of input wastage.

Fig. 4. Horti-pastoral system in CIFS model

Table 2 and 3 illustrate the nutrient recycling and livestock water productivity within the context of the Climate-Resilient Agriculture (CIFS) project. The combined nutrient recycling from various sources in the CIFS project, including farm yard manure, goat manure, poultry manure, vermicompost, and vermi-wash, amounted to 157.21 kg of Nitrogen, 66.5 kg of Phosphorus, and 170.52 kg of Potassium. The utilization of these recycled nutrients not only enhances crop yields but also reduces the need for synthetic fertilizers, leading to an overall increase in net returns.

Table 2: Nutrient recycling through different sources in CIFS

Nutrient Recycling	Quantity (Kg)	Nutrients	Nutrient Supply (kg)
FYM (Kg)	8760	N	43.8
		P	17.52
		K	43.8
Goat manure (Kg)	5840	N	90.52
		P	37.96
		K	113.88
Poultry manure (Kg)	150	N	3.75
		P	2.4
		K	2.25
Vermicompost (Kg)	1143	N	18.288
		P	8.001
		K	9.144
Vermiwash (Kg)	164	N	0.8528
		P	0.574
		K	1.148

Table 3: Water productivity in Livestock in CIFS

Livestock	Water productivity (Rs/m3)	Water productivity for (unit /m3)
Cattle	15.22	Milk-0.223
Goat	13.49	Meat-0.033
Poultry	42.12	Eggs-2.45
		Poultry (live weight)-0.14

Fig. 5. Improving the water productivity in CIFS model

In the Climate-Resilient Agriculture (CIFS) project, the water productivity for cattle, goat, and poultry was measured at 15.22 Rs/m3, 13.49 Rs/m3, and 42.12 Rs/m3, respectively. Furthermore, the water productivity for specific livestock products, measured in units per cubic meter (unit/m3), was as follows: 0.223 for milk, 0.033 for meat, 2.45 for poultry eggs, and 0.14 for poultry live weight. It's crucial to note that water scarcity poses a significant challenge in livestock farming. One approach to address these challenges, as suggested by Haileslassie et al. (2009), is to enhance Livestock Water Productivity (LWP). Many small-scale farmers have limited resources, so improving the efficiency of resource utilization is of paramount importance. The Integrated Farming System (IFS) approach, which involves diversifying agricultural activities to maximize profits per unit of time and land area, empowers farmers to enhance their resource efficiency, reduce reliance on external inputs, and attain sustainable income levels.

Conclusion

The Climate-Resilient Integrated Farming System (CIFS) approach offers numerous benefits and is indeed a viable strategy for small and marginal farmers. CIFS promotes resource conservation through efficient recycling of crop and animal waste, minimizing resource wastage, and optimizing resource utilization. By integrating crops, livestock, and other components, CIFS reduces the need for inorganic fertilizers, lowering input costs and environmental impact. The diversified components within CIFS ensure a steady income throughout the year, reducing income fluctuations associated with single-crop farming. CIFS fulfils the nutritional demands of the farmer's family, ensuring access to a variety of food items. CIFS contributes to environmental protection by reducing pollution, mitigating greenhouse gas emissions, and promoting sustainable land management practices. By increasing organic matter and carbon stock in the soil, CIFS improves overall soil health and fertility, leading to better crop yields. CIFS helps farmers adapt to climate change by diversifying income sources and promoting practices that reduce climate-related risks. It offers small and marginal farmers an opportunity to increase their income and improve their standard of living, aligning to enhance rural livelihoods. To effectively promote the adoption of CIFS and maximize its impact, the development and demonstration of CIFS models tailored to different landholding sizes and agro-ecological regions is essential. These models should be adaptable and scalable to suit local conditions. Policymakers, rural development agencies, and extension services need to work in close coordination to disseminate CIFS technology to farmers. This collaboration can help ensure the sustainable income and resource efficiency of farming communities.

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Dragon Fruit- prospects and production techniques in India

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Introduction

The Dragon fruit, scientifically known as *Hylocereus* spp. (Haworth) Britton & Rose, belongs to the Cactaceae family. It is a perennial epiphytic vine cactus. Its genus name, *Hylocereus*, is derived from the Greek word "hulos," which means "forest," alluding to its natural habitat, and it also signifies its ability to withstand drought due to the waxy cereus covering on its stems. Dragon fruit has gained global acclaim, initially as an ornamental plant and later as a fruit crop. Its exquisite flower has earned it various nicknames, including "Noble Woman" and "Queen of the Night." In different countries, this fruit goes by several names, such as Pitaya, Dragon fruit, Dragon pearl fruit, Queen of the Night, Strawberry pear, Buah naga, and Zunlongguo. Gunasena et al. (2007) categorized the various edible cacti species based on their stem habit, fruit skin, and pulp colour (Table 1).

Table 1. *Hylocereus* species and their respective fruit skin and pulp colours:

Species	Fruit skin color	Fruit pulp color
Hylocereus undatus	Pink	White
Hylocereus undatus, H. costaricensis, H. polyrhizus	Pink	Pink, Red
H. ocamponis	Yellow	Red
H. megalanthus	Yellow	White

Uses:

Dragon fruit is gaining popularity as a super fruit due to its abundant nutrient content and antioxidant properties (Vaillant et al. 2005). This versatile fruit serves both table and processing purposes. With its vibrant bracts, deep red flesh, and edible tiny black seeds nestled in white flesh, dragon fruit is a preferred choice for salads. Furthermore, value-added products such as juice, jam, jelly, candy, syrup, and wine can be crafted from dragon fruit pulp. The fruit peel is a rich source of pectin, and various methods have been documented to yield as much as 7.5% of pectin from the fruit peel. This pectin can be utilized as a food colouring agent and a raw material for the food colour industry (Gao-Xi and Wan, 2004). Pitaya seeds are particularly noteworthy, containing 50% essential fatty acids, specifically linoleic acid and linolenic acid.

Composition and nutrients of dragon fruit:

To et al. (2000) conducted a comprehensive analysis of the composition of the endocarp of red dragon fruit from various samples in Vietnam. They provided average values for different components, vitamins, and minerals in red dragon fruit, with the fruit weighing approximately 394 grams, as presented in the below table.

Test	Average value (g/100 g edible portion)	Test	Average value (g/100 g edible portion)
Moisture	85.30	Vitamin C	3.0
Crude protein	1.10	Thiamin	Not detected
Fat	0.57	Riboflavin	Not detected
Glucose	5.70	Niacin	2.8
Fructose	3.20	Vitamin A	0.0111
Sucrose	Not detected	Calcium	10.2
Maltose	Not detected	Iron	3.37
Sorbitol	0.33	Magnesium	38.9
Carbohydrate	11.20	Phosphorous	27.5
Crude fibre	1.34	Potassium	272.0
Ash	0.56	Sodium	8.9
Energy	67.70 kcal	Zinc	0.35

Origin and geographical distribution:

The Pitaya, also known as Dragon fruit, originally hails from the tropical and sub-tropical forests of Mexico, Central America, and Northern South America. It is naturally distributed across these regions (Britton and Rose, 1963). Over time, it has been successfully introduced to numerous countries, where it has been cultivated with great success. These countries include Australia, Cambodia, China, Colombia, Ecuador, Guatemala, Hawaii, Indonesia, Israel, Malaysia, New Zealand, Peru, The Philippines, Taiwan, Thailand, Spain, Sri Lanka, and Vietnam. In India, the cultivation of Dragon fruit is a recent development, with a few growers in Maharashtra, Karnataka, and Gujarat states taking up this fruit crop. As of now, Vietnam holds the distinction of being the major producer and exporter of Dragon fruit. The introduction of this crop to Vietnam can be traced back to the efforts of a French priest in the mid-nineteenth century, which successfully acclimatized it to the region's climate, eventually leading to its status as a major fruit crop in the area. Presently, India imports Pitaya fruits from Vietnam and Thailand.

Soil and climate:

Dragon fruit can thrive in a variety of soil types, but it thrives best in well-drained soil, as waterlogging can impede its growth and encourage bacterial rot. Loamy soil enriched with organic matter is optimal for commercial dragon fruit cultivation. The ideal soil pH for dragon fruit growth falls within the range of 5.5 to 6.5. This crop has shallow roots, typically active root zone extending no deeper than 40-60 cm, making soil depth less of a concern for its cultivation. Dragon fruit prefers slightly acidic soil and can tolerate some level of soil salinity. Originating from tropical rainforest regions, dragon fruit cultivation is most successful in areas with ample rainfall. However, over time, this fruit crop has adapted well to regions where rainfall is limited, and it can be grown in arid areas with the aid of micro-irrigation. A rainfall range of 500-1500 mm, appropriately distributed throughout the year, is conducive to its growth. Excessive water can lead to the shedding of flowers and young fruits. The ideal temperature range for dragon fruit cultivation is between 20-30°C. Higher temperatures can cause the stems to turn yellow, and the succulent stem may lose water and wilt (Kakade et al., 2023). In drier and warmer conditions, providing optimal shade is essential. Dragon fruit can be cultivated at altitudes of up to 1700 meters. It is light-loving and can be grown in full sun. However, in areas with exceptionally high light intensity, the necessary shading should be provided to prevent sunburn and flower bud drop.

Varieties:

Currently, the dragon fruit varieties cultivated in farmers' fields in India are primarily imported from other countries. There is no reported evidence of a systematic breeding program for dragon fruit germplasm assessment or varietal evaluation in the country. In India, growers predominantly favour red-pulped dragon fruit varieties.

Planting:

Dragon fruit planting is best carried out during the rainy season, following the onset of the monsoon. The presence of rainwater, high atmospheric humidity, and lower air temperatures during this season facilitates the establishment of dragon fruit without the need for additional irrigation, which is typically required in other seasons. Dragon fruit thrives in open areas with good drainage. Dragon fruit is a semi-epiphytic vine plant that can naturally climb and cling to any suitable support it encounters. Consequently, a support system must be set up before planting. 3-4 dragon fruit plants around pole can be planted. These pits should be filled with topsoil, organic material like farmyard manure, and approximately 200 g of diammonium phosphate. Mop top trellis systems often involve planting four dragon fruit plants around the support structure (Fig. 1). In contrast, Israeli trellis systems, known as wall systems, may not require planting 3 or 4 plants around the support. Following the planting of cuttings, it's important to provide regular watering within basins prepared around the plants to ensure satisfactory rooting.

Spacing:

Different countries and regions have adopted various planting spacing, such as 2.5 × 2 meters, 3 × 1.5 m, 3 × 3 m and 4 × 3 m. When using a vertical support system with 2 to 3 meters of distance between planting lines, it can accommodate around 2000 to 3750 cuttings per hectare, assuming that three cuttings are planted per support (Barbeau, 1990). In contrast, when employing horizontal or inclined supports, a higher planting density is achievable. Cuttings are typically planted every 50 to 75 cm around the production table, accommodating approximately 6500 cuttings per hectare (Bellec and Vaillant, 2011). An alternative spacing strategy involves planting at a distance of 2.5 meters between rows and between individual plants, with 4 cuttings per support. This arrangement can accommodate 6400 plants per hectare and is known to yield good fruit quality and quantity.

Training requirement:

It is a climbing cactus, and successful cultivation necessitates use of support systems or training methods. It's crucial to consider the economic lifespan of nearly 20 years when choosing a support system for dragon fruit. During its productive phase, the plants bear a heavy load of fruit, so the support system must be robust and durable. Cement concrete poles typically 5-6 feet in height, are recommended for supporting the plants (Fig. 1). Wooden poles are relatively weaker and not suitable for long-term use. Various training methods can be employed to guide the cactus vines, including the T-bar system, mop top and vertical trellis system. The mop top trellis system, adopted by many growers worldwide, involves planting four dragon fruit plants around a central support pole and allowing the shoots to bend down. In the vertical trellis system, the shoots are hung on wires at a height of less than 160 centimetres, creating walls with fruit production on both sides. This design facilitates access for growers during pollination and harvesting. Notably, in Mexico, live trees have been used for trellising purposes (Ortiz-Hernandez and Carrillo-Salazar, 2012).

Fig. 1 Support system and planting in Dragon fruit

Water requirement:

Dragon fruit, a member of the Cactaceae family, employs the Crassulacean Acid Metabolism (CAM) pathway, making it highly water-efficient and low in water requirements compared to C3 and C4 crops. Dragon fruit only requires approximately 10% of the water that most other C3 fruit crops like pears, citrus, peaches, avocados, and so on demand (Mizrahi et al. 2007). They recommend an annual irrigation of 120 to 150 mm to meet the water requirements of dragon fruit. Dragon fruit has a very shallow root system which makes excessive water application impractical since most of the water would escape from the root zone. Originally hailing from tropical and sub-tropical rainforests and having shallow roots, dragon fruit's water needs and irrigation frequency are higher compared to other cacti.

Different studies have reported varying quantities of water and irrigation frequency for dragon fruit. For instance, Mizrahi and Nerd (1999) suggested an annual application of 150 mm of water. The daily irrigation rate per plant varies, ranging from 2 litres (Lichtenzveig et al. 2000) or 2.5 litres (Nerd et al. 1999) during the winter season to 4 liters under different agro-climatic conditions (Raveh et al. 1997). Applying smaller amounts of irrigation at shorter intervals is more effective in ensuring proper growth and achieving higher fruit yields. The critical stages are during flowering and fruit enlargement.

Manures and fertilizers:

It is crucial to apply manures and fertilizers judiciously to achieve higher fruit yields with better quality. Different countries have recommended various fertilizer doses for dragon fruit. For instance, in Taiwan, the recommended dose is 100 grams of commercial 13-13-13 fertilizer per plant, combined with 4 kilograms of organic manure at four-month intervals. In Vietnam, for three-year-old mature plants, Tri et al. (2000) suggested an application of 540 g of nitrogen, 720 g of phosphorus, 300 g of potassium, and 20 kg of manure per plant per year, divided into four splits. In the Chittagong Hill Tracts of Bangladesh, Chakma et al. (2014) found that applying 540 g of nitrogen, 310 g of phosphorus, and 250 g of potassium, along with 20 kg of cow dung manure per pillar, resulted in a higher fruit yield of 32 tons per hectare. This same nutrient dose also led to increased fruit numbers and improved fruit size in terms of length, width, and weight. A nutrient dose of 450 g N, 350 g P_2O_5, and 300 g K_2O for each pillar containing four plants to achieve higher fruit yield and better fruit quality. The schedule for nutrient application should align with the plant's growth stages. It is advisable to use soil tests to determine the soil's nutrient deficiencies, which can help optimize fertilizer application, improve crop health, and reduce unnecessary fertilizer expenses.

Split dose	Plant growth stage	N		P_2O_5		K_2O	
		%	g	%	g	%	g
First	Before flowering	10	45	10	35	30	90
Second	Fruit set	20	90	40	140	25	75
Third	Harvesting	30	135	20	70	30	90
Fourth	Two months after harvest	40	200	30	105	15	45
Total percentage and NPK dose		100	450	100	350	100	300

Propagation:

Dragon fruit can be propagated through both sexual (seeds) and asexual (cuttings) methods. However, plants grown from seeds are not true to type and have a longer juvenile period compared to those propagated from cuttings. The most efficient and rapid method of propagating dragon fruit is through cuttings (Fig. 2). Plants produced via asexual methods are true to type and mature more quickly, often starting to flower as early as the second year. A significant impact on root initiation, root numbers, root length, and root growth is observed based on cutting size, the use of rooting hormones, and rooting substrates (Kakade et al., 2019). A cutting size of 25 cm in length yields 100% rooting within the first week, whereas smaller cuttings of 15 cm and 5 cm take longer. The best results in terms of root numbers, length, and growth are achieved with 25 cm cuttings. Using a 10mM IBA quick dip of cuttings for 10 seconds is recommended for optimal rooting. In cases where a large number of cuttings are not available, 5 cm cuttings with a 10mM IBA treatment are efficient for mass propagation. Mature cuttings measuring 15 to 60 cm or entire segments of cladodes with uniform colour should be chosen for multiplication. It's essential to make a clean and sharp cut when separating cuttings from the mother plant. Ideally, cuttings should be separated from the mother plants after the fruiting season. Additionally, dragon fruit can be successfully multiplied through *in-vitro* propagation using areoles from mature plants as explant material. This method can help address the challenge of obtaining a large number of plants by employing tissue culture techniques.

Fig. 2 Propagation of dragon fruit using stem cuttings

Flowering, pollination and fruiting:

The cylindrical flower buds emerge from the margins of the stem and develop into light green flowers. These flowers are large, hermaphrodite, nocturnal, and strikingly showy. Their opening process begins in the evening, typically between 6:30 and 7:30 pm, with full bloom occurring around 10:00 pm. By 2:00 am, the flowers start to close and eventually wilt. Dragon fruit exhibits a pattern of flowering in waves, with the flowering season extending from May to November and sometimes even into December in certain regions (Mizrahi and Nerd, 1999; Pushpakumara et al. 2005). Typically, flowering commences in May and continues until the first week of December, approximately 14 months after planting cuttings, featuring seven major flowering cycles. The number of flushes varies depending on the dragon fruit species, ranging from seven to eight for *H. costaricensis* and five to six for *H. undatus*. A 3 to 4-week interval separates two flowering flushes, allowing floral buds, flowers, young fruits, and mature fruits to coexist on the same plant. It takes 15 to 20 days from the emergence of floral buds to flowering, and fruits are ready to be harvested within 25-30 days after pollination. The pollination of dragon fruit flowers is a critical event as it is essential for fruit production. In many countries where this crop is newly introduced, pollination can be a challenge due to the unavailability of natural pollinators. Dragon fruit flowers, being nocturnal, are naturally pollinated by bats and hawk moths. Other pollinators include honey bees, small honey bees, and rock bees (Pushpakumara et al. 2005). Honey bee pollination tends to result in smaller fruits and reduced fruit set compared to hand pollination (Mizrahi and Nerd, 1999). Hand pollination, though manual and labour-intensive, yields fruits of excellent quality (Boraiah et al., 2023). Manual pollination involves carefully opening the flower by gently pinching the bulging part, exposing the stigma. *H. undatus* exhibits a reduced self-incompatibility, underscoring the importance of planting compatible clones for effective pollination and fruit set (Mizrahi and Nerd, 1999). The dragon fruit is an epigenous berry that develops from both the ovary and the receptacle surrounding the fruit. It is medium to large with various pulp colours, which can be red, white, or light pink, and tiny black seeds embedded in the pulp. The peel can be either red or yellow at maturity, depending on the species. The endocarp of the dragon fruit has a melt-in-your-mouth texture and offers a taste reminiscent of kiwi fruit with a mild sweetness.

Harvesting:

Pre and post-harvest technologies for dragon fruit were reported by To et al. (2000). The key findings related to harvesting indices, post-harvest storage conditions, grading, and quality parameters for dragon fruit:

- Acidity and Fruit Color: During the early stages of fruit development, the biosynthesis of organic acids takes place, leading to an increase in H+ concentration. An anthocyanin pigment layer forms between the flesh and skin, expanding outward, and the skin turns red around the 19th day (Fig. 3).

- Total Soluble Solids (TSS) and TSS/Acidity Ratio: TSS content increases rapidly during the early stages of fruit development. When the fruit is 25 days old, the TSS value exceeds 12°Brix and remains between 12–16°Brix.
- Firmness: Fruit firmness decreases rapidly between the 16th and 25th days after flowering. When the fruit becomes very soft (firmness <0.90 kg), handling and transportation become challenging, leading to greater damage and reduced market value.
- Change in Peel Color: Changes in the colour of the dragon fruit peel are difficult to discern. For the preferable TSS/acidity ratio of 40, the values for the three colour parameters—value (L*), hue (a*), and chroma (b*)—should be 44.2, 35.5, and 0.8, respectively.
- Eating Quality: The eating quality of the fruit can be assessed using a hedonic scale. The highest score (8.5) is recorded when the mature fruit is 28 to 31 days old, aligning with the preferred TSS/acidity ratio of 40.
- Fruit Grading: Dragon fruits can be graded for export or the domestic market based on fruit weight.

Grade	Fruit weight/Size
Extra large	> 500 g
Large	>380–500 g
Regular	>300–380 g
Medium	260–300 g
Small	<260 g

Yield

Dragon fruit is a high-return, fast-growing perennial fruit crop. In well-managed orchards, flowering can commence as early as the second year, with the potential for a significant yield in the third or fourth year of orchard establishment. Ripe fruits are typically ready for harvest within 30-50 days after fruit set (pollination) (Nerd et al., 1999; Pushpakumara et al., 2005). The flowering pattern of dragon fruit results in staggered harvesting, typically starting in June and continuing until December or even January in some cases. The average yield for dragon fruit can range from 10,000 to 12,000 kg per hectare. However, in well-managed commercial orchards under favourable climatic conditions and proper management, higher yields of 16,000-27,000 kg per hectare and 18,000-22,000 kg per hectare are achievable from the third year onwards. The economic life of a dragon fruit plant can extend up to 20 years with adequate care and management.

However, with the average yield of dragon fruit, growers can expect to earn between 8 to 10 lakhs per hectare from the third year onward, and this income tends to increase as the plants mature and stabilize in yield (Nangare et al., 2020).

Fig. 3 Harvested Dragon fruits

Diseases and their management

Dragon fruit, an exotic crop recently introduced in India, faces various diseases that are often unfamiliar to Indian growers. A survey of farmer's fields has revealed the presence of several diseases, including stem canker, anthracnose, soft rot, and leaf spot/blight. Here's an overview of these diseases and their management:

1. Stem Canker (*Neoscytalidium dimidiatum*):

Overview: Stem canker is a potentially devastating disease found in dragon fruit orchards, with varying levels of intensity. Unmanaged orchards are particularly susceptible to this disease.

Symptoms: Infected cladodes initially display depressed, chlorotic spots with red flecks. As the disease progresses, these spots become elevated and turn red to grey. They eventually expand into hard brown scabs with pycnidia embedded on the surface. Yellowing and rotting of affected cladodes become prominent as the disease advances, with necrotic tissues detaching from healthy tissues and leaving behind shot holes (Fig. 4). On fruits, chlorotic depressed spots are followed by rotting (Salunkhe et al., 2023a).

Fig. 4 Different stages of stem canker symptoms in dragon fruit

2. Anthracnose (*Colletotrichum species*):

Overview: Anthracnose is a disease that often coincides with the rainy season and can impact fruit quality during the fruiting stage.

Symptoms: Infected cladodes develop reddish to dark-brown, sunken, water-soaked lesions with chlorotic haloes that later become mature necrotic patches with black acervuli (Fig. 5). On fruits, small, light brown spots quickly turn into sunken water-soaked lesions with concentric rings of black acervuli (Salunkhe et al., 2023b).

Fig. 5 Anthracnose symptom development in dragon fruit

3. Bacterial Soft Rot (*Enterobacter cloacae*):

Overview: Bacterial soft rot can lead to significant damage in dragon fruit plants and fruits.

Symptoms: Infected plants exhibit yellowish to brownish soft and watery symptoms on stems and fruits. On the stem, the smelly lesion tissues subsequently soften and rot, leaving the main vein intact (Fig. 6). Rotten fruits can be destroyed within three days of infection. Variations in day and night temperatures during October to January can worsen the disease.

Fig. 6 Symptoms of soft rot disease

Disease Management for Dragon Fruit Plantation:

1. Selection of Planting Material

- Utilize disease-free and healthy planting material for dragon fruit plantations.
- Before planting, harden the cladodes in the shade and treat them with carbendazim (0.1%), copper oxychloride (0.25%), or Mancozeb (0.25%) to ensure they are free from pathogens.

2. Orchard Hygiene

- Prune and remove infected cladodes. Leaving diseased cladodes on the orchard floor or in drains can perpetuate spore production and infect young growth.
- After pruning, apply a 1% Bordeaux mixture to reduce pathogen entry through pruned areas.
- Disinfect pruning tools with Copper oxychloride solution @ 0.25% to prevent disease spread through infected tools.
- Maintain proper spacing to facilitate air circulation and light penetration, which helps keep the orchard pest and disease-free and limits disease and pest spread.
- Address anthracnose by reducing spore dispersal and production to mitigate disease outbreaks.

3. Fungicidal Management

- Develop a fungicide spray schedule based on weather conditions and utilize fungicides with different modes of action.
- Include protectant fungicides like Mancozeb (0.25%) and copper oxychloride (0.25%) in the spray schedule.
- Incorporate fungicides with penetrative activity such as difenoconazole + azoxystrobin at a rate of 0.1%.
- During the wet season with frequent infection periods, emphasize fungicides with curative action in your program.
- In the dry season, consider a program of protectant fungicides and longer spray intervals to manage the disease effectively.

By implementing these disease management practices, dragon fruit growers can minimize disease occurrence and maintain the health and productivity of their orchards.

Managing insects and pests in dragon fruit orchards:

1. Fruit Fly and Thrips:

- Fruit Fly: To control fruit flies, the use of pheromone traps is a good practice. Placing pheromone traps at a rate of 10 per acre in the orchard can help in monitoring and trapping fruit flies, reducing their population.
- Thrips: Consider the use of insecticides that are effective against thrips. Regular monitoring and early intervention are crucial for managing thrips, as they can damage dragon fruit plants.

2. Aphids, Mealy Bugs, Termites, Snails, and Birds:

- Aphids and Mealy Bugs: Utilize insecticidal soaps or neem oil to control aphids and mealy bugs. These are effective, environmentally friendly options.
- Termites: Address termite infestations by using termite control methods suitable for your region, such as bait stations or soil treatments.
- Snails: Hand-picking snails during the early morning or late evening when they are most active can be an effective control method.
- Birds: Install bird netting or use scare devices to deter birds from feeding on dragon fruit.

General Integrated Pest Management (IPM) Practices:

- Promote natural predators like ladybugs and parasitoid wasps to control aphids and mealy bugs.
- Use sticky, pheromone and mechanical traps for control of insects and pests.
- Maintain proper orchard hygiene by removing fallen fruit and plant debris to reduce hiding places for pests.
- Apply mulch to the base of dragon fruit plants to discourage snails and reduce soil moisture.
- Use biological controls, such as beneficial nematodes, to manage soil-dwelling pests.
- Monitor your orchard regularly for signs of pest infestations and take action as needed.

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Medicinal and Aromatic plants-Alternate and sustainable option for Abiotic stress regions

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Introduction

India is renowned for its remarkable biodiversity, encompassing a wide array of flora and fauna. This biological diversity extends to an invaluable repository of medicinal and aromatic plants (MAPs) that flourish in diverse ecological regions (Harisha et al., 2019). India is recognized as a global hotspot for the diversity of medicinal plants, and it ranks among the primary producers of these invaluable botanical resources. The abundance of medicinal plants in India is primarily concentrated in tropical regions, with a significant presence in the Himalayas, Western and Eastern Ghats, and the Aravalis, collectively contributing to approximately 70% of the plant diversity (Purohit and Vyas, 2004). In many developing countries, herbal remedies play a pivotal role in healthcare, with approximately 80% of the population relying on these natural remedies. Remarkably, around 30% of pharmaceutical drugs worldwide incorporate constituents derived from plants.

There is a growing awareness of alternative medicines that harness the potential of MAPs. Beyond their medicinal uses, these plants have found applications in various industries. They are utilized in the flavour and fragrance sector for crafting cosmetics, perfumes, aromatherapy products, and beverages. Furthermore, the pharmaceutical industry incorporates them into herbal remedies, drugs, and vitamins. In the functional food industry, MAPs are instrumental in producing health-enhancing foods, herbal teas, and herbal supplements (Harisha, et al., 2022). They also contribute to the bio-pesticide industry by facilitating the production of insect repellents, crop pesticides, and household pesticides.

Abiotic stresses are emerging due to changing climatic conditions such as moisture drought or floods, extreme temperatures, radiation, nutrient deficiencies, salinity, sodicity, alkalinity, acidic soils, heavy metal contaminations, erosion, slope topography, shallow soils, poor water-holding capacity and drainage. Moisture deficit stress drought, water logging, salinity and terminal high temperature are occurring more frequently and are the important reasons for the decline in agricultural production (Boraiah et al. 2021). All of these stress factors are found detrimental to agriculture production including medicinal and aromatic crops. However careful consideration of crops suitable for stressed soils, weather uncertainties and precision cultivation make the cultivation of medicinal and aromatic plants less vulnerable to stresses. Most medicinal and aromatic plants are abiotic stress tolerant due to their hardy nature, leas water demand, high temperature tolerance, suitable for marginal lands with salinity, drought and metal contaminated soils.

The objectives of this chapter are multifaceted. Firstly, it seeks to comprehensively understand how abiotic stressors impact the yield, physiology, and phytoconstituents of medicinal and aromatic plants.

Importance of MAPs

The importance of Medicinal and Aromatic Plants (MAPs) cannot be overstated, particularly in the context of Ayurveda and traditional medicine in India. Here are several key reasons highlighting the significance of MAPs:

1. Ancient Medicinal Tradition: Ayurveda, one of the world's oldest systems of medicine, relies heavily on the use of MAPs. It recognizes over 2,000 plant species with medicinal properties, and ancient texts like the Charaka Samhita provide a rich repository of knowledge about their therapeutic uses. These plants have been used for centuries to treat a wide range of ailments.
2. Cultural Heritage: These plants are deeply ingrained in the cultural and indigenous health traditions of India. They are an integral part of the country's heritage and have been passed down through generations.
3. Economic Significance: The commercial value of MAPs is substantial. They are essential ingredients in the pharmaceutical, herbal remedy, cosmetic, fragrance, and food industries, contributing significantly to the economy. MAPs also support livelihoods, especially in rural areas where traditional knowledge is passed down.
4. Biodiversity Conservation: Due to a lack of proper conservation in their natural habitats, many MAP species are under threat. This has led to increased attention from scientists and entrepreneurs who recognize the need for sustainable cultivation and harvesting to ensure their availability for future generations. Many of these plants have unique ecological roles and are essential for maintaining ecosystem balance.
5. Health and Well-being: The use of MAPs in traditional and alternative medicine contributes to the overall health and well-being of individuals. They provide accessible and affordable healthcare options, particularly for those in rural or underserved areas.
6. Reducing Pressure on Wild Habitats: Sustainable cultivation of MAPs can alleviate the pressure on wild habitats. This is crucial for preserving biodiversity and preventing the extinction of plant species due to overharvesting and habitat destruction.

Table 1. Important Indian medicinal plants, economic part and uses.

S. No	Common name	Scientific Name	Parts used	Medicinal Uses
1	Amla	*Phyllanthus emblica*	Fruit	Triphal, constipation, diabetes
2	Anantmul	*Hemidesmus indicus*	Root	Hypertension, Cough, dysentery
3	Ashok	*Saraca asoca*	Bark, leaf	Heart disorder, tonic
4	Ashwagandha	*Withania somnifera*	Root, leaf	Asthma, eye complaints, cough
5	Bael	*Aegle marmelos*	Fruit, bark	Dysentery, diarrhoea, fever
6	Bhui amla	*Phyllanthus amarus*	Entire plant	Dysentery, jaundice, aphrodisiac
7	Brahmi	*Bacopa monnieri*	Entire plant	Fever, brain tonic, blood purifier
8	Sandalwood	*Santalum album* L.	Heart wood	Dysentery, skin diseases
9	Chirata	*Swertia chirayita*	Entire plant	Malarial fever, immunity
10	Giloe	*Tinospora cordifolia*	Entire plant	Immunity, Jaundice, fever
11	Gudmar	*Gymnema sylvestre*	Root, leaf	Diabetics, gastric disorders
12	Guggul	*Commiphora wightii*	Resin, bark	Typhoid, asthma
13	Indrajava	*Wrightia tinctoria* .	Latex, Bark	Piles, toothache, dysentery
14	Isabgol	*Plantago major* L.	Whole	Wounds, weakness, laxative
15	Jaiphal	*Myristica fragrans*	Fruits	Asthma, fever, cough
16	Jatamansi	*Nardostachys jatamansi*	Rhizome	Bronchitis, hysteria
17	Kabab chini	*Piper cubeba* L.	Fruits	Cholera, fever, cough
18	Kachora	*Curcuma zedoaria*	Rhizomes	Jaundice, blood pressure
19	Kakadshingi	*Pistacia chinensis*	Fruits	Scorpion bite, dysentery
20	Kalihari	*Gloriosa superba* L.	Rhizomes	Snake bite, leprosy, tonic
21	Kalmegh	*Andrographis paniculata*	Entire plant	Malaria, liver complaints
22	Khair	*Acacia catechu*	Root, bark	Asthma, bronchitis
23	Kokam	*Garcinia indica* Choisy	Fruits	Skin diseases
24	Kulanjan	*Alpinia galanga*	Bulbs	Health tonic
25	Kunja	*Artemisia maritima*	Entire plant	blood purifier Antiseptic,
26	Makoy	*Solanum nigrum* L.	Fruits	Jaundice, piles, skin diseases
27	Mulethi	*Glycyrrhiza glabra*	Roots	Gastric disorders
28	Patharchur	*Coleus barbatus*	Roots	blood pressure Tonic
29	Pippal	*Piper longum* L.	Roots	Indigestion, cough
30	Safed musli	*Chlorophytum tuberosum*	Tubers	sexual tonic, immunity
31	Sarpagandha	*Rauvolfia serpentina*	Roots	Malarial fever, snake bite
32	Senna	*Cassia angustifolia*	Leaves	Laxative
33	Shatavari	*Asparagus racemosus*	Roots	Dysentery, cough, wounds
34	Tulsi	*Ocimum sanctum* L.	Seed, leaf	liver complaints, fever, blood purifier

Source: Kala et al. (2006)

Table 2. Important aromatic plants and their economic parts.

Sr.No	Scientific name	Common name	Parts used
1	*Acorus calamus*	Sweet flag	Rhizome
2	*Amomum globosum*	Chinese cardamom	Fruit
3	*Artemisia pallens*	Davana	Aerial parts
4	*Chrysanthemum morifolium*	Chrysanthenum	Flower
5	*Cinnamomum camphora*	Camphor	Bark
6	*Cinnamomum verum*	Cinnamon	Bark
7	*Cinnamomum tamala*	Indian cassia	Bark
8	*Curcuma domestica*	Turmeric	Rhizome
9	*Cymbopogon flexuosus*	Lemongrass Indian)	Leaf
10	*Cymbopogon martinii* var. *Motia*	Palmarosa	Leaf
11	*Cymbopogon winterianus*	Citronella (Java)	Leaf
12	*Elettaria cardamomum*	Cardamom	Fruit
13	*Eucalyptus globulus*	Eucalypt	Leaf
14	*Jasminum samboc*	Jasmine	Flower
15	*Matricaria chamomilla*	German chamomile	Flower
16	*Mentha arvensis.*	Japanese mint	Aerial parts
17	*Mentha citrata*	Bergamot mint	Aerial parts
18	*Mentha piperita*	Peppermint	Aerial parts
19	*Mentha spicata*	Spearmint	Aerial parts
20	*Myristica fragrans*	Nutmeg/Mace	Seed/aril
21	*Ocimum basilicum*	Basil	Aerial parts
22	*Pimpinella anisum*	Anise	Seed
23	*Pinus caribaea*	Turpentine	Resin
24	*Piper nigrum*	Black pepper	Berry
25	*Pogostemon cablin*	Patchouli	Aerial parts
26	*Syzygium aromaticum*	Cloves	Flower bud
27	*Tagetes minuta*	Marigold	Flower
28	*Vanilla planifolium*	Vanilla	Pod
29	*Vetiveria zizanioides*	Vetiver	Root
30	*Zingiber officinalis*	Ginger	Rhizome

Source: Kala et al. (2006)

The cultivation of Medicinal and Aromatic Plants (MAPs) offers numerous advantages, especially in abiotic stress conditions, making them an attractive option for farmers and the herbal product industry:

1. Higher Returns: MAPs often provide better returns compared to traditional crops, making them financially appealing for farmers, especially in regions with abiotic stresses.

2. High Demand: There is a substantial demand for MAPs in both domestic and international markets, driven by the growing interest in herbal products and natural remedies.
3. Flexible Market Timing: Some MAPs can be partially processed, stored, and sold when market prices are favourable, offering farmers flexibility in timing their sales.
4. Stress Tolerance: MAPs are known for their tolerance to abiotic stresses like moisture stress, making them suitable for cultivation in challenging environments.
5. Low Pest Incidence: They often have a low incidence of pests and diseases, reducing the need for costly pesticides and promoting sustainable farming.
6. Cost-Effective: Compared to conventional crops, the cost of production for MAPs is generally lower, making them economically viable.
7. Inter-Cropping: MAPs can be cultivated as inter-crops or in mixed cropping systems, utilizing marginal lands and solving land allocation issues for both domestic and export markets.
8. Quality Assurance: The herbal product industry requires MAPs that are consistent in quality, free from contaminants, unadulterated, and reliably identified botanically.
9. Active Ingredients: Medicinal plants must contain the required active ingredients, which can be achieved through proper cultivation practices.
10. Compliance with Regulations: Meeting the regulatory requirements of different markets is essential, and MAPs can be produced in a way that satisfies these varied regulations.
11. Increased Cultivation: The growing demand for herbal products has led to a significant increase in the commercial cultivation of medicinal plants.
12. Good Agricultural and Collection Practices (GAP/GCP): By adopting GAP and GCP, farmers can ensure the safe and high-quality production of raw materials for herbal products.
13. Yield and Quality Factors: Various factors such as crop variety, irrigation, soil conditions, climate, nutrient management, pollutants, and post-harvest practices influence MAP yield and quality.
14. Climatic Adversities: Abiotic stresses like drought, floods, frost, heat stress, and pollutants can impact MAP cultivation. Proper care and management practices are essential to overcome these adversities and achieve desired yields and quality.
15. Suitable for Stressed Environments: Many important MAPs are naturally adapted to stress environments, requiring minimal management practices and making them a suitable choice for farmers in such regions.

In summary, cultivating Medicinal and Aromatic Plants offers a range of benefits, including economic advantages for farmers, meeting the demand for herbal products, and the potential for sustainable and environmentally friendly agriculture. Proper management practices and conservation efforts are essential to ensure the continued availability and quality of these valuable botanical resources.

Drought stress in medicinal and aromatic plants

Drought stress is a significant challenge in the cultivation of medicinal and aromatic plants (MAPs). This type of abiotic stress can have various effects on the growth, development, and phytoconstituent production in these plants. Here are some key findings and observations related to the impact of drought stress on MAPs:

1. Limitations on Growth and Yield: Drought stress significantly limits plant growth, maturity, and crop yield in MAPs. Vegetative dry matter and biomass production are reduced in plants like lemon balm, lemongrass, and mint when exposed to moisture deficit conditions.
2. Drought Tolerance Variability: Different MAP species may exhibit varying levels of drought tolerance. Some, like *Eucalyptus citriodora*, may be less drought-tolerant than others, impacting their growth and essential oil content under moisture stress conditions.
3. Reduced Leaf Area: Drought stress can lead to a decrease in leaf area, resulting in poor growth and smaller leaves in MAPs like mint.
4. Altered Flowering Patterns: Drought stress during the flowering phase can induce early flowering and affect the yield negatively. For example, coriander is known to experience a significant reduction in yield when subjected to moisture stress during the flowering phase.
5. Impact on Essential Oil Content: The composition of essential oils in MAPs can change under drought stress. Some studies have reported an increase in major essential oil constituents, such as geraniol and central, in plants like *Cymbopogon* species. This increase may be due to restricted growth and biomass production, leading to higher oil concentrations in leaves.
6. Effect on Oil Yield: In some cases, water deficit conditions can reduce essential oil yield. For instance, *Artemisia annua* experiences a decrease in essential oil yield when subjected to water deficit, particularly during the flowering stage. In thyme and citronella grass, an increase in oil content under low moisture stress conditions was observed.
7. Herb Yield and Essential Oil Content: Herbs like rosemary and anise experience reduced herb yield and essential oil content when exposed to low moisture stress.

Overall, the impact of drought stress on MAPs can vary depending on the specific plant species, growth stage, and duration of stress. Understanding how drought affects the growth and phyto-constituent production of these plants is crucial for implementing appropriate irrigation strategies and other management practices to mitigate the adverse effects of moisture deficit stress and ensure the quality and yield of MAPs.

Salinity stress in medicinal and aromatic plants

Soil salinity poses a significant challenge in agriculture, negatively impacting crop growth and productivity. It arises due to factors such as excessive irrigation with saline water and frequent flooding, which are common occurrences in arid and semi-arid regions. The consequences of salinity are severe, as it disrupts normal growth patterns, physiological processes, and biochemical functions in crops, leading to issues like delayed germination, increased seedling mortality, poor crop development, and reduced yields (Harisha et al., 2023). This problem is especially detrimental to staple food crops, pulses, oilseeds, and various horticultural crops, which are unable to withstand increasing salinity levels.

Given the higher need for fertile land in agriculture, it becomes crucial to identify salt-tolerant medicinal and aromatic plants that can thrive in saline-affected soil or under saline water irrigation. In India, for instance, there are more than 1100 plant species distributed across various saline habitats that exhibit salt tolerance. Promising experiments have been conducted in arid and semi-arid regions of the Indian subcontinent, demonstrating that several aromatic and medicinal plants, including Gooseberry, neem, Bael, Arjun, Jatropha, Vasaka, Ashwagandha, Castor, Isabgol, Periwinkle, Indian aloe, Senna, liquorice, Tulsi, Dill, Celery, German Chamomile, Vetiver, Palmarosa, and Lemongrass, can successfully thrive with saline irrigation and in moderately alkali soil conditions, without the need for soil amendments. This indicates the feasibility of cultivating aromatic and medicinal plants on degraded lands through bio-saline agriculture (Dagar et al., 2013).

The rise in salt concentrations indeed inhibits plant growth and productivity; however, there is a diverse range of medicinal and aromatic plants that exhibit salt tolerance. Notable examples include Indian aloe (8dsm^{-1}), adathoda (10dsm^{-1}), isabgol (8dsm^{-1}), cumin (8dsm^{-1}), periwinkle (8dsm^{-1}), ashwagandha (8dsm^{-1}), liquorice (8dsm^{-1}), guggul (8dsm^{-1}), basil (8dsm^{-1}), senna (8dsm^{-1}), asparagus (10dsm^{-1}) and henbane (8dsm^{-1}) is important. Among aromatic crops vetiver, palmarosa, lemongrass and chamomile can tolerate salinity up to 10-12dsm^{-1}. Other crops such as dill cumin, mints and celery can tolerate up to 6 dsm^{-1}.

Shallow and wastelands

In peninsular India, a significant portion of the landscape is characterized by shallow basaltic soils, which are porous, gravelly, and low in organic matter. These soils present several challenges for plant establishment and growth, including poor soil quality, low water retention capacity, and the presence of hard rocks and murrum. Not all plant species can thrive under these conditions. To address these challenges, various strategies and plant species have been employed:

1. Stone Breaking for Pit Opening: Stone breaking is used to create pits in the hard rock substrata. This practice facilitates better root penetration by loosening the soil, allowing plant roots to access deeper layers with moisture and nutrients.
2. Soil Amendment: Native soil devoid of stones is mixed with black soil in a 1:1 proportion to fill the pits created by stone breaking. This soil mixture improves the moisture-holding capacity at the root zone, providing a better initial environment for plant growth.
3. Soil and Water Conservation Measures: Several soil and water conservation techniques are employed to mitigate the challenges of shallow basaltic soils. These include mulching, the construction of half-moon-shaped bunds to trap rainwater and prevent soil erosion, and in-situ water harvesting methods to enhance water availability for plants.
4. Selection of Hardy Tree Species: Various tree species have been identified as suitable for these edaphic conditions. Examples include *Azadirachta indica* (Neem), *Butea monosperma, Putranjeeva roxburgaii, Ptreocarpus santalinus* (Red Sanders), *Satalum album, Sapindus spp., Cassia sinuata, Gmelina arborea, Limonia acidissima, Swertania mahgoni, Terminalia species, Aegle marmelos* (Bael), and *Pongamia pinnata* (Indian Beech). These tree species have demonstrated their ability to adapt and grow well in these challenging soils.
5. Small Trees and Shrubs: Alongside large trees, smaller tree and shrub species like *Adathoda zylanica, Lawsonia inermis* (Henna), *Commiphora wightii* (Indian Bdellium), *Eucalyptus globulus, Premna integrifolia, Vitex nigundo*, and *Carissa caronda* have also shown promise in these soil and moisture stress conditions.
6. Climbing Plants: Climbing plants such as *Tinospora cordifolia, Gymnema sylvestre, Cissus quandrangularis, Abrus precatorius, Jasminum sambac* (Jasmine), and J. grandiflorum (Spanish Jasmine) exhibit favourable growth patterns and adaptability to the specific soil and moisture constraints of shallow basaltic soils.

Figure 1: Use of half-moon shaped bund filled with crop mulch for moisture conservation in summer months

Adoption mechanisms by MAPs to the high temperature and shallow soils

1. Plants are capable of extending the roots to deeper and longer in search of anchorage and moisture. Best example is *ficus* group of plants can extend the roots even in rocks, buildings to anchor the roots and absorb the moisture. In same way many plant species can utilize the moisture in proper manner for their survival
2. Having cooler canopy by reduced transpiration during high water and stressed condition make them adopt for less moisture an high temperatures
3. Hardier plants such as *Aloe vera*, guggal, agave, opuntia are having leaves of mucilaginous mesocarp and can able survive for long period of time without moisture and also high temperature. They can also survive in poor soils with shallow and rocky conditions too.

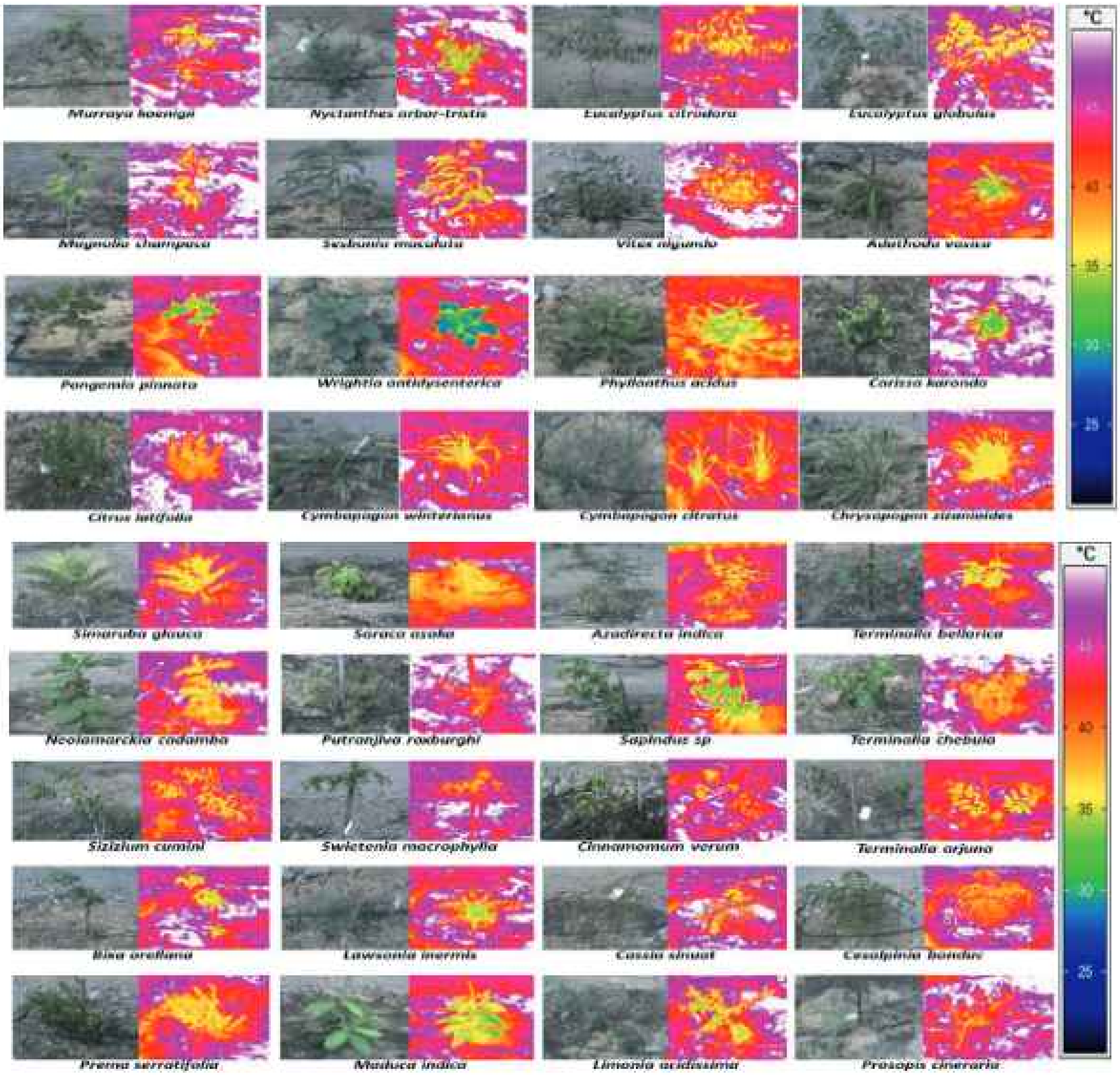

Figure 2: Infrared image showing canopy temperature range of many plant species in shallow rocky soil during summer months.

These plant species are considered hardy and well-suited to the unique edaphic conditions found in peninsular India. Their ability to thrive in such environments makes them valuable choices for afforestation, soil conservation, and sustainable land use in these regions.

Heavy metals stress

Medicinal and aromatic plants have the remarkable ability to absorb and mitigate soil or water contaminants to varying degrees. Several factors come into play when considering the accumulation of contaminants, including the plant species, contamination levels, duration of exposure, and soil conditions. A range of aromatic plants, such as vetiver, lemongrass, and citronella, can be employed for a process called phytoremediation. These aromatic plants offer substantial potential for bioremediation since they are non-food crops.

Essential oils extracted from aromatic plant species find applications in various industries, including food and fragrance, for the production of items like soaps, perfumes, toiletries, and insect repellents, among others. These aromatic plants are considered non-edible because their primary purpose is the extraction of volatile oils, which are not directly consumed by humans or animals. One significant advantage of cultivating these aromatic plants is that the volatile oils obtained through distillation methods are typically free from heavy metal contamination due to the volatile nature of the oils (Lal et al., 2013). Consequently, by growing aromatic and select medicinal plants, the risk of heavy metals entering the food chain can be significantly reduced. Another benefit of cultivating these aromatic plants is that grazing animals are typically deterred from consuming them due to their strong aroma or taste. Some perennial aromatic grasses, such as Lemon grass (Cymbopogon flexuosus), Khus grass (*Chrysopogon zizanioides*), Palmarosa (*Cymbopogon martini*), and Citronella (*Cymbopogon winterianus*), produce substantial biomass and are frequently harvested for essential oil extraction. These grasses have significant potential for phytoremediation of heavy metals as they can effectively remove these metals from soil or water.

In addition to the mentioned grasses, other aromatic plants like Geranium, Mints, *Ocimum*, Sage, Lavender, Rosemary, and Chamomile also exhibit substantial potential for phytoremediation (Pandey et al., 2019). Given their stress tolerance and perennial nature, cultivating these plants is highly advisable. They can be harvested in subsequent years for essential oil extraction while simultaneously contributing to environmental remediation efforts. Therefore, cultivation of aromatic and medicinal plants serves a dual purpose by not only providing essential oils for various industries but also aiding in the removal of contaminants from soil and water, thus minimizing the risk of heavy metals entering the food chain and offering environmental benefits.

High temperature stress

Temperature is indeed a critical factor influencing plant growth and development, and its impact varies from one plant species to another. Each plant species has specific temperature requirements for optimal growth. Temperature stress can have detrimental effects on plant vegetative growth, development, and secondary metabolism. Some of these effects include changes in flowering behaviour, hormone imbalances, alterations in gene expression, pollen malformations, and reduced seed setting.

However, it's worth noting that in the case of Medicinal and Aromatic Plants (MAPs), heat stress can sometimes be advantageous due to its role in triggering the production of secondary metabolites as part of the plant's stress tolerance mechanism. This can lead to the enhanced synthesis of valuable compounds with medicinal or aromatic properties. For instance, in *Panax quinquefolius*, a reduction in photosynthetic activity was observed under increased atmospheric temperatures. Paradoxically, this increase in temperature was associated with an improvement in the production of ginsenosides, which are important bioactive compounds (Jochum et al., 2007).

In the case of *Camellia sinensis*, the genes responsible for heat stress tolerance (CsDHAR1 and CsMDHAR) showed increased expression just one hour after exposure to high temperatures (Li et al., 2016). This indicates the plant's ability to quickly respond to heat stress by activating specific genes associated with stress tolerance. Similarly, in Agarwood, exposure to high temperatures up to 50 °C for 30 minutes resulted in the upregulation of genes involved in the Jasmonic Acid pathway. This pathway is crucial for the synthesis of Jasmonic acid, which, in turn, is required for the production of sesquiterpenes, valuable aromatic compounds (Xu et al., 2016). In total heat stress can have adverse effects on plant growth and development, certain Medicinal and Aromatic plants have developed mechanisms to respond positively to elevated temperatures. They activate specific genes and pathways that lead to the enhanced production of secondary metabolites, making heat stress a potentially beneficial factor for these plants in terms of medicinal or aromatic compound synthesis.

Conclusion

The cultivation of medicinal and aromatic plants in abiotic stress environments holds tremendous potential. It allows for the utilization of otherwise unproductive or wasteland and areas affected by stress factors. By doing so, fertile lands are conserved for the cultivation of essential food and other horticultural crops. Additionally, this expansion of MAP cultivation can contribute to the economic growth of a country.

Research efforts in this field focus on several key aspects:

1. Crop Selection for Specific Stress Environments: Identifying the most suitable MAP species for particular stress conditions, whether it's water stress, salinity, metal stress, or temperature stress.
2. Stress Management Practices for MAPs: Developing effective agronomic practices and management strategies to ensure the optimal growth and yield of MAPs in stress environments.
3. Breeding for Abiotic Stress Tolerance: Implementing breeding programs to create MAP varieties that are more resilient to abiotic stress factors, thus improving their adaptability to challenging conditions.
4. Economic Viability: Evaluating the economic feasibility and viability of cultivating specific MAPs in abiotic stress-affected areas and soils.
5. Identification of New MAPs: Exploring and identifying new medicinal and aromatic plant species with similar benefits to existing crops, which can thrive in stress conditions.

Therefore, the cultivation of medicinal and aromatic plants in abiotic stress environments offers a sustainable and economically viable solution for utilizing underutilized lands and conserving fertile soil for food crops. Research efforts encompass a wide range of activities, from selecting appropriate species to breeding for stress tolerance and the development of best management practices. This approach not only benefits the environment but also contributes to the growth of the MAP industry and the overall economy.

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Sandalwood based agroforestry for higher profitability

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Introduction

The Indian sandalwood tree (*Santalum album*), which belongs to the Santalaceae family, is a highly sought-after hardwood species found primarily in India, Sri Lanka, China, Malaysia, Australia, and New Zealand. The Santalaceae family consists of 29 genera with approximately 400 species, with 19 species being specific to the Santalum genus. Sandalwood is a valuable tree species known for its fragrant wood, which is used in the production of perfumes, incense, and traditional medicines. Sandalwood trees are highly prized for the aromatic oils found in their heartwood and are considered one of the most valuable non-timber forest products.

For centuries, these oils have been utilized for religious and cultural purposes and are now utilized globally in cosmetics, aromatherapy, soap perfumery, and medicine. Additionally, the oil-rich heartwood is used for decorative or ceremonial carving and can be ground into powder to make incense sticks that are in high demand in the international agarbatti (incense) market. The tree has a long history of cultivation and use, dating back thousands of years in some cultures. Despite its cultural significance and widespread use, the demand for sandalwood has often outstripped its supply, leading to the over-exploitation of wild populations in many countries. With a history of sandalwood cultivation and production spanning over 5000 years, India has long been a leader in the production of sandalwood oil for use in fragrances and medicines.

The heartwood of Indian sandalwood is particularly valued for its high oil and santalol content, with oil concentrations of up to 6% and santalol upto 90% being found in the heartwood of mature trees. However, despite a global demand for 5000 to 6000 tonnes of sandalwood wood and 100 to 120 tonnes of oil per year, India's annual production has fallen dramatically in recent decades. In 1950, the country produced 4000 tonnes of sandalwood, but by 2007 this had fallen to just 500 tonnes. This decline has been attributed to factors such as the lethal sandal spike disease, indiscriminate harvesting, and other environmental pressures. In the 1960-1965 period, India's sandalwood production was 2287.8 tonnes, but by 1995-2000 this had fallen to just

366.74 tonnes. The decrease in production has led to a sharp increase in sandalwood prices on the global market.

The Indian sandalwood tree grows to a diameter of 1.0 to 2.4 meters and a height of 12 to 15 meters, with thin, drooping, upright branches. It thrives in partial shade during its early stages, but by the middle and late phases it can no longer tolerate heavy overhead shadow (Das et al. 2021a). With its hemiparasitic nature, the sandalwood tree can parasitize over 300 species, ranging from grass to other sandal plants, and even exhibits self-parasitism under conditions of clustered growth. Its adaptability to a wide range of soils and adverse conditions, as well as its resilience to disease and high value, make it an attractive choice for agroforestry and plantation crops (Viswanath and Chakraborty, 2022). Despite its enormous potential for use in plantations and agroforestry due to the expanding supply-demand deficit, large-scale sandalwood planting has been hindered by its root parasitic nature and a lack of understanding of host-parasite connections. As a result, this book chapter focuses on the distribution of sandalwood trees, nursery techniques, host management, field techniques, disease management, and yield in agroforestry systems.

Distribution

The sandalwood tree is naturally distributed across a vast geographical range, spanning from approximately 30°N to 40°S latitude. Its natural habitat extends from Indonesia in the east to the Juan Fernandez Islands in Chile in the west, and from the Hawaiian Archipelago in the north to New Zealand in the south. Indian Sandalwood, a distribution that covers approximately 9,600 square km. This distribution is primarily concentrated in the deciduous forests of the Deccan region, as reported by Gairola et al. (2008). The majority of the natural population of *S. album* can be found in the southern Indian states of Karnataka and Tamil Nadu, accounting for more than 90% of the species' total distribution, according to Dutt and Verma (2005). The extent of sandalwood's presence in India can be visualized in Figure 1.

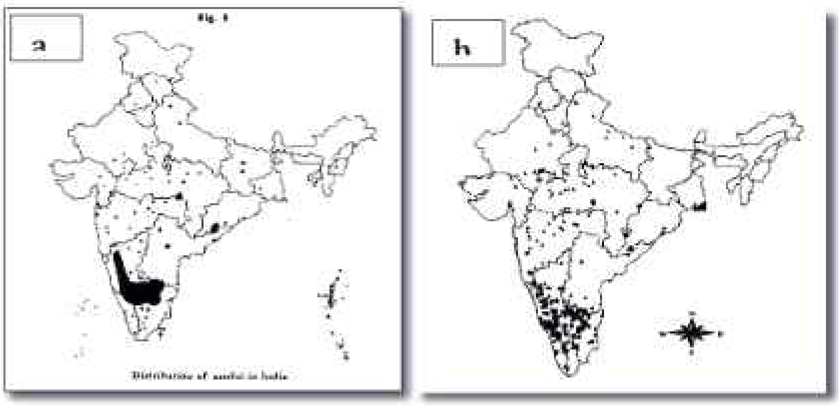

Figure 1. Distribution of sandalwood in India a) Rai and Sharma (1990) & b) Rao et al. (2007)

The growing demand for sandalwood has inspired many farmers to take up its cultivation as a means of boosting their income. Since 1995, forest departments and farmers have been making efforts to grow the tree in non-traditional parts of India, leading to the establishment of isolated populations in various states such as Bihar, Gujarat, Haryana, Maharashtra, Punjab, Madhya Pradesh, Rajasthan, Tamil Nadu, Orissa, Uttar Pradesh and West Bengal. More recently, Sandalwood has been reported in Himachal Pradesh and Assam. Despite being protected, the sandalwood tree has been classified as "vulnerable" by the International Union for Conservation of Nature and Natural Resources due to excessive harvesting (Arunkumar et al. 2019). The decline of sandal tree forests is being caused by several factors, including spike disease, yearly fires, invasive weeds like *Lantana camara*, and the growth of monoculture plantations of Eucalyptus (Basappanavar, 1977), as well as illegal felling and smuggling (Rao et al. 1999).

Climate & Soil

Sandalwood is renowned for its adaptability, as it can thrive in a diverse range of conditions. It is capable of growing at various altitudes, from sea level to as high as 1800 meters. It can withstand moderate rainfall, typically ranging from 600 to 1600 mm, and it tends to thrive in a cool climate characterized by extended dry periods. It can grow in various soil types, including sand, clay, loam, laterite, and black cotton soil. Soil with higher levels of organic carbon and macronutrients is better suited for seedling growth, with red ferruginous loam being the most ideal. The tree produces more oil in dry areas with red, stony, or rocky soil. Sandalwood requires well-drained soil and cannot tolerate waterlogged conditions. Porous, well-drained soil promotes root-shoot development and improved root respiration in seedlings. Sandalwood seedlings develop best in soils with high levels of organic carbon and macronutrients (N, P, K) (Das et al. 2018). The growth in girth and height of a tree is influenced by a range of factors, including the lime status of the soil, its water-holding capacity, pore space, volume expansion characteristics, the presence of exchangeable calcium and magnesium, and the availability of accessible potash (Das et al. 2018).

Nursery techniques

Sandalwood can be propagated through seed germination or vegetative means, such as cuttings or tissue culture. The tree produced profusely seeds after

Seed collection

Sandalwood trees begin to flower after two to three years of vegetative growth. The flowering occurs twice a year, from March to May and from September to December. To ensure the formation of high-quality heartwood, it is recommended to collect seeds from middle-aged or mature trees from forest departments. To gather the fruits, it is recommended to pick them fresh from the trees or to collect the fruits that have recently fallen to the ground. The months of April to May and September to October are the ideal times to gather the pods. After collecting the pods, the fleshy section is removed and the pods are then thoroughly dried. Once the pods have been dried, the fruits are rubbed to remove the pulp and are then shade-dried, treated with a fungicide, and stored in airtight containers (Das, 2021a). The seeds of sandalwood trees are known for their polymorphic characters, which can come in different sizes and shapes. Both the seeds from the two seasons are of comparable quality. To maintain the viability of the seeds for a longer amount of time, it is recommended to store them in airtight containers and to keep them at a low temperature of 5°C (Das, 2021b).

Seed treatment

Sandalwood seeds often exhibit a high level of dormancy, which can be attributed to various factors. These factors include impermeable seed coatings, mechanically resistant seed coats, the presence of primitive embryos, and physiologically immature embryos. Germination begins 4 to 12 weeks after the dormant phase, with 90% of seeds still viable after nine months. Sandalwood seeds have a low germination rate of 20% due to inherent morpho-physiological dormancy, which affects the germination and establishment of seedlings. To enhance seed germination, pre-sowing seed treatments are necessary to break seed dormancy. Black fruits exhibit a higher germination rate compared to brown or red fruits, with rates of 73.2%, 68.2%, and 29.0%, respectively. Soaking seeds in GA_3 solution for 12-16 hours can increase germination to 74% (Chavan et al. 2021), while 24-hour cold water soaking results in 30-40% germination. Removing the seed's testa and dipping it in a fungicide for five minutes can achieve 67% germination for Indonesian sandalwood.

1. A raised bed measuring 3x1 meters in size was prepared using a mixture of red soil, black soil, and farmyard manure (FYM) in a proportion of 3:2:1.
2. The treated seeds, (400 grams), were evenly spread on a raised bed of 3 m^2 area. A layer of 2 cm of potting mixture was used to cover the seeds. The raised beds were then covered with polythene tunnels to help maintain the required humidity and temperature levels for germination and seedling growth.
3. To fasten the germination watering was done twice a day.
4. Germination commenced within 22 days and extended for 45 days. In total, a germination rate of 74% was observed. Seedlings at the 3-4 leaf stage were then transplanted into polybags of 5x7 inch size. Before the transplantation, the bed was irrigated to moisten the soil, and a fungicide solution, such as Bavistin at a rate of 1 g/liter of water, was applied to the soil to protect against fungal diseases.
5. Utmost care is taken in transplanting and to avoid transplanting shock the seedlings were kept in shade for 5-6 days.

6. At the end, GA_3 @ 500ppm was recommended to produce quality planting stock in sandalwood.

The seedlings are transferred into either 500 cc plastic bags or 300 cc hycopots along with *Cajanus cajan* seed once they have grown five to six leaves. The pot host plant *Alternanthera*/ Red gram/ *Mimosups pudica* should be inserted as stem cuttings or seeds when the sandalwood has reached the 4-6 leaf stage. If the pot host is planted too soon, it will grow at a rapid pace and overpower the young seedling, resulting in stunted growth and death of the sandalwood. On the other hand, if the pot host is planted too late, the sandalwood's growth may be slow.

Figure 2: Nursery techniques for enhanced sandalwood seed germination

Carefully uprooting the seedlings with all the roots intact, they are placed in a container with a fungicide solution of Agallol 0.1 percent (Rai 1990). To avoid transplant shock, the seedlings are transplanted with great care and kept in the shade for 5-6 days, making sure the roots do not dry out (Chavan et al. 2021). Daily watering is advised, but excessive moisture should be avoided. The host plants are trimmed regularly to prevent them from growing too tall and hindering the growth of the sandalwood (Rai 1990). Conventional polyethene bags of 13 cm x 30 cm size filled with a potting mixture of soil, sand, and FYM in a ratio of 2:1:1 are used to produce high-quality seedlings. A 6-month-old, well-branched seedling with a brown stem and a height of 30 cm can be transplanted to the field with *Cajanus cajan* or *Mimosa pudica* as the primary host. The seedlings do not require a lot of light in their early stages and need to be shaded (Viswannath and Chakraborty, 2022).

Planting techniques

The following techniques are frequently used in artificial regeneration:

1. Dibbling of Seeds into Bushes: This technique involves depositing four to five seeds at the base of the shrub. It has shown decent success in scrubby forests.
2. Dibbling or Planting of Seeds into Pits or Mounds: Along with sandalwood, a perennial host plant is also cultivated either on the mound or beside the pit. The seedlings are transplanted to the main field in pits at a spacing of 6 m × 2.5 m or 4 m × 3 m after sufficient rain. Certain species like *Cajanus cajan, Ocimum sanctum*, and *Catharanthus roseus* are excellent choices and should be planted alongside sandalwood seedlings. Additionally, *Cynodon dactylon, Albizia saman, Casuarina equisetifolia*, and *Pongamia pinnata* can be selected as secondary host plants in the field. While this technique may involve some expenses, it is known for its high success rate in fostering the growth and development of sandalwood.
3. Planting Container-Raised Seedlings: Healthy seedlings are planted in 50 m3 pits at 3 m × 3 m spacing and alternate rows are sown with various secondary hosts either in a square or staggered manner. This system is called "fence cultivation." Cassia siamea, Schleichera oleosa, Sesbania formosa, Ceiba pentandra, and Aleurites moluccana are suited for this system. The community can use the space between rows to grow food crops like corn, peanuts, green beans, and Cajanus cajan, in addition to side crops and hedgerows. A spacing of 3 × 3 m and 3.6 × 3.6 m was determined to be the best for planting Santalum album with higher growth characteristics and the highest amount of wood, followed by 4.6 × 4.6 m, 5.5 × 5.5 m, and 2.4 × 2.4 m spacing. Figure 2 shows the special arrangement of host and sandalwood in agroforestry systems.

Hosts of Sandalwood

Sandalwood requires a host plant for successful establishment and growth as it is a parasitic plant species. Sandalwood can parasitize other plants, which means that it derives its nutrients and moisture from its host. The selection of a suitable host plant is crucial to the success of the sandalwood plantation. The development of heartwood in sandalwood is impacted by the host tree it parasitizes, environmental conditions, and its age. Sandalwood is known to parasitize a broad range of plants, ranging from grasses to trees, and in some cases, it has been observed to resort to self-parasitism. Lack of a host results in deficiencies in nutrients such as N, P, K, S, Ca, Mg, Fe, Zn, and Cu in sandalwood seedlings (Srikantaprasad et al. 2022).

Sandalwood plants form haustoria with various plant species, referred to as hosts. Some species, especially legumes, are particularly beneficial in promoting the growth and vitality of sandalwood. There are three primary types of host plants used for cultivating sandalwood: pot host, intermediate host, and long-term host.

1. **Pot Host:** The pot host is a low-growing herbaceous plant that is easy to propagate and is typically planted in a poly bag. It serves as an initial host for young sandalwood plants, helping them establish themselves.
2. **Intermediate Host:** The intermediate host is usually a small tree or a large shrub, often a nitrogen-fixing legume. These plants facilitate rapid early growth of the sandalwood and provide necessary support during the initial stages of sandalwood development.
3. **Long-Term Host:** The long-term host is a large tree that acts as a host for the entire sandalwood rotation. These trees need to be pruned and managed to prevent them from outcompeting the sandalwood and to ensure the proper growth and development of the sandalwood over time.

The success of the sandalwood plant and its host plant is measured based on factors such as the number of haustoria produced, survival, growth, vigor, and mortality rate of both the sandal and host plants. Sandalwood relies on host plants for its water and nutrient supply, as it lacks root hairs. This is achieved through the development of haustoria on the sandalwood's roots that attach to the host's roots and transport the necessary resources (Srikantaprasad et al. 2022). The number of haustoria on the sandalwood increases as it ages in the presence of a suitable host (Nagaveni and Srimathi, 1985). With a suitable host, sandalwood trees generally have a thick canopy and wider, darker green leaves, while with an unsuitable host, the leaves are small and yellowish. Leguminous host species such as *Acacia* and *Sesbania* tend to result in better growth of sandalwood. This is likely due to the higher availability of nitrogen which can enhance the formation of haustorial connections. However, it's better to have a mix of leguminous and non-leguminous host species to reduce the risk of decline or death of both the host and sandalwood due to excessive parasitic load.

Within 30 days of germination, the development of haustoria and the necessary host occurs. Although various species have been tested as primary hosts, including *Acacia nilotica, Azardirachta indica, Casuarina equisetifolia and Pongamia pinnata*, farmers prefer *Cajanus cajan* as the primary host in the same pit (Viswannath and Chakraborty, 2022). Horticultural crops, such as mango, pomegranate, ber, custard apple, lemon, and aonla, are also planted as hosts in farmers' fields with an interspace of about 3-4m available in sandalwood plantations. Other annual crops such as Soybean, cowpea, turmeric, and field beans are grown as intercrops in the first 10 years of planting to generate sustainable income. Later, long-term intermediate hosts needed to be planted between the rows of sandalwood, maintaining a minimum distance of 2.5m from the base of sandalwood. Planting the host close to the sandal is not necessary but proximity to other plants within 30 feet can still establish a haustorial relationship (Rocha et al. 2017). Although farmers prefer horticultural crops, studies have reported mortality in *Citrus lemon* and *Punica granatum* after five years of planting with sandalwood rows due to intensive parasitism, but it has also boosted incremental growth in sandalwood. According to the literature, aonla, pongamia, According to some studies, certain short- to medium-rotation tree species such as *Casuarina equisetifolia*, *Sesbania grandiflora*, *Melia dubia*, and *Acacia mangium* can serve as good hosts for sandalwood, but they are typically harvested after 8 to 12 years, making them unsuitable for long-term hosting. To ensure the longevity of sandalwood, it is recommended to choose perennial species over annuals or short-rotation species, neem, babul and lemon are the best secondary hosts among all.

Table1: Suitable good host species for sandalwood

Host	Host species
Primary host	*Cajanus cajan, Mimosa pudica* (nursery stage) *Macrotyloma uniflorum, Alternanthera* sp. *Cajanus cajan, Catharanthus, Zea mays, Arachis hypogaea* and, *Phaseolus radiatus*
Intermediate host	*Annona squamosa, Carica papaya, Moringa oleifera, Psidium guajava, Punica granatum* *Sesbania grandiflora, lemon Casuarina equisetifolia, Melia-dubia*
Secondary/ long host	*Acacia nilotica, Emblica officinalis, Grafted Tamarind, Acacia nilotica, Azardirachta indica, Mango and Zizyphus, Dalbergia sissoo, and Acacia mangium, Acacia nilotica and Cassia siama, Prosopis juliflora*

The ideal ratio of host to parasite plants is 1:1, however, a ratio of 2:1 or 3:1 can also be considered. The current practice is to have 4 host plants with a spacing of 5m x 5m and 1 sandal plant in the middle. It's recommended to have a mix of leguminous and non-leguminous commercially important trees as hosts with sandalwood as the subsidiary crop.

Planting and aftercare

The cultivation of sandalwood is a complex process due to its relationship as both a host and a parasite. Sandalwood requires proximity to a host plant to extend its lateral roots and establish association, while also needing space to avoid hindering its growth. The ideal spacing between sandalwood and host is 1.5-3 m. Beyond 2.2 m, the growth of sandalwood is significantly impacted and its attraction to the host is limited to 3 m. In the absence of a host, sandalwood may parasitize its root suckers for survival.

At planting time, a pit of size 3×3×3 meters can be dug in summer conditions with spacings of 4×3 meters, 6×2.5 meters, or 6x5 meters. The current practice is to have a 5m x 5m spacing for host plants with a sandalwood tree at the centre surrounded by four host plants, with a host-to-parasite ratio of 4:1. It is recommended to use a variety of host species that include both leguminous and non-leguminous commercially important trees, while sandalwood serves as a secondary crop

The pit can be filled with a potting mixture of 3 parts soil, 2 parts sand, and 1 part FYM (farmer's yard manure) for optimal root growth and seedling establishment. After planting the sandalwood, a suitable host plant can be planted in an alternating pattern or alternate rows. Some farmers choose to plant the host in the same basin as the sandalwood for early haustorium formation and connection. After planting, Inter-culture operations can be carried out, utilizing appropriate host crops that can provide additional income and serve as hosts for sandalwood, while also adding nitrogen to the soil. Fertilizers such as a mixture of NPK (10:26:26) can be placed at the time of planting at a rate of 40 grams per plant gives better growth. The amount of fertilization varies based on the size and age of the plant, with a yearly recommendation of 30-50 grams of nitrogen, 25-50 grams of P_2O_5, and 30-50 grams of K_2O, in addition to 40 grams of FYM per plant.

To obtain a valuable carving log from sandalwood, it is crucial to have a single-stemmed trunk without branches. This is typically achieved through early formative pruning within the first 3-4 years, improving the chances of obtaining a desirable carving log. The development of heartwood begins in the roots and the lower part of the tree and gradually moves upward. A fork in the trunk can impede this process. It's important to note that pruning is no longer effective for trees older than 3-4 years and can harm the tree's overall growth. Without early pruning, the chance of obtaining a carving log and extending the rotation may be lost. Pruning should be performed cautiously, with a spacing of up to 10 feet over a 2–4-year period. Prune only branches and branch clusters smaller than a little finger, once a year. Avoid reducing the height of the tree by more than one-third, and retain at least 40-50% of the canopy. A canopy that covers approximately two-thirds of the tree's height provides adequate space for photosynthesis and promotes healthy growth.

Harvesting and yield

Sandalwood is a slow-growing tree species that requires a minimum rotation period of at least 30 years in natural conditions. The commercial value of sandalwood is determined by the concentration of santalol and the amount of heartwood, not the total wood biomass. Heartwood begins to appear after 7 years of development and ideal conditions for its creation include gravelly dry soil, insolation, and an elevation range of 500-700m. The concentration of heartwood varies in the stem depending on location and may make up to 90% of the stem wood. Trees with higher oil content in their roots are typically uprooted instead of chopped from the ground level. Heartwood and oil percentages increase with age, with mature trees having more than 90% santalol and 2-6.2% oil content in their heartwood. Indian trees with 100cm girth have produced 85 kg to 240 kg of heartwood and each tree can produce at least 1 kilogram of heartwood annually after 20 years in Tamil Nadu conditions.

The heartwood production of wild sandalwood trees typically begins around 27-30 years of age, with an estimated yield of 25-30 kilograms (Das 2021). With the implementation of modern cultivation techniques, trees with a diameter of around 15 cm at breast height have been observed to produce at least 15 kilograms of heartwood by the age of 15 years, making this a more economically viable rotation period than the previously believed 20 years (Mishra et al. 2018). Recent studies have shown that heartwood initiation can occur as early as 6-8 years of age and substantial heartwood can be formed by 15 years.

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Promising fodder crops for resource poor situations

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Introduction

The increasing demand for animal-derived food products such as milk and its by-products, meat, and related items, coupled with declining returns for traditional agriculture, has generated significant interest in animal husbandry and dairying, both in rural and urban areas. Rising prices of these commodities also serve as incentives for promoting animal husbandry (Anonymous, 2015). One of the critical factors determining the cost of animal maintenance in the country is the availability of quality fodder in sufficient quantity, which accounts for approximately 50% of the total cost. As a result, India is the world's largest milk producer (207 million metric tons as of 2022-23) and ranks first in the total buffalo population, second in cattle and goats, and fourth in sheep population. Despite the highest milk production, the productivity of Indian livestock is 20-60% lower than the global average. Therefore, a crucial challenge for us is to enhance livestock productivity with existing fodder resources and a diminishing land area through technological intervention.

Over the years, the reliance on crop residues as a source of fodder has become increasingly untenable and unreliable due to structural changes in agriculture. Modern-day crop varieties with higher harvest indices reduce fodder availability. Additionally, the poor quality of fodder due to unsafe use of pesticide makes crop residues less suitable for animal consumption. Overall, the net deficit of fodder in the country has been gradually increasing over the years. Presently, India faces a net deficit of green fodder by 35.6%, dry fodder by 10.5%, and concentrate feed by 44% (Anonymous, 2015). In animal husbandry, there have also been subtle shifts from traditional breeds to high-yield exotic breeds and crossbreeds and from subsistence animal husbandry to modern high-tech systems that require quality fodder to fully realize the benefits of animal husbandry. Recently, there has been a shift towards goat and sheep rearing, leading to increased pressure on sensitive natural grazing resources and placing strain on land resources. Moreover, the nature of animal husbandry, primarily undertaken by small and medium landholders who keep more animals than large landholders, raises questions about feasibility. Small landholders often struggle to meet the fodder demand due to an inability to grow fodder consistently to meet their requirements. Additionally, those who rely on crop residues as a source of animal fodder often face difficulties due to shortages and an overemphasis on food crops. This creates an imbalance in the demand and supply of fodder in the country, resulting in a significant gap at both national and state levels.

Other important challenges in fodder production include variations in availability due to growing conditions and seasons. Rain-fed areas face acute fodder shortages during lean periods like summer, where there is a complete absence of fodder availability. In irrigated areas, the feasibility of fodder availability depends on the types of food crops grown and the economics of agricultural production. This also hinges on the nature of animal husbandry; modern-day dairy-based animal husbandry with high-yielding animals requires a continuous supply of green and dry fodder along with feeds. The high cost of fodder during lean periods and the uneconomic returns in concentrate-based animal husbandry are causing significant stress for animal keepers. Additionally, issues such as regional scarcity of rainfall, dry and hot climates, regional fodder deficits, imbalanced rations (with only crop residues accounting for less than 60% of the diet), heavy dependence on commercial concentrates, non-preference of fodder crops in fertile lands, availability of problematic soils (saline, poor physical conditions), and lack of awareness and knowledge collectively contribute to poor per-animal productivity. These challenges can be effectively addressed through systematic planning and execution of fodder production plans on farmers' fields (Anonymous, 2017). A rational mix of annual and perennial fodder crops will ensure a continuous supply of fodder to animal stock throughout the year under different farming systems. Annual fodder crops such as fodder maize, fodder sorghum, fodder bajra, and fodder cowpea have already become major components in animal husbandry-based systems, both in rain-fed and irrigated farming systems (Kumar et al., 2012). The selection and cultivation of perennial fodders like bajra napier hybrid, guinea grass, lucerne in irrigated areas, and signal grass, perennial fodder sorghum, and *Stylosanthes* in rain-fed areas could provide stability to animal-based farming systems by ensuring a steady supply of green and dry fodder to the animals throughout the year.

Perennial fodder crops constitute an important component of modern-day animal husbandry. They are capable of effectively meeting the fodder requirements without adversely affecting the farmers' economy and can offer monetary returns comparable to the best food and commercial crops, even under irrigated areas with high productivity and palatability. It is imperative to understand the nuances of selecting suitable fodder crops and their production technology to maximize the benefits from these crops (Anonymous, 2018). Perennial fodder, by providing continuous green fodder through recurrent cuttings for more than 2-3 years without the need for repeated sowing or planting, proves to be less burdensome for growers and ensures higher monetary returns compared to other sources of fodder. Many perennial fodder crops have been successfully grown in different agro-ecosystems. In the states of Karnataka, Maharashtra, and Tamil Nadu, bajra napier hybrid, guinea grass, lucerne in irrigated conditions, and signal grass, perennial fodder sorghum, and *Stylosanthes* in rain-fed areas have proven to be highly successful with farmers (Kumar et al., 2012). In this chapter, authors have made an effort to explain the important fodder crops, their yield potential and possible management practices.

1. Anjan grass

- Commonly known as Buffel, African foxtail grass, and Anjan, the botanical name for this species is *Cenchrus ciliaris* Linn.
- It is a perennial, tufted grass that stands between 0.3 to 1.2 meters in height and bears dense inflorescence. Native to arid and semi-arid sub-tropical regions characterized by dry sandy terrain, it thrives in areas such as Rajasthan, Punjab, Haryana, Gujarat, and certain parts of western Uttar Pradesh and Tamil Nadu. Buffel exhibits robust adaptability, flourishing in zones with precipitation levels ranging from 125 to 1250 mm. It demonstrates remarkable resilience to drought conditions and also exhibits vigorous growth under irrigation. Notably, it retains its nutritional value admirably even in fully ripened states.
- In terms of soil and land preparation, Buffel thrives best in well-drained soils with a light to medium texture. Its successful establishment on heavier soils, particularly clay or lateritic compositions, is limited, especially on soils deficient in lime content.
- Several varieties of Buffel have been identified, including Mallapo, Buttel, IGFRI No.3108, 3132, CAZRI-358, and Marwar Anjan (75). For soil conservation purposes, strains such as S-262 and S-358 are recommended.
- The recommended seed rate for Buffel is 4 to 5 kg per hectare for line sowing. Alternatively, six-week-old seedlings or rooted slips can be transplanted at a spacing of 50 x 30 cm, amounting to 33,000 seedlings or rooted slips per hectare, with two seedlings at each spot.
- Sowing should be done at a depth of 0.5 to 1.0 cm. Following sowing, a small twig or branch from a tree is utilized to gently cover the seeds with a thin layer of soil.

- In terms of nutrient management, a basal application of Farm Yard Manure at 5 t/ha, along with 40 kg of N and 20 kg of p, is recommended. An additional 20 kg of N per hectare can be top-dressed after one month of crop growth. In subsequent years, a single top dressing of 40 kg N + 20 kg P_2O_5 per hectare is advised at the onset of the monsoon. An additional dose of 20 kg N per hectare may be applied after the first harvest to enhance fodder yield.
- Regarding harvest management, Buffel undergoes a single cut at 60 days, typically in mid-October during the first year. Subsequently, it yields 3-4 cuts or more. It is advisable to maintain a cutting height of 5-10 cm from ground level to encourage healthy regrowth in subsequent years.
- Forage yield from a well-established Buffel pasture ranges from 9.0 to 11.0 t/ha of green fodder in arid regions with less than 300 mm of rainfall. In semi-arid regions with 950 mm of rainfall, the yield varies from 6.0 to 11.4 t/ha.

2. Pearl millet (fodder bajra)

- Commonly known as Bajra, with the botanical name *Pennisetum glaucum* L., this forage crop holds significance in tropical climates due to its high nutritive value and palatability. It can be utilized as green fodder, dried forage, or conserved as hay or silage. Bajra displays notable resilience in conditions of soil moisture stress.
- For optimal growth, well-drained sandy loam to loamy soils with good drainage are essential. A pH range of 6.5 to 7.5 is preferable, as Bajra cannot thrive in acidic soil conditions. Adequate land preparation involves a single ploughing with two harrowing and planking. Prolonged water stagnation should be avoided.
- Here are some recommended varieties along with suitable areas and green fodder yields (t/ha) for different purposes:
  - **Single cut varieties:**
    - Raj bajra chari-2 (suitable for the entire Bajra growing region, yield: 35-40)
    - CO-8 (suitable for all of India, yield: 35-50)
    - APFB (suitable for Andhra Pradesh, yield: 30-40)
    - GFB-2 (suitable for Gujarat, yield: 30-40)

- **Dual-purpose variety:** Avika bajra-1 (suitable for central India, yield: 35-40)
- **Multicut varieties:** Giant bajra (suitable for all of India, yield: 55-100), Pro agro No.1 (yield: 65-95)

- The recommended seed rate for Bajra is 10-12 kg per hectare, with sowing at 25 cm row spacing and a depth of 1.5-2.0 cm.
- Sowing timings vary:
  - For summer (March to mid-April)
  - For monsoon season (after the onset of rain in the first fortnight of July)
  - In southern India, rabi sowing is recommended during October and November.
- Intercropping with clusterbeans, cowpea, and lablab is suitable for semi-arid to arid areas. A 1:1 row ratio of pearl millet and cowpea has proven to be effective in most growing situations.
- For nutrient management, apply 10 t FYM/ha as basal, along with 50:30:30 kg $N:P_2O_5:K_2O$/ha. Follow this with top-dressing of N at 30 kg/ha one month after sowing. Additionally, N at 20-30 kg/ha can be applied coinciding with rain at 30-35 days after sowing in rainfed conditions. A 2% urea solution spray is recommended for enhanced biomass production during dry spells. Seed treatment with *Azospirillum* improves fodder yield and reduces N fertilizer requirements by 15-20%.
- In terms of water management, rainfed crops may require 1-2 irrigations depending on rainfall distribution, while summer-sown crops demand 4-5 irrigations due to high evaporative demand.
- Effective weed management includes one hoeing through a weeder cum mulcher at 3-4 weeks. Atrazine @ 0.50 kg a.i./ha can be applied as a pre-emergence herbicide in 600 liters of water. Pre-emergence spraying of alachlor @ 1.0 kg a.i. per ha is advised in intercropping with cowpea or guar.
- For disease and insect-pest management, seed dressing with Metalaxyl @ 2.0 g/kg of seeds or Ridomil @ 1000 ppm spray can be employed against ergot and downy mildew.
- Harvesting management varies based on a variety type:
  - Single cut varieties should be harvested at 55-60 days after sowing (initiation of flowering).
  - Multicut varieties should receive the first cut at 40-45 days after sowing, with subsequent cuts at 30-day intervals.

3. Fodder Cowpea

- Commonly known as Lobia, with the botanical name *Vigna unguiculata* L., this leguminous crop is known for its rapid growth and is typically cultivated in combination with cereal fodders and grasses to enhance the nutritional content of the forage. It boasts a high crude protein content of 20-24% with over 70% digestibility. Lobia can be cultivated during both the kharif and zaid seasons.
- For optimal growth, it is best suited to light-textured soils with good drainage capabilities. Achieving a levelled and weed-free seedbed for prompt germination necessitates two rounds of cross harrowing and planking.
- Here are some recommended varieties along with suitable areas and green fodder yields:

Variety	Condition/ location	Yield (t/ha)
EC-4216	North zone	30-35
UPC-5286	Whole country	35-40
IFC-8503, EC-4216	North, West and Central India	30-40
UPC-5287	North zone	30-45
FC-8	Tamil Nadu	30-45
UPC-4200	North-East region	30-35
GFC-1, GFC-2, GFC-3, GFC-4	Gujarat	25-35
Sheweta	Maharashtra	35-40
Bundel lobia-1	Whole country	30-35
Bundel lobia-2	North west zone	35-40
UPC-618, UPC-622	North- west, North-east and Hill zone	35-45

- Sowing should be carried out in irrigated areas during summer, and in rainfed areas after the onset of rains. In summer, the sowing period extends up to mid-July starting in March. In southern regions, sowing can be done throughout the year.
- For seed rate and sowing, 35-40 kg/ha is recommended. Sowing should be conducted using a seed drill or behind the plough with an inter-row spacing of 25-30 cm and a depth of 2-3 cm.
- Lobia fits well into various cropping systems, thriving alongside other food and fodder crops as an intercrop at different proportions. Consequently, it plays a crucial role in intensive cropping.
- Regarding nutrient management, while Lobia possesses nitrogen-fixing capabilities, applying 20 kg N and 60 kg P_2O_5/ha as a basal treatment promotes robust growth. In soils deficient in sulfur (below 10 ppm), an additional 20-40 kg of sulfur per hectare is recommended.
- Water management for the kharif season crop typically does not require irrigation, except in cases of prolonged dry spells (in which case irrigate at intervals of 10-12 days). Conversely, the summer crop necessitates 6-7 irrigations with intervals of 8-10 days.
- For weed management, Kharif crops may experience dense weed infestations at the initial stage. One round of hoeing, manual weeding, or using a weeder cum mulcher at 3 weeks of crop growth proves effective. Pre-plant soil incorporation of Trifluralin or Fluchloralin@0.75 kg a.i. /ha is also advisable.
- In terms of insect pest management, spraying profenophos at 2 ml/l against leaf-eating caterpillars at the seedling stage and at 25 days after sowing (DAS) is recommended. In cases of severe pod borer infestation, consider spraying fame (flubendamide) at 0.3 ml/l and actra (thiomethaxam) at 0.3 ml/l.
- Harvesting during the rainy season should occur after 50-60 DAS at 50% flowering, while the summer crop may require a few additional days. Under irrigated conditions, cowpea crops yield approximately 25-30 t/ha of green biomass. In rainfed conditions, yields are lower, ranging from 15-20 t/ha.

4. *Guinea grass*

- Commonly known as Guinea grass, its botanical name is *Panicum maximum* Jacq. This tall, perennial, robust grass is indigenous to tropical and sub-tropical regions of Africa. It stands out as the most valuable fodder plant, characterized by its high leaf-to-stem ratio, rendering it exceptionally palatable. Guinea grass is widely cultivated to provide green and nutritious fodder across the country.
- In terms of soil and land preparation, Guinea grass displays adaptability to a broad spectrum of soils, thriving best in deep soils with medium to high fertility. To ensure a successful crop, it is recommended to undertake 2-3 ploughings accompanied by planking.

❖ Here are some varieties, suitable areas, and green fodder yields:

Variety	Condition/ location	Yield (t/ha)
Macuenni Kerala	Rainfed	-
Hamil	South and North-East central India	70-85
PGG-1 and PGG-9	Hill and North west	70-100
PGG-14	Central India	95-140
PGG-19 and PGG-101	Punjab	90-120
CO-1 & CO-2	Tamil Nadu	200-280
Bundel guinea-1	Sub temperature hills, North -west, central and south zone, rainfed,	60-80
Bundel guinea-2	Entire country rainfed	70-90

❖ Sowing/planting time:
- Under irrigated conditions: from mid-February to July.
- Under rainfed conditions: during the monsoon season.

❖ The recommended seed rate for Guinea grass is 3-4 kg/ha. For sole stand cultivation, rooted slips of 40,000 are required, whereas for intercropping, 20,000 rooted slips are needed. The rooted slips, aged 20-25 days, should be planted with a spacing of 50 cm x 50 cm.

❖ Guinea grass is integrated into various cropping systems, such as Guinea grass + (cowpea-berseem), sole Guinea grass, Guinea grass in horti-pasture, and Guinea on field bunds.

❖ For nutrient management, it is advised to apply 20-25 t/ha of farm yard manure during land preparation. Additionally, a basal application of 60 kg N, 50 kg P_2O_5, and

40 kg K_2O/ha is recommended. After each cut, apply 40 kg N/ha. Guinea grass exhibits positive responses to organic manures and biofertilizers like *Azotobacter* and *Azospirillum*.

- In terms of water management, regular irrigation at intervals of 10-12 days is necessary, especially during the summer months.
- Inter-cultivation involves regular hand weeding and hoeing to ensure proper aeration for crop growth and effective weed control.
- Disease and insect-pest management for Guinea grass are generally straightforward, as it is not significantly affected by pests or diseases. Leaf spot, caused by *Bipolaris hawaiiensis*, is occasionally observed during the wet season.
- Harvesting management begins with the first cut at 60-65 days after planting, followed by subsequent cuts at intervals of 25-30 days.

5. *Fodder maize*

- Commonly referred to as Makka, with the botanical name *Zea mays* L., this versatile crop is widely cultivated throughout the country. Known for its faster growth, high yield, and palatability, it remains digestible at any stage. Makka serves as excellent fodder whether fed green or dry, and it is also a valuable component in silage production.
- Here are some recommended varieties, suitable areas, and green fodder yields:

Variety	Condition/ location	Yield (t/ha)
African Tall	Suitable for the entire country	55-80
Vijai, Jawahar composite, and Moti	Suitable for the entire country	35-47
J-I006	Suitable for Punjab	45-55
VL-54	Suitable for hilly areas	30-45
APFM-8	Suitable for the South zone	35-40
Pratap Makka Chari-6	Suitable for the North-west zone	45-50

- Sowing time depends on the region:
  - Irrigated areas: February last week to March last week.
  - During the rainy season: June-July.
  - Sown as *rabi* crop in October-November, particularly in southern and eastern parts of the country.
- The recommended seed rate of 40-50 kg /ha should be line-sown in 30-40 cm row spacing.
- For intercropping, a combination of Maize (30 kg/ha) and cowpea (20 kg/ha) in paired alternate rows (2:2) is preferred across the entire growing tract.
- In terms of nutrient management, apply FYM at a rate of 12-15 t/ha and 80-100 kg N + 40 kg P_2O_5/ha. At sowing, apply 50% N + 15-20 kg $ZnSO_4$/ha, and the remaining half at the knee-high stage. For mixed crops, apply 35 kg N + 40 kg P_2O_5/ha as basal, and 35 kg N at the knee-high stage. Incorporating biofertilizers such as *Azospirillum* and *Azotobacter* with nitrogen fertilizers can save 15-20% of nitrogen fertilizer.
- Water management: Requires 5-6 irrigations at 10-12 days intervals during summer, 3-4 during winter, and 1-2 during the rainy season. Ridge planting is recommended in areas where water stagnation is more than 15 days.
- Bacterial stalk rot disease can be managed by soil drenching with bleaching powder at a rate of 3 g/10 litres of water.
- Crop is ready for harvest at 60-75 days after sowing (silking stage) for fodder purposes. This can continue up to the milk stage. Early harvesting produces higher quality fodder but may reduce yield, while late harvesting may adversely affect fodder quality.

6. *Bajra Napier Hybrid (BNH)*

- Commonly known as Sankar Napier, its botanical name is Napier Bajra Hybrid (*Pennisetum glaucum* × *P. purpureum*). This hybrid grass has higher value due to its abundant herbage yield, year-round palatability, and high-quality fodder. It is prominent fodder due to its versatile and rapid growth, suitable as green fodder, silage, and hay. However, it is not tolerant of flooding or waterlogging.

- In terms of soil and land preparation, well-drained clay loam soil is preferred. It can tolerate soil acidity up to a limited extent of pH-5.5. Achieving a fine tilth typically requires 2-3 ploughings and planking.
- Here are some recommended varieties, suitable areas, and green fodder yields (t/ha):

Variety	Condition/ location	Yield (t/ha)
IGFRI Hybrid Napier	North and Central zone	70-100
NB 21	Suitable for the entire country	100-160
CO-1	South zone	300-350
CO-2	South zone	350-450
CO-3	South zone	400-450
Yashwant	Maharashtra	190-250
PBN 83	Punjab	125-170
APBN-1	Southern region	260-295
IGFRI-10	North and Central zone	185

- Propagation is solely through vegetative cuttings, and can be done throughout the year, except during winter months. Under assured irrigation February planting is recommended whereas, July-August is suitable under rainfed conditions.
- For sole crops, approximately 35,000 rooted slips or stem cuttings with two nodes per hectare are needed. For intercropping, about 20,000 rooted slips are required. Stem cuttings should be planted in soil at 45-degree angle with the spacing of 75 cm x 50 cm, in which one node should be pushed into soil and one should remain above the soil surface.
- For nutrient management, apply 20-25 tonnes of farm yard manure per hectare during land preparation. The basal dose should be 60:50:40 kg N, P_2O_5, and 40 kg K_2O per hectare. After each cut, apply 30 kg N per hectare (approximately 240 kg N per hectare per year).
- During the monsoon season, irrigation is less needed. The crop requires regular irrigation at intervals of 15-18.
- Periodical hand weeding/hoeing is crucial for providing good aeration, promoting crop growth, and controlling weed growth.
- For harvesting management, the first cut should be given at 60-65 days after planting, and the subsequent cuts should be done at an interval of 25-30 days. A minimum of 6-

8 harvest can be taken annually. To facilitate quicker regeneration, stubbles of 10-15 cm should be left in field at the time of harvesting.

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Application of Feed for Stress Management in Aquaculture

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Introduction

Aquaculture has established itself as the most rapidly expanding food production sector, with an impressive annual growth rate of 7.5% since 1970. This substantial growth is primarily fuelled by the increasing global appetite for fish and seafood products. This heightened demand stems from increased fish consumption and stagnant production from capture fisheries, leading to a growing reliance on aquaculture. To sustain the current rate of fish consumption globally, aquaculture production must reach 109 million metric tons by 2030. To attain this, the aquaculture sector has undergone expansion both in terms of intensity (vertical growth) and scale (horizontal expansion) in recent years. The intensification of aquaculture systems has proven to be a promising approach, especially as available land resources continue to dwindle. The success of aquaculture largely hinges on the fish's culture environment, physiology, and health status. Over the years, the routine use of antibiotics, pesticides, synthetic growth promoters, and other chemicals has become commonplace in aquaculture to boost production levels. Nonetheless, the indiscriminate application of synthetic chemicals disrupts the ecological equilibrium, subjecting aquatic organisms to increased stress.

The overall stress experienced by fish results from the cumulative and interactive effects of multiple stressors. These stressors include disturbances in the aquatic environment due to changes in physical and chemical factors such as temperature, pH, dissolved oxygen (DO), ammonia, and nitrite. These stressors contribute to poor growth, immunosuppression, decreased disease resistance, and ultimately, the mortality of cultured fish resulting in financial losses for aquafarmers. Stress has a significant economic impact and is now a critical factor affecting the sustainability of aquaculture. However, intensive aquaculture operations require controlled and monitored environments; failure to ensure these conditions can lead to stressful situations that compromise the health and survival of the fish. Hence, stress should not be overlooked when striving for sustainable aquaculture production, and enhancing the stress resilience of fish is of utmost significance in achieving targeted production levels. In this regard, the aquaculture sector is actively exploring strategies to mitigate significant economic losses resulting from stress or stress-induced vulnerabilities in fish.

Over the last few decades, our comprehension of stress in aquaculture has made substantial progress, revealing the physiological mechanisms that influence growth, metabolism, immunity, reproduction, and, ultimately, productivity.

Consequently, monitoring and managing stress in fish have become pivotal in the aquaculture sector in recent years. Mitigating stress in fish can lead to enhanced farm productivity, making stress alleviation an essential pathway toward optimizing sustainable aquaculture. Therefore, the implementation of empirical stress management strategies is crucial for the industry's sustainability and economic success. In recent years, several studies have concentrated on efficiently managing and alleviating stress in fish and aquaculture through a variety of methods. Embracing a dietary intervention approach, which encompasses the supplementation of nutritional and non-nutritional compounds and additives to mitigate stress in fish, has demonstrated both promise and practicality. Nevertheless, data regarding stress-alleviating compounds and additives in fish is dispersed, and currently, there is no comprehensive reference document accessible for researchers and aqua nutritionists. Therefore, the need of the hour is to compile all the existing scientific knowledge into this chapter. We aim to summarize the importance of feeding, feed types and management for feeding practices to mitigate the stress response in aquaculture.

Types of feed Ingredients in Aqua Feeds

Fish is one of the most economical sources of protein, and this vital protein is derived from fish and prawns through the utilization of both natural and artificial feed ingredients, including those sourced from animals and plants. Understanding the biochemical composition, such as protein, carbohydrates, fats, vitamins, and minerals, is crucial for identifying and selecting appropriate feed ingredients when formulating diets for fish and prawns. Meeting the nutritional requirements of fish and prawns in aquaculture is fundamental, and it is the responsibility of nutritionists, feed mills, and feed manufacturers who collaborate with aquaculturists to provide these essential dietary needs for the animals.

Criteria for selection of feed ingredients

- When selecting feed ingredients for prawn feeds, several key factors need consideration, whether it's for commercial or on-farm production:
- Availability of Regular and Local Ingredients: Prioritize ingredients that are consistently and locally accessible.
- Nutritional Suitability: Assess the ingredients' suitability based on the nutritional requirements of the target species.
- Cost-Effectiveness: Evaluate the overall cost of feed ingredients, including raw material costs and transportation charges.
- Handling and Processing Requirements: Minimize the need for complex handling and processing, including transportation logistics.

- Ingredient Freshness: Ensure the ingredients are fresh and free from any off-flavours. Maintain a moisture content within the range of 10-13%, as moisture levels above this range can lead to fungal growth.
- The quality of the ingredients directly impacts the quality of the feed. Therefore, consumer decisions regarding ingredient selection play a pivotal role in maximizing profitability within the aquaculture system.

Classification of feed ingredients

While it's important to note that the nutrient content of individual feed ingredients can vary significantly from one country or region to another, depending on factors such as local climate, storage conditions, maturity at harvesting, post-harvest processing methods, and storage duration, we can still make some generalizations about the chemical composition of these feedstuffs.

The ingredients divided into two parts

1. Energy rich feed ingredients
2. Protein rich feed ingredients

Protein-rich feed ingredients typically contain more than 20% crude protein, while energy-rich feed ingredients contain more than 20% crude protein and less than 18% crude fibre. These protein-rich feed ingredients can be derived from both animal and plant sources. It's worth noting that protein from animal sources generally has a more favourable amino acid profile compared to plant-based proteins.

A wide variety of ingredients are available for use in fish and crustacean feeds. Some of these ingredients are listed below:

1. Cereals
2. Animal products
3. Root crops
4. Grasses
5. Legumes
6. Oil bearing seeds and oilcakes
7. Miscellaneous fodder plants
8. Miscellaneous feed stuffs
9. Additives

1. **Cereals**

Cereals and cereal by-products, despite their high carbohydrate content, are essential components in aquaculture diets. The starch content in these ingredients plays a crucial role in enhancing the water stability of the feed, especially during heat-based processing. Additionally, cereals significantly contribute to the overall protein and lipid content of the diet. While they may be deficient in certain amino acids, such as Lysine, cereals can effectively complement high-protein animal and vegetable ingredients. Some common cereals used in aquafeeds include sorghum, maize, wheat, and the remains left after starch extraction from grains. Plant proteins typically contain crude protein within the range of 20-30%, examples of which include corn gluten meal and wheat gluten meal.

2. **Animal products**

Animal by-products can originate from terrestrial, avian, or marine animals and represent vital ingredients in aquaculture feeds. They play a crucial role in addressing amino acid and vitamin deficiencies often found in cereals and other plant-based ingredients within complete diets. Remarkably, animal by-products, like fish meal, are thought to contain yet-to-be-identified growth-promoting factors. Among these by-products are blood meal, feather meal, poultry by-products meal, fish meal, meat meal, raw fish, fish oils, fish silage, shrimp meal, and a variety of other sources from both aquatic and terrestrial origins.

3. **Root crops**

Root crops, while rich in carbohydrates and thus serving as an excellent source of energy, have limitations when used in aquaculture due to their deficiencies in protein, calcium, phosphorus, and vitamins.

4. **Grasses**

Grasses are typically utilized in their fresh form or as hay or silage. In the case of fish and prawn, grasses are primarily employed as a source of carotenoids. Due to their high fiber content, grasses have limited value in fish feed, except for herbivorous fish.

5. **Legume**

Ipil-ipil and alfalfa have proven to be successful ingredients in aquaculture feeds. Legume fodder is renowned for its richness in protein, typically ranging from 20-25%, and minerals. However, leguminous seeds often exhibit richness in lysine but deficiency in methionine. Some common legumes used in fish feed include acacia, clover, lucerne, groundnut (peanut), gram, lentil, locust beans, guar, chickpeas, ipil-ipil, lima beans, field peas, mung beans, and soybeans.

6. Oil bearing seeds and oilcakes

Oilseeds typically boast higher protein content than cereals, typically ranging from 20-50% protein. However, oilseeds are deficient in essential amino acids such as lysine, and some may also lack threonine. Common examples of oilseed cakes include groundnut or peanut cakes, mustard oil cake, linseed oil cake, cottonseed cake, sesame meal, soybean oil meal, sunflower oil meal, safflower meal, and others.

7. Miscellaneous fodder plants

The leaves and other aerial parts of numerous plants, which are not primarily cultivated for fodder, fall into the category of miscellaneous fodder. These plant parts are typically prepared through methods like soaking in water and/or sun-drying and are used in the form of leaf meal. For instance, examples include cassava leaf meal (*Manihot esculenta*) and ipil-ipil leaf meal (*Leucaena leucocephala*).

8. Miscellaneous feed stuffs

Numerous other ingredients possess the potential for utilization in aquaculture feeds; nevertheless, their complete value has not been comprehensively evaluated. Several of these ingredients, often termed as unconventional or non-traditional feedstuffs, are deemed conventional feed components for other animals. This category of feed ingredients includes leaf protein concentrate, minerals, seaweed, by-products from the sugar and fermentation industries, lipids, microbial proteins, algae, manures, and cellulases.

9. Additives

An expanding range of additives is being incorporated into animal feed, including synthetic amino acids, vitamins, binders, antioxidants, preservatives, prophylactic medications, hormones, and growth enhancers. Many of these additives serve very specific functions and may not be primarily nutritive. For instance, some examples include amino acids like L-lysine and DL-methionine, vitamins, binders such as CMC, agar, and carrageenan, antioxidants like BHT and BHA, carotenoids, and preservatives like propionic acid and benzoic acid, among others.

Farm Feeding Management

In any aquaculture operation, feeding is the most important daily activity, consuming a significant portion of staff time, regardless of the technology employed. Cultured organisms can be fed through one of two methods: manual broadcasting or the use of feeders, or by suspending feed on bamboo poles (20-30 per hectare), or by employing a catamaran. It is crucial to provide quality feeds to ablated shrimps, as the fecundity and egg quality depend on the feed's quality. Fresh feeds, such as the flesh of clam (*Meretrix casta*), mussel (*Perna viridis*), squid (*Loligo sp.),* polychaete worms, and Artemia biomass rich in long-chain polyunsaturated fatty acids, are used as maturation feeds. Clams, squid, mussel, and oyster meat are rotated, making up 15% of the total biomass and distributed four times a day, while polychaete worms (6% of the biomass) or Artemia biomass (3% of the biomass) are provided once daily. Research on the nutritional requirements of penaeid shrimps has demonstrated that polyunsaturated fatty acids (PUFA) such as arachidonic acid, eicosapentaenoic acid, and docosahexaenoic acid are essential for the shrimps to reach maturity. Therefore, pelleted feeds containing 50% protein and 10% PUFA are provided to achieve the desired results. The best outcomes can be obtained by using fresh feeds in combination with pellet feeds.

Feeding schedule for Carps:

Carps are herbivorous and omnivorous in their feeding habits, consuming both zooplankton and phytoplankton in ponds. In a cultured environment, fish are provided with supplementary and artificial feeds at varying doses.

Feeding schedule for Indian Major Carps

S. No.	Stage of the fish	Body weight (g)
1	Spawn	
	1st 5 days after stocking	Double of the body weight
	6th to 10th days after stocking	Three times of the body weight
	11th to 15th days after stocking	Four times of the body weight
2	Fry	5-10% of the body weight
3	Fingerling	
	1st Year	2-5% of the body weight
	2nd year	5-6% of the body weight
4	Adult	2-3% of the body weight
5	Brood fish	1-2% of the body weight

Size: Spawn 6-7mm; Fry 14-25 mm; Fingerling 40-100 mm; Adult 300-400 mm

Feeding methods

1. **Broadcasting:** Broadcasting or hand feeding is the most common form of feeding in semi-intensive and intensive cultural practices to varying degrees. It is a labour-intensive method. Hand feeding essentially involves the dispersion of a known quantity of food into the system.

2. **Feeders:** There are two types of feeders, automated and mechanical feeders to dispense feeds.

I. Automated feeders

The use of automated feeders not only reduces labour costs on the farm but is also claimed to improve the Feed Conversion Ratio (FCR) and minimize the need for manual feed handling. Automated feeders also enable feeding at any time of the day and every day of the year. This advantage is particularly significant in cases of labour constraints and for off-shore cage culture operations.

II. Mechanical feeders

Automated mechanical feeders come in two basic types: Non-demand and Demand types.

(i) Non-demand feeders: In non-demand feeders, feed is dispensed at predetermined time intervals.

(ii) Demand feeders: Demand feeders differ from other feeding mechanisms in that they are activated by the stock rather than the controller. As such, demand feeders allow for ad libitum feeding and do not necessitate precise knowledge of the biomass of the stock.

Feed supply

The methods of diet delivery can play a critical role when evaluating feed intake, weight gain, or obesity. Below are several feeding methods:

1. Adlibitum and Restricted Feeding

When an animal's feed intake is limited by any method, the process is referred to as controlled feeding, while unrestricted feed intake is termed ad libitum feeding. Both feeding methods have advantages for certain animals.

Factors affecting feed supply

The following factors are important, which effect the feeding of the fish

i. Seasons

ii. Weather

iii. Water quality

iv. Time

v. Position

vi. Feeding ratio

vii. Particle / size

Overall the management of feeding involves the seasons, weather, water quality, food intake status, fixed position, feeding rate etc.

Conclusion

In conclusion, the role of feed in stress management within the field of aquaculture is of paramount importance. Stress can have detrimental effects on the health and growth of aquatic organisms, ultimately impacting the productivity and profitability of aquaculture operations. Through careful formulation and implementation of specialized feeds, aquaculturists can mitigate the adverse effects of stress, bolstering the resilience of their stocks. Nutritional strategies, such as incorporating specific additives and optimizing feed compositions, offer promising avenues for stress reduction. These strategies aim to bolster the immune system, enhance resistance to diseases, and promote overall well-being in aquatic species. Additionally, the use of high-quality feeds and precision feeding techniques can reduce competition and aggression among cultured organisms, further reducing stress levels. Furthermore, the adoption of automated feeding systems provides a means to ensure consistent and controlled feed delivery, minimizing disturbances and maintaining a stable environment for the aquatic population. In the face of environmental challenges, disease outbreaks, and changing climate conditions, the integration of stress-reducing feeding practices into aquaculture operations is pivotal. By prioritizing stress management through thoughtful feeding strategies, the aquaculture industry can not only enhance the welfare of the cultured species but also secure sustainable and resilient production in the years to come.

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Waste Water Management in Agriculture through Water conservation strategies and their safe reuse

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Introduction

Water is a renewable natural resource on which all life depends. It covers about 70% of the earth's surface and holds 97% in the ocean which is saline while freshwater is just 3% of the total water; out of which 1% is frozen in ice caps and glaciers at the poles & Himalayas, another 1% resides in groundwater, aquifers and soil moisture with limited accessibility, and rest 1% present in rivers, ponds, lakes and atmosphere which are available for us. Water has some unusual properties important for ecosystem functions as it is present in all three different forms solid (ice), liquid (water) and gas (vapour); having hydrogen bonding causes cohesion force and surface tension; having high thermal stability (important for ecosystems living in water); having exceptionally high heat of vaporization (41 kJ/mol) and heat of fusion (6.02 kJ/mol) for thermal stability; having the highest surface tension (allows seeds and molecules to float and allow aquatic organisms to swim); having high viscosity (stronger intermolecular interactions) and high cohesion (molecule's polarity and intermolecular forces); water is liquid at room temperature with tetrahedral arrangement and when freezes into ice (hexagonal structure) it expands 9% by volume and floats; water acts as an universal solvent because of its polarity and able to dissolve or dissociate many particles. Water contributes more than 60% of living organism's body weight and plays a major role in the transportation of nutrients, excreted materials and thermal stability either in plants, animals, micro-organism or on our planet.

Water scarcity is one of the major abiotic stress factors and among the greatest challenges of the twenty-first century. Agriculture, comprised of crops, livestock, fisheries, aquaculture and forestry, accounts for an estimated 70 per cent of global water withdrawals and continuously competes with other sectors. Securing access to water – especially in water-scarce countries is crucial for achieving food security and improving rural and peri-urban livelihoods (FAO 2016). Ministry of Agriculture and Farmers Welfare, Govt. of India estimated that presently ten out of 28 states (266 districts and 33% of net sown area) in the country are facing severe drought stress conditions (State Indian Agriculture 2015-16). Along with water stress; the quality of the existing freshwater resources is also affected by urbanization, industrialization, damming of rivers, mining, destruction of wetlands, deforestation, agriculture, energy use, accidental water pollution, waste dumping, climate change, fossil fuel burning, leakage from sewer lines, leakage from landfills, soil erosion etc. Under these circumstances conserving freshwater and recycling marginal quality have now become important for managing water in scarce regions.

Strategies for Water Conservation

Water conservation encompasses the policies, strategies and activities to manage fresh water as a sustainable resource i.e. to meet current and future human demand, to protect the water environment and to conserve energy in water management. This can be possible in the following ways:

1. Decreasing run-off losses:

Huge water-loss occurs due to run-off during irrigation, which can be reduced by allowing most of the water to infiltrate into the soil.

- ***(a) Contour cultivation:*** In this small furrows and ridges are made across the slopes to trap rainwater and allow more time for infiltration. It is applicable on relatively low slopes (up to 8%) and fairly stable soils. Contour ridges slow the downhill flow of water and hold in between these contours, thus reducing water erosion and increasing soil moisture.
- ***(b) Terrace farming or bench terracing:*** It involves the construction of a series of benches for catching the runoff water. Bench terraces are suitable where soil depth is more than 2.5 feet deep with high water-storage capacity and slope ranges from 8 to 30%. In sloppy lands, three types of bench terraces are planned *viz.* horizontal, inward and outward based on soil type and water holding capacity. Terraced fields decrease erosion and surface runoff, and are effective for growing high water requiring crops, such as rice.
- ***(c) Water spreading:*** It is done by making channels around the field or lagoon or farm pond at the lowest zone of the field. In Channelling, water flow is controlled by a series of diversions with vertical intervals. In lagoon levelling, small depressions are dug in the area for temporary water storage. Water-storage structures like farm ponds, dug-outs etc. will be useful for conserving water through reduction of runoff.
- ***(d) Applying wetting agents:*** Increasing water intake rates in soil by crop residues, tillage, mulch, animal residues, biopolymer etc. and also helping in reducing run-off by allowing more time for water to penetrate the land. Chemical conditioners like gypsum ($CaSO_4.2H_2O$) and HPAN (hydrolyzed polyacrylonitrile) improve soil permeability and reduce runoff in sodic soils.

2. Reducing evaporation losses:

Reducing the direct contact of sunlight on soil by surface crop residues, mulch, animal residues etc., making horizontal barriers of asphalt placed below the soil surface increases water availability. This is more effective on sandy soil but less effective on loamy sand soils.

3. Storing water in soil:

Allowing water storage in the soil root zone that can be available for longer periods e.g. hydrogel, organic matter, biopolymer, crop residue, compost, and manure can absorb water and store it for a longer period.

4. Reducing irrigation losses:

a. Use of lined or covered canals to reduce seepage.
b. Irrigation in early morning or late evening to reduce evaporation losses.
c. Selection of suitable irrigation methods also impacts water use efficiency (WUE) e.g. flood irrigation (about 30%), Level basin (about 40%), Ridge furrow method (about 50%), Overhead irrigation (about 60%), Sprinkler irrigation (about 65%), Sprinkler rain pipe (60%), Irrigation with run-off reuse (70%), drip irrigation to increase water use efficiency (WUE) up to 90%. In drip irrigation selection of dripper of proper flow rate viz. 2, 4, 8, 16 or 32 L/hr. as per the crop or plant water demand, removable dripper or inline dripper, as well as their placement in the field i.e. surface drip (WUE about 90%) or subsurface drip (WUE about 95%) is also important.
d. Growing hybrid crop varieties with less water requirements (drought resistant varieties) and tolerance to saline water (salt tolerant varieties).
e. Using soil-moisture monitoring equipment like a Vacuum gauge tensiometer, piezometer, and soil moisture meter to measure how much moisture is in the soil at different depths is useful for irrigation scheduling.
f. Know each crop's tolerance to drought stress and irrigate accordingly.
g. Precision farming and site-specific water management by using a global positioning system and soil-moisture monitoring equipment are also important.
h. The use of a water meter and pressure reducer also helps in reducing water wastage.
i. Use of a water timer is useful for automated water application by selecting the time of irrigation, volume of irrigation and frequency of irrigation in the crops either in the field, terrace garden, kitchen garden, balcony garden, high-tech hydroponics, aquaponics system etc.
j. Use of shade net of different shading like 25%, 50%, 75%, 90%, playhouse and greenhouse use in high-tech agriculture also reduces water losses.

5. Preventing wastage of water:

In households, commercial buildings and public places, farms closing taps are necessary when not in use and repairing any leakage from pipes. Use of water-saving taps, shower heads, and nozzles in the house, using gravity fed to siphoning i.e. vacuum assisted to pressure assisted toilets and from single flush to dual flush toilets, car washing by pipes to bucket and cloth or pressure assisted washers to hydrophobic coating on cars are some other measures to reduce losses of water at domestic level, offices and public places.

6. Increasing block pricing:

The consumer has to pay a proportionately higher bill with higher use of water. This helps in economic use of water by the consumers.

7. Reuse of water:

(a) Rainwater harvesting: It is a method to collect rainwater for storage and future usage, groundwater recharge, reduce urban flooding, and ensure water availability in water-scarce zones and fluctuating climate conditions. It can be easily practised in individual homes, apartments, parks, offices, temples, by rooftop rainwater harvesting and in the village by check dams, farm ponds, etc. and in the city by dams, ponds, lakes etc.

(b) Grey water recycling and reuse: Grey water are drainage water generated in households or office buildings from kitchen, bathroom, showers, wash basin, washing machine, water purifiers etc. without fecal contamination can be utilized after minor treatment for toilet flushing, watering gardens, washing cars or paths, roadside plantation, orchards irrigation and other non-potable uses. Greywater treatment is easier than municipal wastewater treatment which is done just by passing the water through the layers of sand and gravel. Treated grey acts an alternative water source especially in arid and touristic areas, where water demand is high in dry periods. Greywater recycling can **r**educe freshwater extraction from rivers and aquifers, reduce the load on water treatment plants, reduced energy use and chemical pollution from water treatment and groundwater recharge and reclamation of nutrients which has major ecological benefits.

(c) Wastewater treatment and reuse for irrigation:

Wastewater is water that has been adversely affected in quality by anthropogenic activities and liquid waste discharged from domestic residences, commercial places, industry, agriculture etc. (http://en.wikipedia.org/wiki/Wastewater). However, Sewage is the wastewater that is contaminated with faeces or urine coming from domestic, and municipals, and mixed with industrial liquid waste and passing through a sewer system (http://en.wikipedia.org/wiki/Wastewater). So wastewater encompasses a wide range of potential contaminants viz. organic loads, salts, harmful chemicals (Aromatic hydrocarbons, pesticides, phenols and chlorinated compounds), oils and greases, heavy metals (Hg, Cd, Ni, Cr, Pb, Fe, Mn, Zn, Cu etc.), excess nutrients (N, P, K), pathogenic microbes (bacteria, viruses, protozoa), helminths (intestinal worms and parasites) etc. Sewage wastewater, saline and alkaline groundwater, agricultural drainage water, industrial wastewater, mine drainage water, landfill drainage water etc. are all marginal quality waters and not suitable for their reuse without proper treatment and pose a threat to sustainable agriculture (soil, crop, associated insects, micro-organism) and/or human health due to its quality.

Present status of wastewater treatment and reuse in agriculture

As per the Central Pollution Control Board's (CPCB) report published in March 2021; India generates about 72,368 million litres of sewage wastewater every day with a treatment capacity of 39% and the rest 45,799 MLD (61%) of wastewater without any treatment drained in nearby freshwater rivers, ponds, lakes and groundwater and degrading the existing freshwater sources. In July 2018, the CPCB reported 351 river stretches (46%) of Indian rivers are polluted (https://www.downtoearth.org.in/news/water/351-polluted-river-stretches-in-india-a-list-across-states-78083) mainly Ganga, Yamuna, Godavari, Ghaggar, Gomti, Brahmaputra, Musi river present in the states Maharashtra (53 river stretches), Assam (44), Madhya Pradesh (22), Kerala (21), Gujarat (20), Odisha (19), and West Bengal and Karnataka (17) etc. The government spent >32000 crore rupees since 2014 to clean up river Ganga through the 'Namami Gange' project and similarly for other rivers, city sewage in CETPs and STPs.

In the absence of freshwater resources, many rainfed as well as irrigated farmers use marginal quality waters for irrigation resulting in low crop yield, decreasing food quality and causing environmental degradation. Now wastewater gradually becomes an alternate irrigation water source in some water scare regions due to its easy availability, timely availability, low-cost irrigation water source which reduces the fertilizer application by nearly 80-310kg N, 20-120kg P, 10-345 kg K, 90-1040 kg Ca, 45-550 kg Mg, 135-910 kg Na if applied 5000 m^3/ha (Lazarova and Bahri 2005) due to its nutrient content. In terms of area, India occupies second position just after China in the use of untreated wastewater for irrigation and growing crops on an estimated area of one million ha (Scott et al. 2010). Most wastewater irrigation in India occurs along rivers, which flow through rapidly growing cities as Hyderabad (40,500 ha), Maharashtra (38,507 ha), Kolkata (12,900 ha), Vadodara (14,567 ha), Hubli-Dharwar (5750 ha), Kanpur (2500 ha), Nagpur (1500 ha), Amritsar (1214 ha), Delhi (1214 ha), Coimbatore, Indore, Patna, Varanasi etc. As per the International Water Management Institute (IWMI) 2016 report from wastewater irrigation farmers of Maharashtra get an average profit of Rs.1,19,970 per hectare with the highest of Rs.6,84,650 per hectare in Nagpur and Rs.5,82,046 per hectare in Aurangabad. So in the absence of freshwater, farmers are even willing to purchase sewage wastewater like in Hyderabad @ Rs.75/ha/year, Jaipur @ Rs.400/ha/year and in Maharashtra @ Rs.40,000/- to the irrigation department for drawing wastewater.

Guidelines for safe agricultural re-use of wastewater

Therefore, wastewater seems an extra source of water (in regions with limited water resources). In India, the use of treated sewage in irrigation was emphasized in the

Water (Prevention and Control of Pollution) Act 1974. Food and Agricultural Organization (FAO, 2010), the World Health Organization (WHO, 2006), World Bank already published the guidelines for the safe use of wastewater and suggested their role in achieving future water security. After judicious re-use of treated wastewater, combined with enhanced water-use efficiency has the potential to increase crop productivity and improve the livelihoods of smallholder farmers, and for the rehabilitation of degraded lands. About 67% of the generated wastewater in California (California State Water Resources Control Board, 2003), 41 % in Japan (Arlosoroff, 2002), >85% in Israel and 19% in Spain (Israel Ministry of Foreign Affairs, 2016) are reusing for crop or landscape irrigation after treatment. Environmental and human health risks due to wastewater agriculture/ use can be minimized by suitable treatment of wastewater before use, careful handling, wise application, regular monitoring and proper awareness.

Sewage treatment plants and Constructed wetland system

Apart from plant nutrients; sewage wastewater also contains large quantities of suspended solids, harmful chemicals, heavy metals, and pathogenic microbes which after indiscriminate use can be harmful to sustainable agriculture. The extent of impact depends mainly on the composition of effluent, the extent of treatment, quantity used, irrigation frequency, irrigation methods, period of application, ways of use (planned or unplanned, direct or indirect, raw or diluted), soil type, climatic conditions etc. As per CPCB (2016), in India out of 816 sewage treatment plants (STPs), 79 STPs are non-operational, 145 STPs are under construction and 70 STPs are still proposed for construction. The remaining STPs are also not functioning properly due to improper design, poor maintenance, absence of alternate power supply, and unskilled workforce (CPCB, 2007). The sludge removal/treatment /handling is another major problem in conventional wastewater treatment in STPs.

In view of the aforementioned limitations of the conventional STPs, the use of decentralized treatment systems is of increasing importance mainly due to its flexibility in the scale of operation, wide range of treatment options, low capital, operation and maintenance costs, with reliable treatment capacity and suitable for rural, suburban and urban area for promoting business and job opportunities (US EPA, Tooke 2012). This can reduce pressure on the existing STPs and improve water quality and sanitation in developing countries. Among decentralized treatment systems, constructed wetlands are now being recognized as an efficient technology for wastewater treatment. Compared to conventional treatment systems, constructed wetlands need less cost and energy, are easily operated, have no sludge disposal problems and can be maintained by less skilled personnel (Morari and Giardini, 2009). Due to its effective treatment capacity and eco-friendly nature, it has wide applications in treating various types of wastewater. In constructed wetland plants, media and microorganisms work in association and remove contaminants mainly through physical filtration by media particles/layers, microbial degradation and plant sequestration. To develop an effective filtration system suitable plant selection, media selection, setting hydraulic loading rate (HLR), hydraulic retention time (HRT) are crucial and mainly depend on the contaminant or pollution load and type (Akratos et al., 2009; Kadlec and Wallace, 2009).

Apart from water treatment regular monitoring of treated water quality, soil and harvested crops are also important to ensure treated water is safe for agricultural reuse, safe for human consumption, sign of environmental degradation in the long run. Safe limit of water quality for agricultural reuse/applications is listed (Table-1) as per the international (WHO, FAO) and Indian standards. WHO has set a "Health based target ≤ 10^{-6} (risk removal of 6 log unit) DALY per person per year". DALY (Disease Adjusted Life Years) is sum total of years of life lost to premature death and years of life lived with disability. Selection of suitable irrigation methods and control measures also reduces risk due to pathogenic microbe's e.g. Wastewater treatment (1-6), Drip irrigation (2-4), Sprinkler irrigation (1), Pathogen die-off (0.5-2), Produce washing (1), Produce disinfection (2), Produce peeling (2), Produce cooking (6-7) etc. Moreover, for wastewater agricultural reuse we have go for planned application. If we have High water treatment facility can go for unrestricted crop production (food crops or nonedible crops), with a medium treatment facility with drip irrigation and slight crop restriction (fruit orchards, cereals at the place of growing vegetables), and Low treatment facility we have to go for restricted crop production (nonedible crops e.g. cotton, jute, hemp, lawn irrigation, seed crops etc.). We also have to follow certain precautionary measures e.g. to prevent excess nutrients we can dilute wastewater before application, not continuous application, and limited quantity application; avoid water with TDS (500-2000 mg/l), EC (> 2.25 dS/m); Sprinkler (>100 Cl- mg/l), Flooding (>350 Cl- mg/l), Solid size (>2-5 mm), Take two-week gap between last irrigation and harvesting, harvesting and Consumption, wear boot and gloves during working in the field, etc.

Table 1: Safe limit of water quality parameters for agricultural reuse/applications

Parameters	**Safe limit**	**Parameters**	**Safe limit**
pH	6.5-8.5	Potassium (K)	0.5 me/l
EC	2.25 dS/m	Fluoride (F-)	1.0 mg/l
Temperature	30°C	Aluminium (Al)	5.0 mg/l
Dissolved oxygen (DO)	5.0 mg/l	Arsenic (As)	0.10 mg/l
Turbidity	50 NTU	Beryllium (Be)	0.10 mg/l
Residual sodium carbonate (RSC)	< 1.25 Excellent	Cadmium (Cd)	0.01 mg/l
	1.2-2.5 Good	Chromium (Cr)	0.10 mg/l
	> 2.5 Bad	Cobalt (Co)	0.05 mg/l
	< 10 Excellent	Copper (Cu)	0.20 mg/l

Sodium adsorption ratio (SAR)	10 – 18 Good	Iron (Fe)	5.0 mg/l
	18 – 26 Medium	Lead (Pb)	5.0 mg/l
	> 26 Bad	Lithium (Li)	2.5 mg/l
Total dissolved solid (TDS)	2000 mg/l	Manganese (Mn)	0.20 mg/l
Sodium (Na)	9.0 me/l	Molybdenum (Mo)	0.01 mg/l
Bi-carbonate (HCO_3^-)	8.5 me/l	Nickel (Ni)	0.20 mg/l
Boron (B)	3.0 mg/l	Selenium (Se)	0.02 mg/l
Chloride (Cl^-)	10 me/l	Vanadium (C)	0.10 mg/l
Nitrate (NO_3^-)	30 mg/l	Zinc (Zn)	2.0 mg/l
(Ca + Mg)	10 me/l	Intestinal nematode	≤ 1 no. of eggs/ l
Phosphate (PO_4^{3-})	50 mg/l	Faecal coliform	≤ 1000 no. /100 ml
Sulphate (SO_4^{2-})	50 mg/l	Escherichia coli	≤ 100 no./100 ml

Constructed wetland system at ICAR-NIASM, Baramati

At ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati a pilot-scale constructed wetland system has been designed using locally available media, wetland plants and inhabiting microbes for the treatment of 3000 liter per day of wastewater generated from the institute campus (Fig.1). Treated water was found suitable for agricultural reuse and so using for growing leafy vegetables, fish, commercial flowers and fruit orchards. The agricultural produce grown from the treated water has been found safe for human consumption. The designed system has a treatment time of 48 hours, removal capacity >95% for Pathogenic microbes (faecal coliform and E.coli), >90% for heavy metals (Fe, Mn, Zn, Cu, Ni, Cd, Pb) while for salts (EC 25%, sodium 38%, Ca+Mg 34%, bicarbonate 83%, chloride 43% and nitrate 74%). The system has a life >10 years if the treatment tank of cemented and >5 years if PVC material is used and has a setup cost of Rs.2000 for 100 liter constructed wetland and Rs.2000 for 100 liter aquaponics system

Fig.1 Pilot scale Subsurface-flow Constructed wetland system for treating wastewater generated from ICAR-NIASM, Baramati

Therefore, marginal water can act as an extra source in regions with limited water resources and constructed wetland systems may be utilized for the treatment of marginal waters and reuse for sustainable agriculture. Water conservation is not a job just for the technician, soil scientist, hydrologist, forester, wildlife manager, plant scientist, city planner, park manager, farmer alone. It is a job for the everyday person who just likes to have access to the life sustaining resource of water.

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Strategies for Abiotic Stress Management in Agriculture

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This e-book is a compilation of resource text obtained from various subject experts for the Collaborative Online Training Programme of ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra & MANAGE, Hyderabad, Telangana on Abiotic Stress Management in Agriculture for Enhancing the Farmers Income with Special Reference to Natural Resource Management conducted from 01-06 August 2023. This e-book is designed to educate extension workers, students, research scholars, and academicians related to veterinary science and animal husbandry about various technologies in Livestock Nutrition for improvement of Health and Production

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