Natural Resource Management for Sustainable Dryland Horticulture

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This ***e-book*** is a compilation of information with enriched research experience obtained from various subject experts for Collaborative Online Training Programme of ICAR-CRIDA & MANAGE, Hyderabad on **Natural Resource Management for Sustainable Dryland Horticulture** held during 9-11 February, 2022. This ***e-book*** has good information which is useful to the Extension personnel of Agri-allied sector, Faculty and students of Agricultural Universities, Subject Matter Specialists of KVKs, extension functionaries of NGOs etc. Neither the publisher nor the contributors, authors and editors assume any liability for any damage or injury to persons or property from any use of methods, instructions, or ideas contained in the ***e-book***. No part of this publication may be reproduced or transmitted without prior permission of the publisher/editor/authors. Publisher and editor do not givewarranty for any error or omissions regarding the materials in this e-book.

Foreword

ICAR-Central Research Institute for Dryland Agriculture (CRIDA) is a premier research institute in the field of Natural Resource Management for Dryland Agriculture in India under ICAR, Ministry of Agriculture and Farmers Welfare, New Delhi. ICAR-CRIDA is working closely with different stakeholders (farmers, line department officials, SAUs, other ICAR institutes, different ministries, etc) towards the development of climate resilient agriculture in India. This institute is constantly working for production enhancement and revenue generation through introduction of easily adaptable cost-effective technologies in a sustainable ecosystem based approach in drylands of India.

To ensure livelihood security especially in drylands horticulture crops play an important role. Dryland horticulture offers possibilities to farmers for full utilization of their land resources. Scientific approaches coupled with appropriate technologies is essential for better farm incomes. The book provides comprehensive ideas on dryland horticulture management practices which will certainly lead horticulture farmers to withstand impacts of climate change.

This e-book will be of immense importance for researchers in appraising themselves about the current status of research on different aspects of natural resource management in horticultural crops. It will also be useful for practitioners/farmers for adopting appropriate practices on natural resource management for improving income from their production system in a sustainable manner.

VKSingh

February, 2022

Vinod Kumar Singh
Director, ICAR- CRIDA

Preface

Natural Resource Management (NRM) Strategy addresses the issue of natural resource while also promoting the benefit of horticultural production. It is a clear and practical plan that provides a benchmark for horticulture's profitable and sustainable future. Natural resources, such as soil and water are the foundation of production. Proper use of natural resources is important for agricultural production. Farmers need access to suitable and sustainable natural resources for production today and into the future. Horticulture for tomorrow aims to increase efficiency, while ensuring the effective long-term management of natural resource use. By improving efficiencies and management of resource use, the long-term sustainability of horticulture and the environment will be ensured. Horticultural crops have played a major role in ensuring livelihood security of farming community. The last decade has witnessed drastic change in the production scenario of horticultural crops. Effective management of natural resources play important role in improving the productivity of horticultural crops in a sustainable manner. Resource management, appropriate land use, maintaining soil fertility, efficient management of water resources, adoption of farming system approach for harnessing synergy between different components are some of the approaches on natural resource management for improving the productivity. A number of research works have been undertaken around the world on this aspect. It is time that the learning from the research in these areas to be translated into farmer's field directly or after suitable refinement based on local scenario. We here have attempted to compile the available knowledge in horticulture including the findings of research work undertaken in dryland horticulture.

This e-book is a compilation of lecture delivered under the online training program of "Natural Resource Management for Dryland Agriculture". It contains important topics on climate change and horticulture, canopy management in dryland horticulture crops, water management methods and techniques in horticultural crops, bio inoculants in horticultural production systems, soil based crop suitability assessment for alternate land-use planning, IPM for horticulture crops. Hope wide circulation of this book will help a large number of readers to enrich their knowledge on natural resource management for sustainable dryland horticulture.

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Introduction

Making agriculture climate smart through integrated approach is an ideal solution to ensure the food security of the ever-increasing global population at a time when there are twin problems of land degradation and carbon emissions. A multi-pronged strategy is required to check climate change and integrated farming is one of the options to achieve it. It provides multiple benefits that are sustainable and can pave the way for climate-smart agriculture (CSA).Climate change has become a fundamental threat against sustainable development and the fight against global poverty. From shifting weather patterns that threaten food security to rising sea levels that increase the risk of flooding, the impacts of climate change are undoubtedly global in scope and unprecedented in scale. CSA is an integrated approach to develop technical, policy and investment conditions in such a manner so as to ensure sustainable development for food security. The main aim is to achieve sustainable higher productivity, ensure livelihood and food security, adapt to climate change and bring down emission of greenhouse gases. CSA ensures increased productivity in a sustainable way which can strengthen the farming community against the consequences of climate change. It can also increase the mitigating potential of climate change through carbon stocking.

The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands. An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kilograms per hectare (kg/ha) for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas. As well as enhancing food security, carbon sequestration has the potential to offset fossil- fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions (Lal, 2004).

Relevance of integrated farming systems in India

The average size of farm holding in India has declined over time and out of a total 137.8 million farm holdings in India, 85 per cent are less than two hectares. As per agricultural census 2010-11, the number of land holdings in the marginal and small categories have swelled by 56 million and 11 million, respectively during the period 1970-71 and 2010-11. Land holdings in the marginal category (less than1 ha.) constitute 67 per cent of the operational holdings in the country (2010-11). In terms of area operated, the share of marginal holdings has doubled to 22 per cent (2010-11) from a mere 9 per cent (1970-71). Similarly, the share of (operated area under) small farm holdings (1 to 2 ha) increased from 12 per cent to 22 per cent during the same period. Small and marginal holdings together, constitute 85 per cent in terms of number of operational holdings and 44 per cent of the operated area in the country. Thus, over the period, the marginal category has emerged as a distinct and dominant class by itself with its average size dwindling to a mere 0.38 ha.

The progressive fragmentation of land holdings, degrading natural resource base and emerging concerns of climate change are escalating pressure on land and water. Integrated Farming Systems (IFS) seem to be the possible solution to the continuous increase of demand for food production, stability of income and improvement of nutrition particularly for the small and marginal farmers with limited resources. The concept of Integrated Farming Systems (IFS) is more feasible for these small farm holdings as it serves as a tool for linking allied agri- enterprises with the crop production besides offering scope for environment safety and conservation of Agro-biodiversity (Kathiresan, 2009). Further, crop diversification through IFS is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production related activities on various crops and also to lessen risk. The crop diversification may result in enhanced profitability, reduce pest, spread out labour more uniformly, different planting and harvesting times can reduce risks from weather and new crops can be renewable resources of high value products (Reddy and Suresh, 2009).

For smallholder systems numerous adaptation and mitigation options exist through crop – livestock systems by distinguishing risk management, diversification and sustainable intensification strategies. Despite the potential solutions, smallholders face major constraints at various scales, including small farm sizes, the lack of response to the proposed measures and the multi-functionality of the livestock herd. Hence, there is a need for integrated, system-oriented impact assessments and a realistic consideration of the adoption constraints in smallholder systems (Katrein Descheemaeker *et al*., 2016).

The system approach is found to mitigate the climate change impacts through reducing the livelihood dependency on single crop / enterprise with diversified output and enhanced income. A close integration at farm level through production of fodder and recyclable manurial resources, extending the growing season, enhanced diversity at species, varieties and ecosystems levels were found as the advantages of the system approach. The system builds the reserves of water, fuel, biomass and was found resilient through intra system dependency by integration of perennial, semi perennial, animal, soil aquatic organisms, etc. The integration also reduces the need for external inputs through multi step resource recycling, biologicals and other renewable resources and results in energy efficient systems. Inclusion of multi functional elements such as live fences, vermi compost and farm ponds adds to the stability. Generation of on-farm employment and build up soil fertility over the years adds to the sustainability of the system. The benefits of system approach was significant with the flow of intermittent cash in hand for reinvestment in input usage besides moderating the micro-climate changes in the crop vicinity.

Further, Integrated Farming system is an approach wherein risk in dealing with single component can be through effective resource recycling. In this, a judicious mix of one or more enterprises along with cropping has a complimentary effect through effective reutilization of wastes and crop residues and encompasses additional source of income to the farmers (Korikanthimath and Manjunath, 2009).This approach achieves fuller utilisation of available resources to realise maximum profits and also to stabilise returns. Further, it examines the full range of farm activities closely related to one another by the common use of farmer’s land, labour, capital and management factors. IFS activity is focused round a few selected inter-dependent, inter-related and inter-linking production systems, based on crops, animals and related subsidiary professions (Kuruvilla Verghese and Thomas Mathew, 2009). On this basis, IFS models have been suggested by several workers for the development of small and marginal farms across the country (Behera and Mahapatra, 1999; Kathiresan, 2009 and Singh *et* *al.*, 2006). Thus, with a view to mitigate the risks and uncertainties, IFS need to be practiced to meet the demand for greater food production and a better standard of living.

Development of ecologically stable and environmentally sound integrated farming system models to replace or improve the traditional farming systems would maximize the productivity of the farming systems. It is clear that because of the diversity of the ecological settings, socio-economic condition and history of research systems, no single farming system model would be adequate for all the situations (Merrillsands, 1986). Information on the understandings of the linkages and complementarities of different farm enterprises and the means of resource recycling of one enterprise to others are very meager. Although systems approach to nutrient management is rational, proven research findings are few to adopt. With recent thrust on integrated nutrient management and sustainability of crop productivity, there is an urgent need to exploit the possible means of nutrient management to farming systems as a whole. Further, energy flow and environmental impact are the key factors toward sustainable development of agricultural Production (Paramesha *et al.*, 2018).

India- the land of diverse situations

India is gifted with heterogeneous landforms and variety of climatic conditions such as the lofty mountains, the raverine deltas, high altitude forests, peninsular plateaus, variety of geological formations endowed with temperature varying from arctic cold to equatorial hot and rainfall from extreme aridity with a few cms (<10cm) to per humid with world's maximum rainfall (1120 cm) of several hundred cms. This provides macro relief of high plateau, open valleys, rolling upland, plains, swampy low lands and barren deserts. This varying environmental situations in the country have resulted in a greater variety of soils. Therefore, the systematic understanding of agro-ecological regions has tremendous scope in grouping relatively homogenous regions in terms of soil, climate and physiography and conducive moisture availability periods (length of growing season) in planning appropriate land use.

Knowledge and proper understanding of the agro-climatic and socio-economic milieu in which the farmers operate, appropriate to the need and environment of the practicing farmer especially those with limited resources is required. Therefore, developing integrated farming system models is not only the need of the time but also better alternative for optimisation of resources available with small farmers as the by-products of one crop/enterprise may become the input or raw material of the other. Further, as the crop and animal husbandry systems were developed and intensified, per capita land requirement decreases dramatically (Singh and Singh, 1993 and Raman and Balaguru, 1992). There is however, no single blue print of a universally applicable sustainable farming system for the whole tropics, ecological region or even a soil type. Because of site specific soil and environmental constraints and individual preferences and priorities, there are virtually as many sustainable systems as farmers (Saxena *et al.,* 1998).

Crop Diversification is in-built in IFS

The sustainability of a farm system depends on its feasibility under changing circumstances. The availability of wide diversity of genetic resources at the farm level contribute to this flexibility. It is important as farmers choose between varieties with different properties which are influenced by climate, economic, political and social changes. Farmers can maintain biological diversity by using mixtures of different species, mixtures of different varieties of the same species or varieties whose genetic composition itself variable. Mixtures of different species help in unsuitable variable environment to harvest security and nutritional balance. In some cases, they also yield higher total usable biomass than mono crops and increase the sustainability of the yield. Variety mixtures offer additional diversity in the timing of germination, flowering, growth, seed filling and harvest.

A Multiple cropping system is highly suitable practice for maximisng production with low levels of external inputs, minimizing risks with conservation of natural resource base. In multiple cropping system, productivity in terms of harvestable products per unit area is higher than other sole cropping with same level of management. The yield range from 20% to 60%. These differences can be explained by a combination of higher growth rates, reduction of losses on account of weeds, insects and diseases and more efficient use of available resources of light, water and nutrients. As several crops are grown, failures of one crop to produce enough (either as actual harvest or in terms of cash) can be compensated by other crops. This decreases farm risk.

Livestock diversification for continuous family labour engagement

As with multiple cropping, farmers can exploit a wide range of feed resources by a mixed holding of livestock than if only one species is kept. Different animal species supply different products viz., milk, transport and draught power provided by cattle and camel,where as goats and sheep provide meat, chicken often provide the small cash for the household. Sheep and goats can be sold to cover intermediate expenses while larger animals like cattle are sold to meet major expenditures.

Keeping more than one species of livestock is also a risk minimizing strategy. An outbreak of disease may affect only one of the species. e.g. the cow and some other species or breeds are better able to survive droughts and help to carry a family over difficult periods. Advantage can also be taken of different reproductive rates of different species to rebuild livestock holdings after drought. For example, greater fecundity of goats or rabbits permits their number to be multiplied more quickly than cattle. These smaller animals can then be exchanged or sold to obtain large ruminants.

Livestock enterprise at the household level is determined by an interplay of income needs, investment capacity, fodder supply potential, household labour time and public credit support. Most part of the income-wise significant animal categories are owned by households with medium to large farms better placed in terms of both own funds for livestock investment and own fodder for livestock maintenance. The dominant share of poor groups in fodder and labour intensive buffaloes is due partly due to their ability to substitute labour for fodder, i.e using labour for collecting fodder/ open grazing and partly due to credit support under rural development programmes. The share of large farms (especially those in rainfed areas) is almost entirely of sheep usually maintained in large numbers while that of poor groups consists mainly of goats normally kept in one or few units. Poor households rear young stocks mainly for gaining from value appreciation rather than for using them in breeding as it is the case with others.

The livestock composition especially its dairy orientation is important for dairy performance. While buffaloes requiring relatively more labour units in their maintenance, dominate the composition of dairy animals among poor groups, cows with a relatively lower labour requirement have more distinction among groups with larger farms.

The effect of livestock diversification on enterprise performance can be evaluated using structure of livestock income and cost across livestock groups. Although the income share of milk is dominant for all farm groups, dairy income is relatively more significant for households with farms larger than four acres. In contrast, the income share from value appreciation, poultry and manure is higher for households with no or less land.

A gradual decline in the average cost per animal can be noticed as farm size increases. Since farm size and cattle stock size are directly related, the declining cost per animal unit is done as much to scale economics in animal husbandry as to fodder related linkages between crop and livestock enterprise.

Enterprise performance seems depend more on the structure than on the size of the livestock enterprise. Irrespective of the performance criteria used, the livestock enterprise of groups with no or less land performs rather poorly.

Since there is a positive association between income cost ratio (or net return) and income share of milk, dairy orientation plays a major role in determining the overall enterprise performance. Hence to improve the livestock in total animals and diversifying the livestock assets towards income wise more significant categories is important.

Interactions in IFS- the key in mitigating the impacts

The benefits of system approach lies in the mitigation lies in the interactions among the components. Examples of systems interactions are :

- Crop rotations can be used to manage soil and nutrients. Cover crops can be selected to take up nutrients not used by the main crops and then be plowed into the soil to provide nutrients. Water use needs to be considered when selecting cover crops because some of them could increase water use substantially.
- Soil management has influential interactions with pest and disease management partly because good soil management and healthy soil help keep the plants strong and healthy and improve their resistance to pests and disease. The use of excess nitrogen in the soil can provoke some pest and disease problems, but inadequate nutrients, organic matter, or minerals can also weaken the plants and increase susceptibility to diseases.

- An integrated farm typically uses integrated pest management (IPM) that includes bio-control agents and practices and selective use of organic pesticides. In that context, actions can be taken to restore and enhance pest-predator balances. The mere presence of an insect pest does not necessarily constitute a problem; the decision on when to intervene is made on the basis of monitoring, using damage thresholds, and understanding the life cycles of the insects and the causes of outbreaks.

- Water and watershed management interact with soil, pest, and weed management to affect crop growth and environmental effects. For example, the use of excess water or inadequate drainage systems can lead to excess weeds and canopy growth that might provoke pest problems or provide a favorable environment for certain root pathogens. Appropriate soil management can decrease soil erosion and thereby can reduce sediment runoff. Soil management can also improve water infiltration into soil and reduce water use.
- Cover crops have many interactions with and effects upon soil, water, crops, and weeds. Planting cover crops can increase soil fertility and organic matter, increase soil biodiversity and microbial activity, prevent erosion and runoff, protect or improve water quality, attract beneficial insects, and improve soil structure.
- The small nutrient surpluses in integrated farms reduce the risk of nutrient (especially nitrogen) pollution from agriculture to rivers, lakes, wetlands, and coastal oceans.

Input efficiency- the highest through IFS

Management practices designed to maximize de-nitrification efficiencies can reduce the threat of nitrate leaching (which benefits water quality) but can increase nitrous oxide emissions (which are potent atmospheric greenhouse gases). Evidence suggests that de-nitrification efficiency under systems is higher than under a corn crop (70 to 90 percent versus 10 to 15 percent), in part due to subsurface soil environments that are richer in plant, microbial, and macrobiotic activities (Browne and Turyk, 2007). Marois *et al*. (2002) found that adding cattle and forage rotations into traditional cotton–peanut production systems in the Southeastern United States produced increased whole-farm returns. A similar study contrasting cotton–forage–beef systems with traditional high plains cotton monoculture systems found that the integrated system reduced irrigation water needs by 23 percent, reduced nitrogen fertilizer applications by 40 percent, and increased net farm profitability by up to 90 percent on a per-acre basis (Allen *et al*., 2005, 2008). Patterns of nutrient flows in pastures are affected by the impacts of grazing on soil structure, water infiltration and soil microbial activity and those interactions make it difficult to draw sweeping conclusions about the net environmental costs and benefits of grazing systems.

Integrated systems and the green house gas emissions

The greenhouse gas emissions from integrated systems are relatively lower as compared to conventional farms (Meisterling *et al.* (2009). Systematic assessment of greenhouse-gas emissions of different cropping systems or system types over the lifecycle of crop production is sparse.

Evidence is increasing that integration of livestock into diverse cropping systems can produce important benefits (Sulc and Tracy, 2007). In particular, the ability to feed crops to livestock enables producers to capture and potentially recycle nutrients back to farm fields, which reduces the need for purchased fertilizers and enhances such desirable soil attributes as organic matter, water-holding capacity, and soil structure (Schiere *et al*., 2002; Entz *et al*., 2005; Hendrickson *et al*., 2007). Moreover, the ability of livestock to take advantage of underutilized resources (for example, less productive croplands that can be converted to pasture, periods of slack family labor demand, or unused crop residues) can improve the overall efficiency of the farm operation and capture new sources of income (Smil, 1999; Russelle *et al*., 2007). Livestock are often used to convert relatively low-value crops to high-value protein, which can potentially increase total farm returns on integrated crop–livestock farms (Anderson and Schatz, 2003).

Integrated crop–livestock systems have been found to be particularly beneficial when conservation tillage practices are used (Franzluebbers and Stuedemann, 2008). The use of short-term and long-term pasture crops in rotations and the strategic placement of well-adapted forage crops on the landscape can provide particular environmental and economic benefits (Entz *et al*., 2002; Rotz *et al*., 2005; Russelle *et al*., 2007). At the same time, most evidence for successful crop and livestock integration has been linked to the use of ruminant livestock (beef, dairy, sheep, or goats) that can eat forages and crop residues; different challenges exist for finding productive synergies for mono-gastric livestock species such as poultry and hogs.

Grazing livestock have also been identified as a significant potential source of greenhouse-gas emissions (de Klein and Eckard, 2008). Worldwide, pastoral grazing sources are estimated to contribute roughly 8 percent of methane (CH_4) and 15 to 30 percent of total N_2O emissions (Clark *et al.*, 2005). Methane emissions are primarily a function of the fermentation of feed in the rumens of grazing animals, mostly lost through the lungs, not flatulence (Torrent and Johnson, 1994). By contrast, CH_4 losses from animal excreta are trivial sources of net emissions.

Methane emissions are affected by feed and forage type and by the intensity of grazing management. One study shows that grain-finished cattle that spend some time in feedlots produce more CH_4 emissions from enteric fermentation per animal than grass-finished cattle. However, because of their efficient weight gain, grain-finished cattle produce 38 percent less CH_4 emission per unit beef produced than grass-fed cattle. Higher-quality forages, including legumes, also tend to yield less CH_4 in the rumen (Peters *et al*., 2010). Intensive grazing can decrease CH_4 per unit weight gain, but greater rates of forage production and consumption could increase total CH_4 emissions per hectare. Nitrous oxide emissions in grazing systems are primarily a byproduct of the de-nitrification process in soils. Important sources of nitrogen deposition in pastures are livestock urine, commercial fertilizers, and legume crops. De-nitrification is accelerated under wet or anaerobic conditions, which can be aggravated by soil compaction and poaching in pastures (de Klein *et al.*, 2001; Bolan *et al*., 2004). Emissions of both of types of greenhouse gases tend to increase with more productive pastures or intensive pasture management systems, because of higher soil nitrogen levels, rates of plant growth and stocking rates.

There can be a tradeoff between managing farming systems to minimize nitrate (NO_3^-) losses to ground water resources or to reduce the loss of N_2O to the atmosphere. Many management practices designed to maximize de-nitrification efficiencies can reduce the threat of nitrate leaching (which benefits water quality), but can increase nitrous oxide emissions (which are potent atmospheric greenhouse gases). Using an intensive grazing system (particularly if it replaces reliance on traditional crop production for livestock feeds) could affect the balance between nitrate leaching into water and N_2O release into the atmosphere. For example, evidence suggests that de-nitrification efficiency under MIRG systems is higher than under a corn crop (70 to 90 percent versus 10 to 15 percent), in part due to subsurface soil environments that are richer in plant, microbial, and macrobiotic activities (Browne and Turyk, 2007). As a result, grazing farms contribute comparatively fewer nitrates to ground water, but might convert a higher percentage of nitrates and nitrites into N_2O and N_2 gases.

Ultimately, patterns of nutrient flows in pastures are affected by the impacts of grazing on soil structure, water infiltration, and soil microbial activity, as summarized above, and those interactions make it difficult to draw sweeping conclusions about the net environmental costs and benefits of grazing systems.

The effective recycling of farm resources is possible by adoption of farming system research. Crop by-product is utilized as fodder for animals, and animal by-product i.e. milk, and dung may be utilized for increasing income and soil fertility, respectively.

In Karnataka, Punjab, Haryana and western Utter Pradesh, burning of ragi, wheat, and rice residues is common practice, which increased the concentration of greenhouse gases in atmosphere, in addition to huge amount of nutrients are lost. Such situation could be avoided by introduction of some more enterprises like animal husbandry on the farm. Rice straw may be used as animal feed. This farm residues serve as basal diet for dairy animals with little supplementation of concentrates maintains high levels of production. Thus effective recycling of agriculture by products/ crop residues for feeding of farm animals and in turn use animal by-products like dung and urine recycled via bio gas or fish pond will not only maximise the farm income but also will maintain a clean environment.

Temperature in summer season is quite high and need to be managed. It can be achieved by keeping soil covered with biological mulch. Surface mulch has been reported to conserve soil moisture and improve water use efficiency. In the long term experiment at ICRISAT, it has been reported that mulch applied in this manner on the hottest day of summer (April 30) in 2002 the soil temperature at 5 and 10 cm depth in the mulch applied plots was 6.5 to 7.3 ^{o} C lower than in control plot (Rupela *et al.*,2005). Temperature control can also be achieved by planting different types of trees like neem, aonla, tamarind, gular, *Ziziphus* bushes, *Glyricidia* on bunds.

Systems perspective in mitigating the micro-climate change

Moderating temperatures

Water harvesting and storage at selected locations in watershed through silpaulin lining / any other cost effective lining can be an effective tool. Suitable soil and water conservation measures for the crop and the topography of the region so as to increase infiltration into the soil and conserve more rain water *in situ* is a viable option. Thick mulching of the basins especially in widely spaced horticultural crops with non-conducting material like straw, dried leaves, weeds or any other suitable material brings the desired results. Application of coir pith is better known for retention of moisture in the basins. Recycling of stored water for critical irrigations will minimize the ill effects of raised temperature. Periodical removal of weeds to decrease evapo-transpiration losses and their use to dress the soil as surface mulch is more practical. Further, addition of organic manure as surface mulches will go a long way in mitigating the micro climatic changes.

Mitigation the ill effects of carbon dioxide

Providing additional opportunity to capture enhanced CO_2 levels especially in C_3 plants through selection of suitable genotype with better canopy architecture, having optimum leaf area index with ideal nutrient and water supply to the plant is a right step in this direction. Identification of profitable cropping system involving a mix of C_3 and C_4 crop plants will facilitate the additional carbon fixation. Agroforestry species as a component of bund cropping in the farming system will sequester more carbon levels, with production of additional biomass. Paired row planting will facilitate free air circulation in the crop canopy and may minimize the ill effects.

Tackling variations in precipitation

Providing sufficient water storage and recycling structures at suitable points in the watershed so as to collect the excess run off in the abnormal rainy period is required. Increased attention for conservation of moisture with structures for safe disposal of water at suitable points is a necessity. Increased cropping intensity with suitable plant population through planting a combination of erosion permitting and erosion preventing crops keeping in view the plant canopy and spacing into consideration is needed. Addition of tank silt or any water retentive materials in the basins of widely spaced crops is a necessity to sustain drought periods. Following zero tillage / retention of root stubbles /crop residues to decrease the impacts of excessive rain and also act as mulch during drought.

System approach for reduction of green house gas emissions

Construction of biogas unit as a part of the system approach through the use of cowdung produced in the system is required which also serves the purpose of fuel supply to the farm family. Following suitable dietary systems for integrated livestock units will help in minimizing the methane emissions. Insulating the cowshed and other animal units with suitable materials will avoid the extremes. Occasional misting/blowing of water in livestock units will keep the livestock cooler. Covering of all the accumulating drainage units including urine/storage tanks will reduce the emissions. General awareness is also required on mitigation aspects of the changing climate to the farm managers. When compared to row crop farming and extensive grazing systems, there is evidence that well-managed intensive grazing systems can sequester more atmospheric carbon and minimize losses of agricultural nutrients to surface and ground waters (Cuttle, 2008). Conversion of tilled soils into native perennial grasses suggest net increases in soil carbon (Reeder *et al.,* 1998; Potter *et al.,* 1999; Baer *et al.,* 2000). Net gains in soil carbon are highest in the first years of conversion from arable to untilled grasslands (Tyson *et al.,* 1990). At a global scale, however, increased soil respiration as a result of global warming suggests that the world's grasslands could be experiencing net losses of carbon (Bellamy *et al*., 2005; Schipper *et al.,* 2007).

Micro-climate improvement

The use of trees as shelterbelts in areas that experience high wind or sand movement is well-established example of micro-climate improvement that resulted in improved yields. Increase agricultural production due to windbreaks and shelterbelts in India has been reported by Rao and Sita Ram (1980). Establishment of micro-shelterbelts in arable lands, by planting tall and fast-growing plant species *viz.,* castor bean on the windward side, and shorter crops such as vegetables in the leeward side of tall plants helped to increase the yield of lady's finger by 41% and of cowpea by 21% over the control (Venkateswarlu, 1993). In spite of good results the community shelterbelts in arable lands are not very popular with farmers, especially as the technique normally but across their field holding boundaries.

Perennial components like trees and grasses imparts stability to farming due to less effect of yearly variation in rainfall on these components besides protecting crops from water and wind erosion and improvement of soil fertility. In CRIDA, the horti-pastoral system involving *Cenchrus / Stylos* in rainfed guava and custard apple, *Cenchrus* yielded dry forage of 7 t/ha during the first year while stylos recorded 5.6 tonnes of dry fodder during the second year of plantation. In ber based agri-horti system, pearl millet + pigeon pea, pigeon pea + black gram (Rewa), castor (Dantiwada) and cluster bean (Hyderabad) showed promising results in rainfed environment.

There is robust evidence that agroforestry systems have the potential for improving water use efficiency by reducing the unproductive components of the water balance.

Integrated Farming Systems in mitigating the changing climate under different agro-climatic regions

Depending upon the soil, bioclimatic type and physiographic situations, the country has been grouped into 20 agro-eco regions (AER) and 60 agro-eco sub regions (AESR). Each agro-eco sub region has further been classified into agro-eco-unit at district level for developing long term land use strategies. The constraints and potentials with appropriate ameliorative measures have been described and suggested for each region for better understanding and adoption for formulating the plans to suggest crop/cropping system which will help in minimizing the deterioration of land quality controlled by soil physical conditions, nutrient availability and organic carbon pool.

Developing countries like India whose geographical parts comprises of mountainous regions comprising of Himalayas, central plateau region, northern plains, coastal regions, deltas etc. are particularly vulnerable for climate change as little change in the climate will disturb the whole ecology and in-turn the traditional pattern of crops being grown in these regions. Latitudinal and altitudinal shifts in ecological and agro-economic zones, land degradation, extreme geophysical events, reduced water availability and rise in sea level are the factors which effect the crop production. Unless measures are undertaken to adapt to the effects of climate change, crop production in the developing countries like India will be under threat. Extreme and unpredictable weather conditions are part of the reality of climate change even as temperature rise and changes in rainfall, changes in pest and disease incidence etc., will also be the stark reality for farmers. What the situation then requires are resilient and adaptive farming systems with the least amount of loss to the productive resources, production and the farmer.

However, the system approach is known to mitigate the climate change impacts through the following ways:

- Reducing the livelihood dependency on single crop/ enterprise with diversified output and enhanced income.

- Close integration at farm and household level can enhance food security and less disaster prone
- Extending the growing season through enhanced diversity at species, varieties and ecosystems levels.
- Builds reserves of water, fodder, fire wood, etc.
- Increases system resilience through intra system dependency by integration of perennial, semi perennial, animal, soil aquatic organisms, etc.
- Reduces the need for external inputs through multi step resource recycling, biologicals and other renewable resources.
- Reduce inputs and labour through close integration and evolving energy efficient systems
- Eliminate the need for biocides through crop rotation, use of resilient indigenous varieties, trap crops, etc.
- Inclusion of multi-purpose and multi functional elements such as live fences, hedge rows, farm ponds, etc.
- Makes available more cash in hand

The sustained food production in different agro-climatic regions of India is envisaged through the following ways:

- Assessment of soil resource in terms of its capabilities for various agricultural and non-agricultural uses.
- Soil and climatic based crop specific land suitability evaluation.
- Evaluation of efficiency of agricultural input and their improvement.
- Controlling soil degradation through monitoring at benchmark sites.
- Restoring soil health through appropriate and cost effective techniques keeping in view of environmental degradation problems.

Integrated farming system models for different agro-climatic zones

On-station and on-farm research, in combination with farming systems simulation and social research provide the capacity to evaluate cropping options through the lens of climate variability. The testing of technologies and strategies, including the use of modern, short and medium duration varieties, opportunistic timing of crop establishment, mechanisation, supplementary irrigation and improved agronomic practice has shown that there is potential to mitigate the effects of variable climate on farm productivity and household income. However, this requires an increased level of farmer/systems flexibility to allow for near to real-time changes in cropping response to observed seasonal conditions. These factors differentiate this research and provide the opportunities to improve the individuals' livelihood and in meeting national production targets.

Integrated farming system models will vary widely in each agro-climatic zones with very high location specific natural resource availability like rainfall and other climatic factors, soil types and market demand. Based on the agro-ecological condition and successful cropping systems adopted in each zone specific faming system models are proposed based on the research carried out and could be recommended with slight modification for each agro-climatic zone. Integrated farming systems research in different agro-eco systems like wetlands, garden land and rainfed ecosystems have demonstrated the technical feasibility and economic viability for different agro-climatic regions through linking of different components.

In this, establishment of farming system will be able to help for the efficient allocation of available resources in the farm and reduce the use of external inputs. With the aid of the developed technology and the knowledge on the strength of farming system, it would be possible to disseminate the integrated farming system models for large scale adoption.

Farming system in improving sustainability

A systems approach, where all available options are considered in an integrated manner, will be the most effective and ultimately the most sustainable, particularly for developing countries in the tropics under a variable climate. This holistic strategy will need global integration of efforts; the resulting synergies will produce impact more quickly than the individual institutions working in isolation could accomplish.

The systems approach recognizes the importance of interconnections and functional relationships between different components of the farming system (for example, plants, soils, insects, fungi, animals, and water). It also stresses the significance of the linkages between farming components and other aspects of the environment and economy. A systems approach to agriculture is generally guided by an understanding of agro-ecology, as a scientific basis and agro-eco-system interactions. Agro-ecology provides a framework to integrate the biophysical sciences and ecology for management of agricultural systems. It emphasizes the interactions among all agro-eco-system components (for example, biophysical, technical, and socioeconomic components of the farming system) and recognizes the complex dynamics of ecological processes (Vandermeer, 1995). The approach aims to maintain “a productive agriculture that sustains yields and optimizes the use of local resources while minimizing the negative environmental and socio-economic impacts of technologies (Altieri, 2000).

The integrative perspective of how the components interact with each other in a system and the study of the potential outcomes of those interactions provide valuable information for designing, implementing and operating a farming system that achieves multiple sustainability goals. Beyond the boundary of a farm, many elements of sustainability, such as product and market diversity and resilience, water resource quality and use, elements of ecosystem health and community well-being are highly influenced at landscape, watershed, and regional scales. Sustainability, thus suggests and requires in most instances an appropriate mix and location of farming system types.

Five major elements of adoptive strategies to climate change by small holder and subsistence agriculture as per Mortimore and Adam (2001) include:

1. Allocating farm labour across the season in ways that follow intra season rainfall variation.
2. Making use of biodiversity in cultivated crops and varieties
3. Increasing integration of livestock into farming systems
4. Working harder in terms of labour input per ha without increasing external non-labour inputs
5. Diversifying livelihoods

Experimental evidences in other countries

Seo and Niggol (2010)examined whether an integrated farm that owns both crops and livestock is more resilient under global warming than a specialized farm in crops. Using around 9000 farm surveys across Africa, the study explored how farmers choose one of the farm types and how the net revenue of each type varies across the range of climate in Africa. The results indicate that an integrated farm increases in number while a specialized farm decreases across Africa under climate predictions for 2060. The relative profitability of each system against each other also changes. An integrated farm becomes relatively more profitable over specialized farms half a century from now. The impacts of climate change on integrated farms range from 9% loss to 27% gain depending on climate scenarios. Behavioral models can capture portfolio diversification benefits that agro-economic models cannot measure.

With high levels of seasonal climatic variability impacting on the consistency of rice production in Cambodian rainfed, lowland systems (Dalgliesh *et al.*,2016), there is a need to identify strategies that improve farmer food security and better meet national domestic and export demands. While there is a substantial gap between actual and potential yield, little research has been undertaken in Cambodia to improve rainfed agronomy or the efficiency of use of natural resources which, in a climate constrained environment can hold the key to better productivity and food security.

The current global trend

Growing evidence shows that, relative to conventional agricultural production systems, integrated agricultural systems (IAS) can lower reliance on external inputs, enhance nutrient cycling and increase natural resource use efficiency. Perhaps for these reasons, IAS (as well as related concepts, known variously as diversified systems, mixed systems, agro-ecological systems, and agroforestry systems) are being promoted by international institutions, agri-businesses and governments. The degree of integration of farming systems is often unobserved and may be at least partially unobservable. Thus, studying the potential benefits of integration requires using observable elements of IAS as proxies for integration. The more mixed, diverse or diversified a system, the more integrated it has the potential to be collectively, the reviewed papers presented evidence that greater levels of integration on farms are associated with greater levels of resilience to climate change and variability. All studies using profit as a proxy for resilience showed a positive association, whereas such trends were not always clear when yield/crop production were examined.(Juliana *et al.,* 2017).

Way Forward

Numerous adaptation and mitigation options exist for crop–livestock systems. Despite the potential solutions, smallholders face major constraints at various scales, including small farm sizes, the lack of response to the proposed measures and the multi-functionality of the livestock herd. Major institutional barriers include poor access to markets and relevant knowledge, land tenure insecurity and the common property status of most grazing resources. These limit the adoption potential and hence the potential impact on resilience and mitigation. In order to effectively inform decision-making, Therefore there is a need for integrated, system-oriented impact assessments and a realistic consideration of the adoption constraints in smallholder systems. Building on agricultural system model development, integrated impact assessments and scenario analyses can inform the co-design and implementation of adaptation and mitigation strategies.

Contrary to the strong expected impact, the actual nature and magnitude of the effects of climate change and of options for adaptation and mitigation on crop–livestock systems are not well understood. One reason for this is that most research addresses isolated system components. Without recognizing component interactions and the influence of processes at different scales, effects at the farming system scale cannot be assessed. A second reason for the lack of understanding is the bias in climate change impact and adaptation studies. Whereas climate change effects on individual crops are relatively well studied investigations of the effects on livestock are rare. Furthermore, effects on whole-farm systems are poorly studied. Likewise, there is a dearth of information on effects on entire farm populations that are heterogeneous in terms of resource endowments (e.g. Masikati *et al.* 2015).

In order to understand climate change impacts and the effects of adaptation and mitigation options on mixed farming systems, a systems approach is needed that takes into account the interactions between the farm components and processes at different scales. In smallholder mixed farms, the multi-functionality of the herd works as a disincentive to reduce herd sizes which would be a promising pathway to improve productivity and reduce greenhouse gas emission rates (Oosting *et al.* 2014).Modeling the effects of climate change, adaptation and mitigation at farm population level, taking farm diversity into account, is a way to unravel the complexity. Secondly, explicitly accounting for the adoption potential through an analysis of costs and benefits and constraints at farm and higher levels helps to make impact assessments more realistic (Katrien Descheemaeker, *et al*., 2016).

Because diversified crops and agricultural systems contribute to more resilient upland agriculture, prioritizing commodities with growing market demand must be balanced with eco-efficient. A systems approach, where all available options are considered in an integrated manner, will be the most effective and ultimately the most sustainable, particularly for developing countries in the tropics under a variable climate. This holistic strategy will need global integration of efforts; the resulting synergies will produce impact more quickly than the individual institutions working in isolation could accomplish.

The role of integrated farming systems in stabilising the productivity and production without degrading natural resources and environment is an established fact. However, small and marginal farmers are not in a position to adopt the recommended systems in a big way due to several location specific problems including poor economic position. To site an example, it is often argued that rearing around 20 sheep / goat is remunerative in dry land farming systems of Andhra Pradesh (Rayalaseema) as the groundnut haulms can be used for feeding them during summer months. However, the scope for such a system is limited in dryland farming where the groundnut haulms are largely used for feeding the draught animals or dairy cattle / buffalos. If the groundnut haulms are fed to sheep / goat, the farmer is forced to feed the draft animals or cattle / buffalos by purchasing the feed and fodder. There is also need for a separate person to maintain a heard of 20 sheep / goat. Under these circumstances, farmers are not for sheep or goat rearing if they have work animals or dairy animals. If the groundnut haulms are going as waste, then sheep / goat raring could be a viable system. Hence, an insight into an existing system is a must for advocating an alternative system under a given farming situation.

The traditional farming systems followed by the resource poor farmers at present are similar to the new improved systems recommended in the recent past in all aspects except that the total output from the traditional systems is relatively low. There is scope for improvement in such traditional systems with minimum investment by way of replacing traditional breeds of cattle, buffalos, sheep, goats, etc with a few improved breeds. As of now, the resource poor farmers may not be in a position to adopt the entire recommended package including housing, stall feeding and feeding schedule to the recommended farm enterprise. Hence, implementable farming systems, as of now, are those traditional systems in practice with a couple of improved breeds of livestock components requiring minimum investment.

More systemic work involving large number of farm families and development of synergies between traditional and sustainable farming systems and modern methods is needed to bring overall prosperity through holistic approach of farming system in rural areas. Research and development on integrated farming systems for sustained productivity of small and marginal farmers has to go a long way before clear recommendations to suit location specific needs in different agro-ecological zones are formulated. Hence, crops and cropping system diversification and adoption of recently developed alternate land use systems are of immense significance to impart sustainability and economic stability in harsh farming environments (Bhale and Wanjari, 2013) .

Future line of work

- Maximizing the synergies between adaptation and mitigation means that these strategies should be developed simultaneously.
- There should be more research and action on adaptation measures in agriculture, especially in developing countries in order to assist farmers there to reduce the adverse impacts of climate change on agriculture.
- Action plans for mitigation measures for agriculture should be urgently researched and implemented. Financing assistance for adaptation and mitigation measures in the agriculture sector in developing countries should be prioritized.
- Arrangements should be made for the sharing of experiences and the transfer of good practices in agriculture that can constitute mitigation and adaptation.
- Efficient and environmentally-friendly farming system utilizing the potential of local resources in optimal way for a sustainable development of agriculture. However, the development of integrated farming system needs to be followed by participatory technology development, which is based on local wisdom in society.

Conclusion

On-station and on-farm research, in combination with farming systems simulation and social research provide the capacity to evaluate cropping options through the lens of climate variability. The testing of technologies and strategies, including the use of modern, short and medium duration varieties, opportunistic timing of crop establishment, mechanisation, supplementary irrigation and improved agronomic practice has shown that there is potential to mitigate the effects of variable climate on farm productivity and household income. However, this requires an increased level of farmer/systems flexibility to allow for near to real-time changes in cropping response to observed seasonal conditions. A systems approach, where all available options are considered in an integrated manner, will be the most effective and ultimately the most sustainable, particularly for developing countries in the tropics under a variable climate. This holistic strategy will need global integration of efforts; the resulting synergies will produce impact more quickly than the individual institutions working in isolation could accomplish.

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Polymers for higher water productivity and yield in tomato and other crops grown in light textured soils

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Introduction

Arid regions account for 45% of world land area – 7% arid, 20% semi-arid and 18% dry sub-humid (FAO, 2000). These arid, semi-arid and sub-humid lands are collectively referred as drylands. In India, about 15 million ha of dryland lies in the arid region which receives <500 mm rainfall; another 15 million ha is in semi-arid region with 500-750 mm annual rainfall. This low rainfall is also characterized by erratic with uneven distribution. Sandy soils (Alfisols) are major group of soils in semi-arid region which occupies almost 30% of area (Subba Rao 2011). These soils are shallow (up to 45 cm deep), coarse textured, contain low organic matter (0.3-0.4% organic C) and are subjected to sever erosion (Rao et al. 2013). Crop yields are low partly due to dry climate, shallow depth of soils, low moisture holding capacity and poor soil fertility. Kaolinite is the dominant clay mineral in these soils. Moisture stress is a major constraint for crop growth in arid and semi arid regions, as the precipitation is low and uncertain in these areas (Rao et al. 2013). Therefore, increasing water holding capacity in sandy soils with limited water retention is important and this could be achieved by using hydrophilic polymers or other soil amendments such as compost or farmyard manure, tank silt etc. which reduce water loss through leaching and improves water use efficiency. Farmyard manure or compost are the commonly used natural soil conditioners in India for reclaiming sandy soil at different rates ranged from 10 to 20 tonnes ha-1. But now sufficient quantity of farmyard manure is not available due to other competitive uses (Sammi Reddy et al. 2005). Therefore, considerable attention is being paid recently to use synthesized conditioners such as super absorbent polymers (SAP) i.e. hydrogels to improve water holding capacity of sandy soils.

Three main types of hydrogels have been developed as agricultural polymers: (i) starch-graft copolymers obtained by graft polymerization of polyacrylonitrile on to starch followed by saponification of the acrylonitrile units; (ii) cross-linked polyacrylates and (iii) cross-linked polyacrylamides and cross linked acrylamide –acrylate copolymers containing a major percentage of acryl amide units. Most of the hydrogels marketed for agriculture come from the latter group as they are claimed to remain active in soil for a much longer time (Nus 1982).

Contact between the polymer granule and water results in absorption until equilibrium is reached (Woodhouse and Johnson 1991). Johnson (1984) reported that, there would be 171% to 402% increase in the water retention capacity when polymers were incorporated in coarse sand. Hydrogels lead to increased water use efficiency since water that would have otherwise leached beyond the root zone is captured. During hot days, the hair root system of a plant pulls out and depletes most of the water from the area close to the root system, thus causing the plant to go into stress. While increasing the amount of available moisture, hydrogels help reduce water stress of plants resulting in increased growth and plant performance (Azzam 1980; Joao et al. 2007; Ekabafe et al. 2011). Earlier literature showed that increased water retention capacity attributed to polymer addition by significantly reducing irrigation frequency (Gehring and Lewis 1980; Flannery and Busscher 1982; Taylor and Halfcre 1986) and total amount of irrigation water required (Sammi Reddy et al. 2013). However, determination of optimum amount of polymer for best performance is influenced by many factors including, climate, polymer type, polymer granule size, soil type, temperature, plant species etc. Many researchers have reported that application of 20 kg ha-1 PAM prior to irrigation increased infiltration rates and reduced runoff and erosion (Smith et al. 1990; Stern et al. 1992).

Tomato is an important vegetable crop in India which occupies about 11% of total vegetable growing area. It is cultivated over 1 million ha area which produces about 16.9 million tonnes fruit yield. Even though tomato is grown throughout the year but it occupies most of the area during monsoon season due to availability of sufficient irrigation water. But monsoon crop would not fetch attractive net returns to farmers due to over production and also because of its perishable nature. Cultivation of tomatoes in off-season (end of winter to summer season) using ground water and stored harvested rain water is very profitable to farmers as the prices of tomatoes in summer season are very high (Bijay Kumar et al. 2011). Growing of off-season tomatoes on sandy soils with harvested water is a major challenge to farmers in peri-urban areas of semi-arid regions. Application of polymers to tomatoes grown on light textured soils could be useful for increasing area with limited water resources through enhanced water use efficiency. Keeping above things in view, investigations were conducted (i) to study water retention and release characteristics of a cross linked polymer of polyacrylamide and potassium acrylate (PAM) and (ii) to assess the effect of their application on water retention capacity of sandy loam and sandy clay loam soils (Alfisols) in a laboratory and to evaluate its effect on yield and water productivity in tomato grown on sandy loam soil under field conditions. The results of these investigations are presented in this lecture notes.

Results and Discussion

(i) Laboratory investigations

***Rate of hydration of polymer*:** Irrespective of source of water, polymer showed rapid initial hydration followed by more or less constant water absorption towards the point of equilibrium (Table 1). Absorption of water by polymer was such that 67-84% of maximum absorption was achieved within five minutes and 80-92% of maximum absorption was absorbed within ten minutes. In case of distilled water, irrigation water, 50% Hoagland solution, maximum of amount of water was absorbed in 40 minutes. After 40 minutes, more or less constant water absorption was maintained. In case of 0.01M CaCl2 and 200% Hoagland solution, maximum absorption of water was achieved in 60 minutes and thereafter remained constant. When critically compared, absorption of water was slow in case of 200% Hoagland solution as compared to others sources of water. In 200% Hoagland solution, only 80% of maximum absorption was achieved in first ten minutes.

Substantial loss of irrigation water occurs by extensive percolation in coarse soils. The speed and efficiency of any storage facility is therefore crucial. If a slow hydrating polymer is used, a relatively longer period of irrigation has to be provided for the polymer to expand fully. This is because much water can be lost through runoff, percolation or leaching during the expansion phase of the polymer. In such cases, the present polymer is found very ideal as it absorbed almost 95-99% of maximum water within 20 minutes. According to Wang and Gregg (1990), complete hydration took up to 12 h in some polyacrylamide polymers.

Table 2.1. Hydration potential (g water absorbed g-1 polymer) of polyacrylamide-potassium acrylate (PAM) in different media

Time (min) of saturation	**Distilled water**	**Irrigation water**	**0.01 M $CaCl_2$**	**Hoagland solution (50% Strength)**	**Hoagland solution (100% Strength)**	**Hoagland solution (200% Strength)**
5	246.9	119.7	96.2	141.0	115.7	86.0
10	310.2	142.5	105.9	148.0	125.0	88.8
20	346.5	148.6	108.5	159.0	137.8	98.7
40	369.0	154.6	109.6	175.0	141.1	104.9
60	368.0	153.2	114.2	173.0	140.1	110.6
120	368.9	152.8	115.0	170.5	139.0	110.0
240	368.3	153.0	114.0	173.4	140.7	109.4
l.s.d (P=0.05)	15.6	5.0	4.9	7.8	6.4	4.5

When the amount of water absorbed by polymer from different sources of water was compared, polymer absorbed the highest amount of water (369 g g-1) from distilled water followed by 50% Hoagland solution, irrigation water, 100% Hoagland solution, 0.01 M CaCl2 and 200% Hoagland solution (Table 1). Overall, the amount of water absorbed by one gram of polymer ranged from 247-369 g in distilled water, 141-175 g in 50% Hoagland solution, 120-155 g in irrigation water, 116-141 g in 100% Hoagland solution, 96-115 g in 0.01 M CaCl2 and 86-111 g in 200% Hoagland solution over 5 – 240 minute saturation period.

Soluble salt content of different sources of water might be the reason for differences in absorption of water polymers from different sources. The electrical conductivity (EC) values varied from 0.03 dSm-1 in distilled water to 2.23 dS m-1 in 200% Hoagland solution. The amount of water absorbed by polymer decreased from 360 g g-1 to 110 g g-1 with increasing EC from 0.03 to 2.23 dS m-1 (Table 2). Soluble salt content in different sources of water significantly affected the absorption of water by polymer which was consistent with previous results (Johnson 1984; Lamont and O’Connel 1987).

Table 2.2 Effect of salinity of medium on hydration potential of polyacrylamide-potassium acrylate polymer

Source of water	EC (dS m^{-1}) of medium	Hydration potential (g water absorbed g^{-1} polymer)
Distilled water	0.03	360.2±12.3*
50% Hoagland solution	0.74	177.7±6.7
Irrigation water	1.14	150.3±6.3
100% Hoagland solution	1.49	140.8±5.2
0.01 M $CaCl_2$	2.17	115.6±4.3
200% Hoagland solution	2.23	110.9±4.0

*Standard deviations

The degree of reduction in water holding capacity of a particular polymer depends upon the structure and chemical composition of the product and the concentration and variety of ions in the soil solution to which the polymer is being exposed (Wang 1989). Earlier work has shown that fertilizer solutions reduced polymer water absorption ability by as much as 75 – 90% (Bowman et al. 1990). In the present investigation, the hydration potential of polymer was reduced by 31-49% with other sources of water as compared to distilled water but still polymer holds good amount of water which is important considering its use in rainfed dryland agriculture. The possible reason for the relatively better performance of current polymer, compared to 75-90% reduction in absorption capacity of other polymers, may be because the solutions used in this experiment particularly Hoagland solution contained a combination of different nutrients. Combining fertilizer nutrients have reduced the impact of salt solution on some polymers (Foster and Keever 1990) which may be a positive thing from the point of view for use in agriculture.

Water release characteristics of polymer: The same hydrated polymer samples in which effect of salinity on water absorption studied were subjected to 0.33 bar (FC) and 15 bar (PWP) pressure in the pressure plate apparatus to extract water (Table 3). Across the source of water, about 92 – 98% of absorbed water was released at 0.33 bar pressure. At FC pressure, lowest amount of water (92.4%) was released in case of distilled water and 98.5% was released with 0.01M CaCl2 which were not statistically significant. When subjected to 15 bar pressure, about 97.6 – 99.6% of absorbed water was released. These results clearly showed that the water held in polymer can easily be available to plants. In earlier studies, Joao et al. (2007) reported that more than 90% of water absorbed by polymer was available to plant roots.

Table 2.3. Water released from hydrated polyacrylamide-potassium acrylate polymer at 0.33 and 15 bar pressure

Source of water	**Weight of polymer + water retained in it before subjecting to pressure (g)**	**Weight of polymer + water retained in it after subjecting to pressure (g)**	
		0.3 bar	**15 bar**
Distilled water	360.2±12.3*	27.3 (7.6)**	1.35 (0.4) **
50% Hoagland solution	177.7±6.7	4.90 (2.8)	4.18 (2.4)
Irrigation water	150.3±6.3	5.30 (3.5)	1.85 (1.2)
100% Hoagland solution	140.8±5.2	3.72 (2.6)	1.45 (1.1)
0.01 M $CaCl_2$	115.6±4.3	1.74 (1.5)	1.75 (1.5)
200% Hoagland solution	110.9±4.0	4.68 (4.2)	2.51 (2.3)

*Standard deviations; **Figures in parenthesis are % of water absorbed

Effect of application of polymer on water retention in soil: At field capacity, water retention in both sandy loam and sandy clay loam soils significantly increased with increased rates of application of polymer from 0.25 to 1% of soil on dry weight basis (Table 4). In sandy loam soil, water retention at field capacity increased by 93% at 0.25% polymer application rate and by 304.5% at1% polymer application rate as compared to no polymer application. In sandy clay loam soil, water content increased by 52.7% with 0.25% rate of polymer application rate and by 209.3% at 1% rate of polymer application. At permanent wilting point, polymer treated soils held more water than untreated soils and the amount of water held by treated soils increased with increase in the rate of application of polymer. At PWP, the water retention in sandy loam soil was increased by 51% with 0.25% polymer rate and by 215% with 1% polymer application rate. Similarly sandy clay loam soil retained higher water at PWP by 16% with 0.25% polymer rate and by 173% at 1% polymer application rate.

Table 2.4. Soil moisture content as influenced by application of polyacrylamide-potassium acrylate polymer

Rate of polymer application (% of soil, w/w)	**Water retention in soil (%, w/w) at 0.33 bar (A)**	**Water retention in soil (%, w/w) at 15 bar (B)**	**Available water content (%, w/w) (A-B)**
Sandy loam soil			
0	8.96±1.1*	5.45±0.6	3.51
0.25	17.31±1.9	8.23±1.0	9.08
0.50	26.80±2.5	14.80±1.6	12.00
0.75	31.24±2.5	18.44±1.9	12.80
1.00	36.25±3.2	21.19±2.2	15.06
Sandy clay loam soil			
0	10.71±1.3	6.07±0.7	4.64
0.25	16.36±1.8	7.04±0.9	9.32
0.50	20.22±2.1	8.82±1.6	11.4
0.75	26.05±2.0	14.04±1.8	12.01
1.00	33.13±2.9	19.58±2.0	13.55

*Standard deviations

As a consequence of increased water retention at FC and PWP in both the soils, the available water content increased with increase in the rate of application of polymer (Table 4). In sandy loam soil, available water content increased by 158.6% with 0.25% polymer rate and by 192% with 1% polymer application rate as compared to no polymer application. Similarly in sandy clay loam soil, available water content increased by 100.9% with 0.25% polymer rate and by 192% with 1% polymer application rate. These results showed that when polymers are incorporated into a soil they retain large quantities of water. The plants absorb stored water from polymer as and when required. It has been reported that 171% to 402% increase in the water retention capacity is recorded when polymers were incorporated into sandy soils (Ekabafe et al. 2011).

This increased water retention attributed to polymer addition leadng to significant reduction in irrigation frequency (Flannery and Busscher 1982).

Table 2.5. Effect of polymer application on tomato fresh fruit yield and water productivity on sandy loam soil

Treatment combination		Plant height at 60 DAT (cm)	Fresh fruit yield (t ha^{-1})	Total dry matter yield (t ha^{-1})	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})	Total No. of irrigations given	Total amount of water applied (ha-mm^{-1})	Water productivity (kg fruit ha-mm^{-1})
Irrigation level	Rate of polymer application (kg ha^{-1})									
Every week irrigation	0	97.2	65.00	8.4	118.8	33.5	122.1	20	400	162.5
	25	102.2	66.57	9.2	122.7	36.8	129.8	20	400	166.4
	50	106.1	69.50	9.8	126.1	38.6	136.0	20	400	173.7
Alternate week irrigation	0	85.7	54.30	6.8	98.5	26.2	101.2	11	220	246.8
	25	95.8	63.93	8.8	115.8	32.1	126.1	11	220	290.6
	50	101.8	68.70	9.6	123.6	36.6	131.6	11	220	213.3
Every third week irrigation	0	72.2	36.33	5.1	67.2	20.1	71.7	8	160	227.1
	25	78.8	40.13	5.2	68.5	22.5	74.8	8	160	250.8
	50	82.8	45.30	6.0	80.8	25.2	85.1	8	160	283.1
l. s. d. (P = 0.05)		7.5	8.91	1.5	8.0	6.0	6.5	-	-	-

The increase in the water retention with application of different rates of polymer at FC and PWP was more in sandy loam soil than sandy clay soil. Hemyari and Nofziger (1981) observed that, addition of PAM at the rate of 0.4% (by weight) to loamy and sandy loam soils resulted in higher water retention compared to their untreated counterparts. However, PAM had only little effect on water retention in clay and loam textured soils.

(ii) Field experiment

Tomato plant height, fruit yield and dry matter production: At every week irrigation, application of polymer @ 25 kg ha-1 or 50 kg ha-1 had no significant effect on tomato plant height and fruit yield (Table 5). Plant height varied from 72.2 cm with every third week irrigation without polymer application to 106.1 cm with combination of every week irrigation and 50 kg ha-1 polymer application. Polymer had no significant effect on plant height when tomato was irrigated every third week. The effects of polymer application and irrigation levels on fruit yield were similar to that of plant height. At every week irrigation, tomato fruit yield produced at different rates of polymer application was at par with that of no polymer application. But when tomato was given irrigation at alternate weeks, application of polymer had significant effect on fruit yield. Alternate week irrigation with application of 25 kg polymer ha-1 produced significantly higher fruit yield as compared to no polymer application. But further increase in the rate of application of polymer to 50 kg ha-1 showed no significant increase in the yield as compared to 25 kg ha-1 at alternate week irrigation. Application of polymer even at 50 kg ha-1 with every third week irrigation produced significantly lower fruit yield as compared to every week irrigation without or with polymer application. Effect of different treatment combinations on total dry matter production of tomato was essentially similar to that of fruit yield. Total dry matter production varied from 5.1 t ha-1 with every third week irrigation with no polymer application to 9.8 t ha-1 with every week irrigation plus 50 kg polymer ha-1. These results clearly brought out that application of polymer is not beneficial when soil water availability is sufficient to meet crop requirement. And application of 25-50 kg polymer ha-1 would not be sufficient to meet water requirement of crops when irrigated at every third week. But application of 25 kg polymer ha-1 can save one irrigation every fortnight during the growing season of tomato crop. Many researchers found that application of 20 kg ha-1 PAM prior to irrigation increased infiltration rates and reduced runoff and erosion (Stern et al. 1992). Application of 28 kg water absorption polymer (Bhagiratha) per hectare along with recommended rates of fertilizers to pigeon pea maintained higher soil moisture level in sandy loam soil at different growth stages of crop and produced higher seed yield and nitrogen uptake by 12 and 10%, respectively as compared to control (only fertilizers) (Mondal 2011).

Super absorbent polymers cause improvement in plant growth by increasing water holding capacity in soils (Boatright et al. 1997) and delaying the duration to wilting point in drought stress (Gehring and Lewis 1980). Water conservation by gel creates a buffered environment being effective in short term drought tension and losses reduction in establishment phase in some plant species. Totally, proficiency in water consumption and dry matter production are positive plant reactions to super absorbent polymer application (Woodhouse and Johnson 1991). Poly (ethylene oxide) hydrogel, polyacrylamide hydrogel and cross-linked poly (ethylene oxide)-co-polyurethane hydrogel were attempted to alleviate the plant damage that resulted from salt-induced and water deficient stress (Shi et al. 2010).

Nutrient uptake by tomato*:* Treatment combinations of irrigation level and polymer application significantly influenced the nutrient (N, P and K) uptake/removal by tomato (Table 5). In general, the trend of effect of different treatments on nutrient uptake by tomato was similar to that of fruit yield and dry matter production. The highest N (123.6 kg ha^{-1}), P (36.6 kg ha^{-1}) and K (131.6 kg ha^{-1}) uptake by tomato was observed in plots those received alternate week irrigation and polymer application at 50kg/ha and were at par with that of alternate week irrigation with 25 kg polymer application rate. Application of polymer either at 25 kg ha^{-1} or at 50 kg ha^{-1} with every week and every third week irrigation had no significant effect on N, P and K uptake by tomato. In earlier studies, nutrient (NPK) uptake by rose was increased in sandy and loamy soils with the application of Igita (a Japan-made super absorbent polymer) at 0.05-0.3% of soil (Karimi *et al.* 2008). Shim *et al.* (2008) by studying on different hydrophilic polymers on nutrient uptake illustrated that increase in N, P, K, Ca and Mg uptake by plant was a result of better plant growth in polymer treated plots.

Water productivity in tomato: At different rates of polymer application, tomato crop in plots with every week irrigation received 20 irrigations, plots with alternate week irrigation received 11 irrigations and plots with every third week irrigation received 8 irrigations during the crop growth period (Table 5). Total amount of water applied to every week irrigation plots was 400 ha-mm, alternate week irrigation plots was 220 ha-mm and every third week irrigated plots was 160 ha-mm. Water productivity was computed using fruit yield data and total amount of water applied during crop growth period. Application of polymer at 25 kg ha-1 with alternate week irrigation recorded the highest water productivity of 290.6 kg ha-mm-1 and saved 180 ha-mm irrigation water during a crop growth season.

In the laboratory studies, this particular polymer retained about 150 g water per g and thereby increased the available water content of sandy loam soil by 158-329%. The results of laboratory studies were reflected in the field studies. The stored water in the polymer is released as required by the plant. Thus, plant growth was improved, and/or water supplies conserved. It has been reported that increased water retention capacity attributed to polymer addition significantly reduced irrigation frequency (Flannery and Busscher 1982) and the total amount of irrigation water required. In an experiment, it was estimated that Conocarpus lancifolius in warm and dry climate of Kuwait, applying Agrihope polymer in 0.4% weight concentration lead to 50% lesser irrigation need than that of control (Bhat et al. 2009). Poormeidany and Khakdaman

(2006) recommended applying of polymer at planting time to different crops in order to reduce irrigation and to have proper amount of plant survival.

(iii) Conclusions

Irrigation water is becoming increasingly limiting world over. It is important to improve the water use efficiency (WUE) of plants. The use of water retaining polymers has potential for enhancing WUE in horticultural and field crops. The Polyacrylamide potassium acrylate polymer (PAM) used in the present study has a fast rate of hydration, which is a very important characteristic in the selection of polymer for agricultural use. The hydration potential of polymer reduced with increasing salt content of source of water but it still holds good amount of water particularly in irrigation water (150 g water g-1 polymer) which is important considering its application in rainfed agriculture. Application of polymer at different rates increased the available soil moisture content by 101-192% in sandy loam and sandy clay loam soils. The characteristics of polymer and effect of its application on soil moisture content were found beneficial in saving irrigation water without affecting the yield of tomato under field conditions. The combination of alternate week irrigation with application of 25 kg polymer ha-1 produced similar tomato growth and fruit yield to that of every week irrigation without polymer use. This combination also recorded the highest water productivity in tomato and there by saved 180 ha-mm irrigation water during a crop growth season. Mostly, tomato is grown with harvested water and /or with ground water in winter and summer seasons in dry land areas. Therefore, the area under tomato and other vegetables is very limited in these seasons due to limited availability of underground and harvested water in dryland areas of semi-arid and arid regions. Thus, these results clearly demonstrated that the application of polymer @ 25 kg ha-1 could enhance the area under tomato with limited water availability in off-seasons on sandy soils of rainfed areas.

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Land use systems for livelihood security in rainfed areas

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Introduction

Rainfed agroecosystems occupy a significant place in Indian agriculture covering about 72 M ha, in arid, semiarid, and subhumid climatic zones, constituting nearly 51% of the net cultivated area. These areas contribute almost 100% of forest products, 73-90% of coarse grain cereals and pulses, 73% of oilseeds, 66% of cotton, and 40% of rice. Further, rainfed regions support 60% of livestock and 40% of human population and contribute 40% of food grains and several special-attribute commodities such as seed spices, dyes, herbs, gums etc. Due to yield plateuing in irrigated area in most of the crops, the second green revolution must therefore explicitly embrace rainfed areas with special focus on pulses and oilseeds to ensure nutritional security and agricultural sustainability. In rainfed regions, wide spectrum of agro-ecological conditions exists in different parts of country which are suitable for growing these crops throughout year.

In India, the farmer in rainfed region has established land use planning merely in two thirds of the arable land with multiple/mixed crops. Current rainfed land use practices comprising monocropping, intercropping and to some extent mixed farming systems (with annuals, perennials and small/large ruminants) are no doubt supporting resource poor farmers by exploitation of natural resources but the productivity levels, viable incomes, year round employment or the sustenance of the ecosystem are usually not taken care adequately. In these complexities, a land use cannot provide a module, which is the need for a rainfed system. The final aim of rainfed land use planning is to build a model for individual farmer to sustain the farming system feeding his family, giving staggered and attractive income, improving the land quality and feed to the livestock apart from returns from perennial trees like woody species.

Land.

As per the UN (1994), land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the:

- Biosphere immediately above or below this surface, including those of the near surface climate,
- the soil and terrain forms,

- the surface hydrology (including shallow lakes, rivers, marshes and swamps),
- the near surface sedimentary layer and associated ground water reserve,
- the plant and animal populations,
- the human settlement pattern and physical results of past and presnt human activity (terracings, etc.).

What is Land Use Planning?

LUP (FAO, 1993) is the systematic assessment of physical, social and economic factors in such a way as to encourage and assist land users in selecting land use options that: a) is an interactive and continuous process of development; b) requires flexibility; c) does not have a clear end-product; d) is problem oriented; e) is area specific; and f) involves all stakeholders.

Why Land Use Planning for Agroforestry Systems Management

Rainfed agriculture and allied enterprises, rural development activities like watershed management, land conservation/development etc. are basically land based activities. Therefore, scientific land use planning at any level forms the basis to achieve sustainable rainfed agriculture and rural development.

Agroforestry

Perennial species also play an important role in areas where cropping of annual plants has reduced total water use and allowed water tables to rise, with resultant salinization. In such areas, an appropriate density of trees in ‘agroforestry’ systems can help reestablish a hydrological balance that keeps the water table and its salt content below the root zone of crops. The emphasis here in agroecological analysis is on the processes and balance of resource supply and capture, and on the competitive and complementary relationships between the planned and unplanned (associated) biodiversity (Connor, 2002) (Table 1).

Table 3.1. Some factors affecting decisions on incorporation of Agroforestry in crop diversification in rainfed regions of India

Short-term profit factors: Crop production and quality; Forage production level, quality and timing; Yields of trees, economic shrubs and forages Input costs;Output prices for annuals, perennials and livestock products

Dynamic factors – short term to medium term:Soil health;Tree and forage density Abiotic stresses; Water harvesting; Optimum tillage
Sustainable factors: Soil degradation; Nutrient loss; Tree/forage establishment
Risk factors: Yield variability; Price variability; Yield/price covariance Flexibility of the enterprise in response to changed conditions; The farmer's attitude to risk
Whole-farm factors; Total arable area; Machinery; Total feed requirements Financial support; Labour availability, quality and cost; The farmer's objectives (profit, risk reduction, sustainability); Traditional wisdom

To remain competitive and survive in the current economy, farmers must be insightful, innovative, and ready to make changes. In recent years, conventional wisdom has encouraged diversification with alternative enterprises and increased on-farm processing, packaging, and other means for adding value to raw products before they leave the producer's hands. While this makes good sense, making diversification and value-added strategies work can be challenging (Table 2).

Table 3.2. Issues and functions provided by Agroforestry in rainfed regions

Issue/Functions provided by diversification
Productivity and stability: Increased yield, reduce intra seasonal variation and improved stability through diverse components viz. crop, tree, plant and animal
High risk and high cost: Risk and cost minimization through yield and income from annual and perennial mixtures
Unabated land degradation;Minimization of kinds, effect and extent of land degradation by appropriate land care through alternate land use systems
Inadequate employment: Staggered employment round the year
Low profitability; High income generation from various components
Poor energy management: Energy efficient implements

Suggested Microlevel Land Use Planning vis-a-vis agroforestry systems in rainfed regions of India

Some of the rainfed agroecology specific agroforestry systems developed in AICRPDA network are briefed below:

A. Agroforestry Systems for Arid - Rainfed Agroecosystem

In an agroforestry based farming system involving sheep rearing and groundnut in arid alfisols at Anantapuramu (Andhra Pradesh), higher groundnut equivalent yield (823 kg/ha), net returns (Rs. 24445/ha) and B:C ratio (0.51) were recorded with groundnut as sole crop with rearing of 10 sheep compared to groundnut + amla system (179 kg/ha) (AICRPDA, 2015).

B. Agroforestry Systems for Semiarid Rainfed Agroecosystem

In drumstick based agri-horti system for Vertisols of Central Maharashtra plateau zone of Maharashtra, drumstick + greengram system gave highest drumstick equivalent yield (2246 kg/ha), net returns (Rs 10807/ha) and RWUE (7.9 kg/ha-mm) compared to sole drumstick (1387 kg/ha with net returns of Rs 6224/ha). In an agri-horti system evaluated under continuous contour trenches (CCTs) in Vertisols of Western Vidarbha zone of Maharashtra, the CCTs (60 cm x 30 cm) helped in efficient harvesting of rainwater since no runoff was allowed to flow out of the land which resulted in efficient in-situ moisture conservation and utilization by the plants of fruit trees (custard apple and Hanuman phal), further helped in groundwater recharge.

In semiarid alfisols of Southern dry zone of Karnataka, fingermillet proved to be better intercrop in amla based agri-horti system with higher amla equivalent yield (1736 kg/ha) and net returns (Rs.43110/ha) and in custard apple based system, significantly higher custard apple equivalent yield (2050 kg/ha) and net returns (Rs 102446/ha) was recorded with fodder maize compared to other intercrops. Similarly in mango based agri-horti system, mango + fingermillet recorded higher mango equivalent yield 1870 kg/ha with net returns of Rs. 28594 ha and B:C ratio of 2.04, compared with intercropping of horsegram in mango (700 kg/ha) (AICRPDA-NICRA, 2016). In dryland horticulture, in-situ moisture conservation with trench–cum-crescent bund method in amla gave higher yield of amla (3273 kg/ha) and net returns (Rs 123320/ha) followed by continuous trenches (2568 kg/ha) and no trenches (1611 kg/ha) (AICRPDA-NICRA, 2016).

A tamarind based agri-horti system developed for (hot dry) Vertisols of northern dry zone of Karnataka includes tamarind spaced at 10 m x 3 m gave overall yield advantage up to 810% and 720%, respectively over sole crops viz. pearlmillet (1571 kg PEY/ha) and sunflower (1760 kg PEY/ha). In sapota based agri-horti system (12 m x 12 m), the maximum gross income can be attained with sapota intercropped with sunflower during kharif followed by rabi sorghum+

chickpea (2:1) sequence cropping system (Rs. 42400/ha) followed by growing of greengram during kharif and rabi sorghum+ chickpea (2:1) (Rs. 39100/ha) (Srinivasarao et al., 2014).

C. Agroforestry Systems for Subhumid Rainfed Agroecosystem

In subhumid (hot moist) Inceptisols of Bastar plateau zone of Chhattisgarh, mango based agri-horti system with trenches at base of trees for in-situ moisture conservation + colocasia as intercrop recorded higher yield of both mango (2879 kg/ha) and colocasia (1887 kg/ha) with higher net returns (Rs.54494/ha), B:C ratio (3.59) and RWUE (3.62 kg/ha) (AICRPDA-NICRA, 2016).

Way Forward

Bottom Up approach

Potential crop zoning, diversification within farm – Farming systems - Climate risks, rainfall, soil type, crop production systems

Building institutions at village level – commodity groups, water user groups, seed/planting material banks, nutrient banks, custom hiring centres, FPOs Capacity building, building value chains

Top-Down approach

Agroecology specificity for technology targeting and upscaling - NRM centric - areas should match with natural resource endowments Mainstreaming rainfed horticulture in land use systems mode: Convergence of Govt. Programmes.

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Watershed approach for alternate land uses

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Introduction

Rainfed agriculture has a crucial role to play in the economy and food security of India. At present, about 55% of the total net cultivated area (139.0 m ha) is rain dependent and contributing 40% to total food grains production. Corse cereals (91%), pulses (91%), oil seeds (80%), cotton (60%) and rice (55%) dominate rainfed areas and are home to 40% of the country's human and 66% of livestock population. Rainfed agriculture is backed up with strengths such as wide range of agro-ecological and edapho-climatic conditions supporting high biodiversity. Thus, there is wide scope for diversified farming activities for increased productivity and profitability in rainfed areas.

Rainfed agriculture continues to be a gamble with monsoon and rainfed farmers face several uncertainties like erratic rainfall and aberrant weather conditions leading to low and unstable productivity and profitability. Although, rainfed agriculture is constrained by several weaknesses but there are ample opportunities for development by employing modern tools and technologies, viz., [i] integration of information using Remote Sensing, GIS and ICT, [ii] positive change in socio-economic condition, [iii] thrust on recycling and use of low external inputs, [iv] large network of NGOs, and [v] greater focus on rainfed ecosystem by government of India under various schemes with good scope for convergence.

The possible threats that are playing 'hide and seek' with rainfed agriculture cannot be overlooked. The threats are: (i) unabated land degradation and depletion of soil organic matter; (ii) global warming, shrinking water bodies and falling groundwater levels; (iii) increasing number of human and livestock heads per unit of land; (iv) political divide in local communities impeding development of villages; (v) increased fragmentation of land and absentee landlordism; and (vi) un-controlled excessive grazing by livestock and felling of trees causing severe loss of biodiversity. Apart from above, the transfer of dryland technology to farmers' field is abysmally slow and low due to natural, operational, institutional, geo-political and socio-economic constraints. Therefore, there is a need to rejuvenate rainfed agriculture, which is possible through consortia approach and convergence of various programmes and schemes focussing livelihoods on watershed mode. Development of rainfed agriculture can serve as an 'effective instrument' for socio-economic change in rural India.

Management of rainfed agriculture through watershed approach

The idea of 'watershed approach' was conceived, designed and developed to test and refine rainfed technologies. The model watershed programme launched by ICAR during 1980's and implemented by CRIDA on 30 sites out of total 47 led to the launch of National Watershed Programme for Rainfed Areas (NWDPRA) by Ministry of Agriculture and later taken up by Ministry of Rural Development.

Evolution of watershed concept in India:

Evolution of watershed concept in the country can be divided into three phases with distinct characteristics, viz., top down approach, participatory and livelihood approaches (Fig. 1).

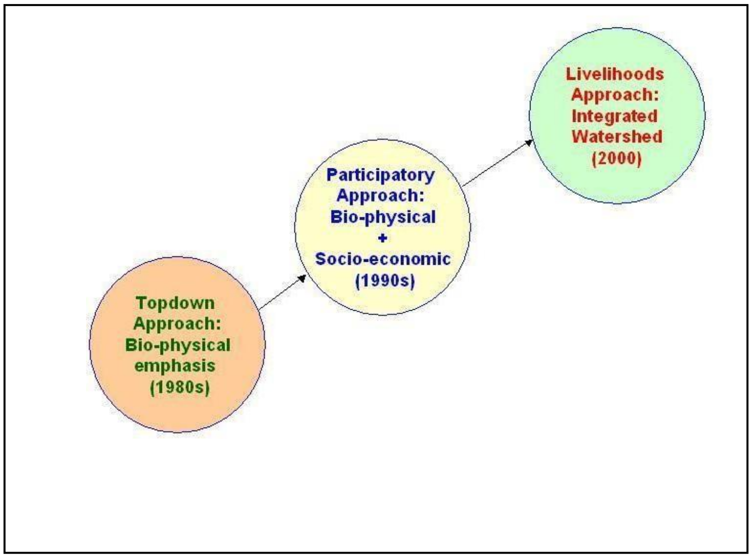

Fig. 4.1 Evolution of watershed concept in India

(1) **Top-down approach:** Top-down approach was followed at the inception of watershed concept in eighties with the emphasis on bio-physical measures and governmental agencies acted as planners and implementers, stakeholders had remained as mere spectators and there was no withdrawal mechanism.

(2) **Participatory approach:** The second phase of the watershed concept is also called transition phase (in nineties) in which (i) due recognition was given to stakeholders for effective participation in the management of natural resources, (ii) conflicts arose due to different norms of implementation by Ministry of Agriculture (NWDPRA) and Ministry of Rural Development (DPAP) and, (iii) no well-defined withdrawal mechanism existed.

(3) **Livelihoods approach:** The third phase of the watershed concept (present stage) is livelihoods approach with special emphasis on integrated watershed management that focuses more on (i) capacity building of stakeholders, (ii) due regard to social and human capital, and (iii) suitable exit policy.

Over a period of time, watershed programmes have evolved from purely technical to community oriented with due emphasis on creation of livelihoods opportunities for the rural community, both landed and landless. The concept of livelihoods approach to watershed management in a participatory mode is the prime focus of the Institute to mitigate the adverse impact of rainfall variability due to climate change.

The objectives and goal of integrated watershed management strategies are depicted in Fig. 2 below:

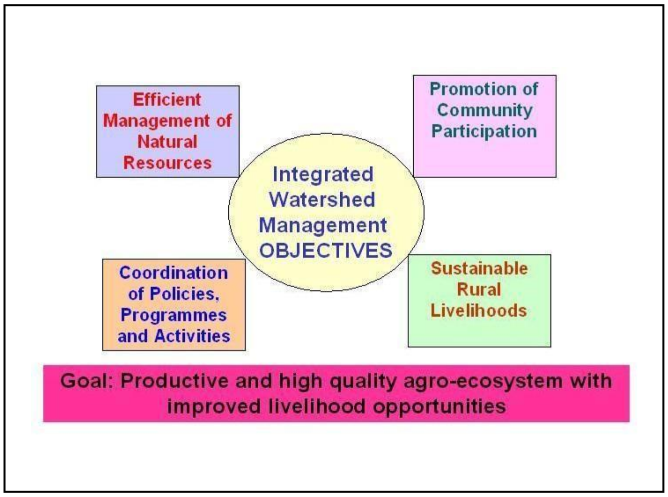

Fig. 4.2 : Objectives and goal of integrated watershed management strategies

Impact Evaluation of Watersheds

The evaluation of watersheds programmes by CRIDA at different times indicated improvement in water table, surface water resource, afforestation, cropping intensity, crop yield, income, and employment generation. The overall improvements in physical parameters in watershed projects in various agro-climatic conditions are set out in the Table 1.

Table 4.1. Impact of watershed programmes on various parameters

Parameter/agro-climate	Arid	Semiarid	Humid
Rise in water table(m)	1.05	1.57	1.38
Reduction in runoff (%)	35.0	33.2	30.5
Reduction in soil erosion (%)	15.0	28.8	25.6
Surface water resource developed (%)	9.0	18.0	20.5
Increase in afforestation (%)	10.0	11.3	21.7
Increase in cropping intensity (%)	6.0	16.0	18.3
Increase in employment (%)	12.5	25.0	20.8

The concept of watershed management is important for the efficient utilization of water resources. Since, rainwater conservation and utilization is the keystone of successful dryland farming, the watershed with distinct hydrological boundary is considered an ideal approach for area development. Past experience of watershed projects implemented in dryland areas have led to improved water availability in terms of additional surface storage and enhanced recharge of groundwater. Increased water availability in wells and storage facilities led to increased cropping intensity by 50% over a period of five years. Consequently these efforts have resulted in adoption of improved rainfed crop production technologies, diversification of land use leading to sustainable livelihoods.

Lessons learnt from watershed programmes in promoting alternate land uses

Selection of Watershed

A micro-watershed may be taken as unit for treatment having 1,000 to 10,000 ha (under the revised guidelines of NRAA, 2011) under a micro-basin and need to be treated from to ridge to valley. Water is going to be critical in the near future, so water budgeting and management policy for each micro-watershed need to be evolved depending upon supply and demand. Incentives to irrigated dry (ID) crops need to be ensured as water loving crops will jeopardize the whole concept of watershed development. Cultivation of irrigated dry (ID) crops and following of System of Rice Intensification (SRI), aerobic method of cultivation for paddy will reduce the pressure on ground water. Social regulations enacted by communities themselves on water use are the need of hour in a democratic setup rather than enacting laws. This calls for creating of awareness among rural masses and suitable policies for discouraging cultivation of water loving crops, like substituting rice and wheat under PDS with millets for enhancing productivity of water and for ensuring food, fodder and nutritional security of both human and livestock by diversifying the land use.

Small Farm Livelihood Technologies – CRIDA's experiences

CRIDA has made social interventions by: (i) ensuring peoples' participation through PRA, focused group discussion, etc. (ii) developing capacity building through training and exposure visits and, (iii) constituting Salaha Samithi (Village Advisory Group) – a novel concept.

Village Advisory Group (Salaha Samithis)

Formation of a Salaha Samithi (SS) in the cluster is an important institutional innovation developed by the communities. Salaha Samithi, an advisory group of villagers, is formed considering the need expressed by the villagers for an institution that can facilitate the implementation of the project activities in association with the project staff, keeping aside political affiliations.

Technical interventions

An array of crop and cropping system choices for location-specific rainfed regions that match with land-capability classes are now available to farmers of different agro-ecological regions based on research carried out by CRIDA and its network centers. In dryland agriculture, drought is a common phenomenon either due to a late onset or early withdrawal of monsoon or dry spells within the cropping season. Several technologies have been developed and tested for their resilience that can tolerate aberrant weather conditions. Generally, short duration crops and varieties have replaced the long duration varieties. In seasons when rainfall is inadequate after planting, mid-season corrections such as interculture, thinning, and reducing plant population have been demonstrated.

Growing of arable crops with compatible tree species has been a traditional practice by dryland farmers who view it as a way to meet the demand for food, fodder, fuel, etc. Such a system offers sustainable productivity by covering land with vegetation, and conservation of natural resources, commonly referred as "alternate land use system". Several such systems have been identified matching to soil and climatic conditions subject to market availability.

Rainfall-based Land Use Diversification

In view of the strong link between natural resources, its access to poor for enhancing livelihood security is varying with different rainfall zones. In very low rainfall regions, livestock production and agro-forestry are the prime drivers of on-farm livelihoods, while in relatively high rainfall regions, crop production, horticulture; poultry with appropriate value addition strategies are suited to both landed and landless. Rural micro-enterprises and outsourcing opportunities for semi-skilled and skilled jobs can also provide gainful employment to the educated youth. This will reduce pressure on limited natural resources. Land use systems based on rainfall and land capability class is presented in a graphical format (Fig. 3) and land use options in table 2.

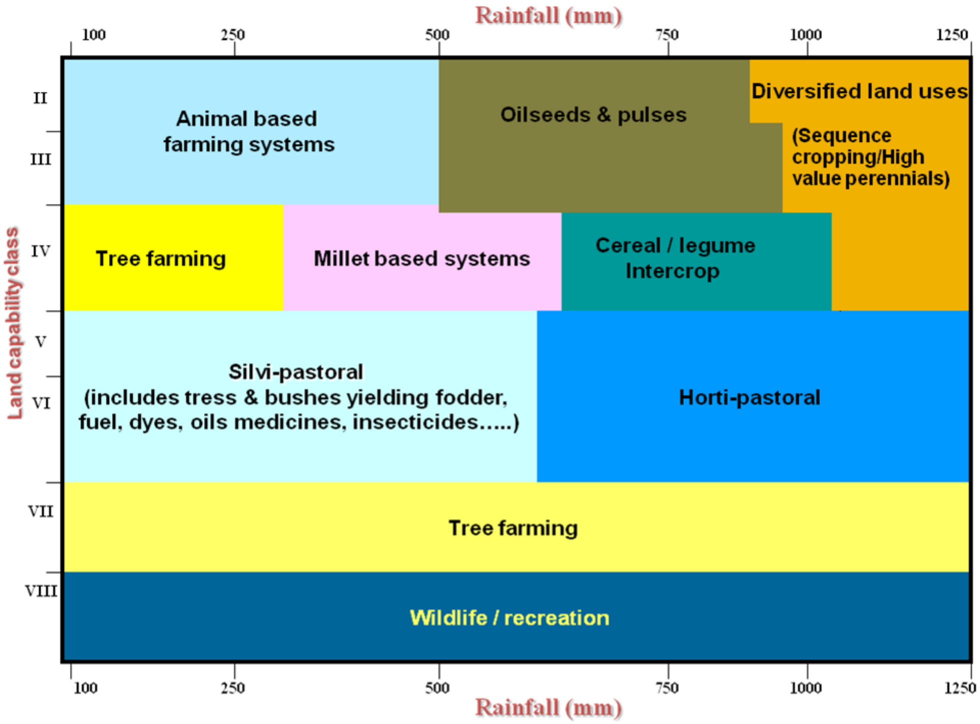

Fig. 4.3 Suitable land use systems based on rainfall and land capability

Table 4.2 Suitable land use systems based on rainfall and land capability for different land capability classes

Land capability class	**Sub-class**	**Suitability for cultivation or not**	**Special precautions**	**Preferable alternate land use and other options**
I. Very good cultivable land	Deep, nearly level	Intensive cultivation for all crops depending upon soil and climate	-	-
II. Good cultivable land	IIe. Good soil with minor erosion problem	Cultivation with precaution	-	Agrihorticulture
	IIs. Land with minor soil problem	Selection of proper crop	-	Agrisilviculture
III. Moderately good cultivable land	IIIe. Good soil on moderate slopes	Cultivation with precaution against permanent land degradation	Special attention to erosion control	Agrihorticulture
	IIIs. Soil with moderate problems due to moderate depth	Cultivation with careful selection of crops adopted to soil limitations	Intensive treatment to offset soil limitations	Selected legumes and grasses
IV. Fairly good land, suited for occasional cultivation	IVe. Moderately steep land subject to serious water erosion	Occasional cultivation in rotation with pasture, or orchards protected by permanent cover crops	Intensive erosion control when in cultivation	Silvipasture
	IVw. Bottom land that is very wet	Cultivation of special crops	Intensive drainage	Silviculture with proper drainage measures
	IVs. Fairly good land with limitations	Occasional cultivation in rotation with pasture	Very intensive treatment to overcome soil limitation,	Hortipasture

	due to shallowness, gravel, stone or strong alkali		careful selection of trees and crops	
	IVc. Good with just enough rainfall in favourable years	Cultivation during wet years	Conserve all	Hardy fruit and fodder trees
V. Nearly level land not suitable for cultivation because of stoniness, wetness, etc		Not suitable	To be developed as range land with regulated grazing	Hortipasture /silvipasture after providing micro-catchment like crescent shape bunding
VI. Steep slopes, highly erosion, prone with shallow soil		Not suitable	Careful management if developed as forest woodlot or grazing land	Silvipasture, Continues Contour Trenches (CCTs) or staggered trenches with provision of bio- fence or Cattle Proof Trench (CPT) or fencing
VII. Steep slope with severe soil erosion resulting in eroded stony and rough soil surface with shallow soil depth		Not suitable	Contour trenching, gully control works and controlled grazing	Cultivation of improved grasses after land treatment

Note: e: susceptible to erosion; s: shallowness to rooting zone and stoniness; w: excess water, poor drainage and high water table; c: moisture limitation due to poor rainfall

Farming Systems Approach for Livelihood Improvement

CRIDA pioneered stylo introduction and identified various perennial species having temporal and spatial complementarily with crop and pasture species for different agro-ecological sub-regions. These were also integrated with livestock based on-station and on-farm studies for their compatibility to enhance productivity and profitability. Research was carried out on integration of livestock, trees and bushes for improving soil fertility and livelihoods through sheep rearing, use of FYM/other organics, planting of bushes rich in nutrients on field boundaries, and value addition to crop residue. Generation of livelihoods constitutes both the main and by-products of land and livestock outputs. Land-livestock-livelihood interaction is set out in figure 5 for promoting integrated farming systems.

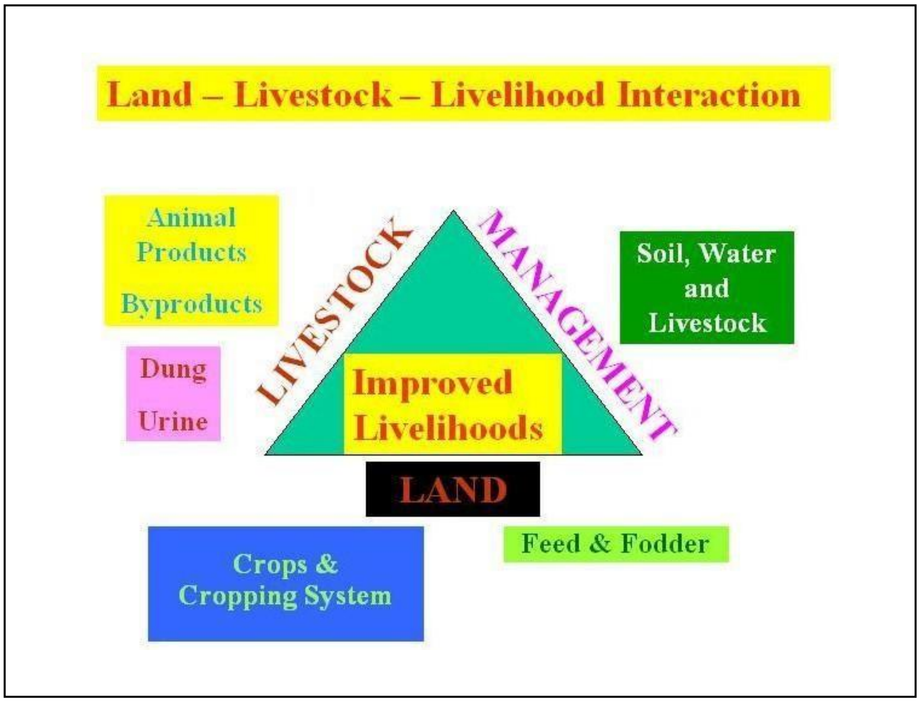

Fig. 4.4 Integration of crops and cropping systems with livestock on watershed mode for improving water productivity and profitability

Rainwater harvesting and recycling for improved livelihoods – A case study

The farm pond dug of 1000 m3 capacity in the village Garkampet, Gudihatnoor mandal of Adilabad district has proved to be a boon for tribal farmers. The water was retained long time without lining even after cessation of monsoon during 2008-09 even after utilization of water for supplemental irrigation to tomato grown on 0.5 acre plot. The total cost of cultivation of tomatoes in 0.5 acre land was worked out to be Rs. 23,600/-. The gross returns accrued from

4460 kg production of tomatoes from 27 pickings in 0.5 acre land was found to be Rs. 1,30,450/-.

The benefit-cost ratios (BCRs) based on total cost of cultivation of tomatoes and based on total cost of cultivation of tomatoes including cost of pond were calculated as 5.53 and 2.23, respectively (Table 3). The case study has come out with conclusive evidence of livelihood improvement in terms of five capitals formation namely natural, social, human, financial and physical of the farmer, Mr. Namdev, belonging to the village Garkampet, Seethagondi Gram Panchayat in Gudihatnoor mandal of Adilabad district in Telangana. The farmer has come out of the debt trap and now making a decent living. The impact has been enormous and 30 more such sites have been identified by the farmers themselves within the Gram Panchayat and were taken up with assistance from the line department.

Table 4.3 Impact of farm pond on net returns accrued from production of tomatoes (in 0.5 acre land)

S.No.	**Particulars**	**Amount (Rs.)**
1	Gross returns	1,30,450
2	Total cost of cultivation of crop (a)	23,600
	Cost of digging of pond (b)	35000
3	Net returns accrued from production of tomatoes (1-2a)	107,350
	Net returns accrued after recovering cost of farm pond [1-2 (a+b)]	72,350
4	(a) BCR based on total cost of cultivation of crop	5.53
	(b) BCR based on total cost of cultivation including cost of pond	2.23

Conclusion

The learning's from watershed development have clearly demonstrated the usefulness of consortia approach and there is a scope for convergence of various programmes. This calls for pooling of strengths of various organizations and developing of partnership between public-public, public-NGO, and public-private for effective delivery and improved profitability.

Integration of modern tools (RS, GIS, ICT) and implementation of programme by community themselves is preferable. Involvement of SHGs and their federation will bring in total transparency and sustainability besides promoting farmer producer organizations (FPOs). The complexity of rainfed areas calls for concerted efforts and building of human resources capabilities for efficient management of natural resources to enhance livelihoods of both landed and landless. Thus, there is a need for continued hand holding and funding for making rainfed rural India free from hunger and poverty.

Fig. 4.5 Impact of rainwater harvesting on diversification of rainfed agriculture – tomato, marigold and rearing of fish

Impact of Climate Change on Horticulture Sector
Experiences from National Innovations in Climate Resilient Agriculture (NICRA)

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Agriculture in India is highly vulnerable to climate change and variability. In recent years, the frequency of climatic extremes has increased resulting in increased risks to agricultural production and food security. One or other part of the country is experiencing frequent extreme weather events causing severe yield and income loss. As per the latest IPCC AR-6 Report increase in rainfall, high inter annual variability, intense and frequent heatwaves, likely temperature increase by 1.5 to 4.0^{o}C and rise in sea level by 300 mm could be the major challenge for sustainable agriculture in the coming years. This necessitates accelerated research on for developing resilient technologies against climate change as well as their mainstreaming through the adaptation mechanism for upscaling. To meet the challenges of sustaining domestic food production in the face of changing climate and to generate information on adaptation and mitigation in agriculture to contribute to global fora like United Nations Framework Convention on Climate Change (UNFCCC), the Indian Council of Agricultural Research (ICAR), Ministry of Agriculture and Farmers Welfare, Government of India launched a flagship network project 'National Innovations in Climate Resilient Agriculture' (NICRA) during 2011. NICRA is the unique project which brings all sectors of agriculture viz., crops, horticulture, livestock, fisheries, natural resource management (NRM) and extension scientists on one platform. The project has the following objectives:

- To undertake strategic and applied research on climate change adaptation and mitigation.
- To validate, demonstrate and assess the impact of climate resilient technologies on farmers' fields.
- To strengthen the capacity of scientists, farmers and other stakeholders on climate resilient agriculture.

NICRA project is implemented through components viz. strategic research through network as well as sponsored/competitive grants mode (57 ICAR Institutes, 16 State Agriculture Universities, Indian Institute of Technology (Chennai), NGOs), technology demonstration and capacity building in 151 clusters of villages in each one of the identified climatically vulnerable districts. About are involved in strategic research. NICRA project is helping to enhance the resilience of Indian Agriculture to climate variability and climate change through both applications of improved technologies and new policies. The project is initiated to develop and promote climate resilient technologies in agriculture to address vulnerable areas of the country. The outputs of the project help the districts and regions prone to extreme weather conditions like droughts, floods, frost, heat waves, etc. to cope with such extremes.

Climate Resilient Horticulture

Climate change impacts several horticultural crops in the country. Flooding for 24 hours severely affects tomato during flowering stage. Onion during blub stage is highly sensitive to flooding, whereas warmer temperatures shorten the duration of onion bulb development leading to lower yields. Similarly, soil warming adversely affects several cucurbits. Reduction in chilling temperature in the recent years in Himachal Pradesh drastically affected apple production, and the farmers are shifting from apple to kiwi, pomegranate and other vegetables. More importantly, temperature and carbon dioxide are likely to alter the biology and forging behavior of pollinators that play key role in several horticulture crops. High throughput screening of germplasm using plant Phenomics, Temperature Gradient Chambers, FATE Facility, Root imaging system, Environmental Chamber, TIR Facility, Photosynthetic System and Rainout shelter enabled to characterizes large number of germplasm lines and identify suitable donors for breeding against drought, heat stress and flooding in tomato, brinjal and onion. Forecasted area expansion of black pepper (97 to 133 districts) and cardamom (24 to 104 districts) using climate analogues for habitat suitability in the future changing climate. Staggered flowering in mango is one of the major issues induced by changing climate. Developed an environmentally safe spray formulation for synchronization of flowering in mango. Spray of this formulation (60 to 75 ml/l) once in September/October helped induction of synchronized flowering in several mango varieties (Alphonso, Dashehari, Kesar, Langra, Amrapali and Banganapalli).

The technique for inter-specific grafting of tomato over brinjal has been standardized and large-scale demonstrations have been taken up to withstand drought and flooding in tomato. A microbial inoculation with osmo-tolerant bacterial strains has been developed to improve yield under limited moisture stress in tomato. Several resilient horticulture technologies viz., resilient varieties, mulching and inte-rcultivation of cauliflower/cabbage in apple orchards, anti-hail nets in apple orchards, spur type of apple cultivation, ridge and furrow cultivation of green pea in

North east, paddy straw and crop residue mulching in ginger, plastic mulching and micro irrigation in marigold, protected cultivation of vegetables in poly house, micro irrigation system in vegetables for efficient use of harvested water to increasing the water productivity, frost management by smoke pockets in onion, crop diversification of brinjal and tomato, zero tillage in field pea, community vegetable seedling nursery for timely availability of improved varieties, broad bed ridge and furrow in brinjal and chilli crops have been demonstrated in farmers' fields in climatically vulnerable districts across the country through Krishi Vigyan Kendras (KVKs).

Large-scale adoption of this climate resilient technologies enables to adopt the changes associated with global warming and also keep pace with increasing demand for horticulture products in the country in the years to come.

Weather-based Agro-advisories for SustainableHorticultural Production Systems

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Introduction

Horticultural production in India is still vulnerable to the vagaries of monsoon rainfall in spite of rapid technological advancements. The majority of the Indian farming community which is broadly comprised of small and medium farmers are often subject to climate extremes such as droughts, floods, heavy rainfall events, heat and cold waves, frost, hail storms during the crop growing season. The probabilities of occurrence of such climate extremes and associated crop damages and production losses are common in tropical countries like India. Timely and accurate advisory to the farmers, regarding the occurrence of the events and associated management practices, can prevent the losses associated due to these events. It provides security and stability to farm income by protecting the farmers' investment in crop production and then improves their risk-bearing capacities.

Importance of horticultural Production Systems

Since independence, the country has progressed immensely in both food grain and horticultural production. However, recently horticultural production has surpassed the food grain production of the country. This shows the tremendous scope in this sector. If we look at the growth trend, it is found that in low rainfall years, the horticultural output is least affected as compared to the food grain output. This shows the resilience of the sector to rainfall variability.

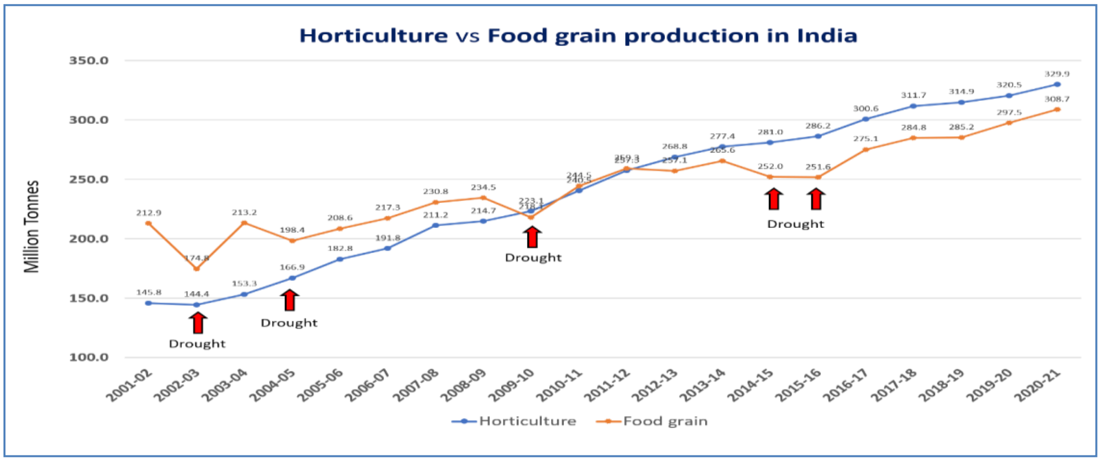

Fig 6.1: Long-term progress of horticultural and food grains production in India

Weather-based agromet advisories

A comprehensive weather-based farm advisory is an interpretation of how the weather parameters both present and in the future will affect crops, livestock and farm operations and suggests interventions to be taken. Agromet Advisory Service (AAS) has been adopted at the district level since 2008 by India Meteorological Department (IMD) and is being continued. The district level AAS provided to farmers makes use of medium-range weather forecast issued by the National Center for Medium Range Weather Forecast (NCMRWF) and IMD. However, the validity of blanket advisories disseminated at the district level had limitations, particularly in view of the large variability in terms of crops, varieties and spatial weather anomalies. To overcome this limitation, All India Coordinated Project on Agro-Meteorology (AICRPAM) has taken an initiative to address these issues with micro-level Agromet Advisory Services under National Innovations in Climate Resilient Agriculture of Indian Council of Agricultural Research(Rao et al., 2016).

Under this project, Each AICRPAM center has selected one district other than the district the center is already located in and one block from this district was selected. 30 farmers were selected from the two villages located in the selected block (Fig.2). Block-level weather forecasts provided by IMD were collected for the 25 AICRPAM-NICRA and Agromet advisories were prepared on the basis of this forecast which includes the current and past weather condition, crop condition and stage, block-level forecast for the next five days and the measures /management practices to be followed for managing different weather aberrations the crop likely to undergo in the following five days.

Fig. 6.2: Conceptual diagram of block-level AAS

Weather variability and horticultural production

Aberration of weather from its normal has emerged as a real concern for the horticulture sector with visible changes in the area, productivity and very prominently quality of the produce already being reported across the globe. In horticultural crops, the temperature is the most important factor. For example, sudden rise in temperature would affect the bulb initiation and formation in onion and fruit size and quality in tomato. In most fruit crops, higher temperature reduces the day interval required for flowering in general and cooler temperature though required more days for flowering, but the number of flowers produced increased proportionally at this temperature (Srinivasarao et al. 2016). The optimum temperature range in citrus is 22–27 °C, and temperatures greater than 30 °C lead to an increased fruit drop (Cole and McCloud, 1985). When the temperatures over 33°C during fruit development stage in citrus, there would be a reduction in sugar content, acid content and fruit size (Hutton and Landsberg 2000). These effects can lead to changes in the choice of orchid crop and geographical shifts in the cultivation of a particular crop.

Climate change and horticultural production

While natural variability continues to play a key role in extreme weather, climate change has shifted the odds and changed the natural limits. It makes certain types of extreme weather especially cold wave, frost, hailstorm, dust storm, heat wave, cyclone and flood more frequent and more intense. However, year-to-year deviations in the weather and the occurrence of climatic anomalies/extremes have become a matter of concern. As the climate has warmed, some of the extreme weather events have become more frequent and severe in recent decades (IPCC 2014). In recent years, weather events especially deadly heat waves and devastating floods have necessitated understanding the role of global warming in driving these extreme events. These events are part of a new pattern of more extreme weather across the globe, shaped in part by human-induced climate change (IPCC 2013, 2014). Limited knowledge is available on the effect of climate change on horticultural crops. Management of ill effects of climate change in horticultural crops is challenging task when compared to annual field crops. The issues of climate change and solution to the problems arising out of it requires thorough analysis, advance planning and improved management. The crop productivity is subjected to number of stresses and potential yields are seldom achieved with stress. For instance, the production of apple has gradually increased but the productivity has fallen from 10.8 to 5.8 t/ha (Awasthi et al., 2001) due to variations in climatic parameters. Among all the productivity-reducing factors, the climate is difficult to manage. The changes in climate in the form of erratic precipitation, increase in temperature, lesser days serving as the chilling period have started affecting the mountain agri- horti production systems and ultimately the food security of the people.

The impact of the weather extremes on horticultural crops is given below.

Hot and cold temperature extremes

A heatwave is of unusually hot days (Three or more consecutive days of unusually high maximum temperatures) but what constitutes a heatwave will differ from region to region given the normal temperatures for that area. There are no precise threshold temperatures or periods for reduced pollination because it is a complex interaction between bee activity and the availability of viable pollen and receptive stigmas. Extreme high temperatures can occur in the field and apple fruit exposed to direct sunlight can reach in excess of 40°C. High temperatures during the late season (leading up to harvest) can enhance the susceptibility of apples to superficial scald which develops in storage. Sunscald of grapes, the soft nose of mango, sunburn in papaya and citrus are mostly related to high temperature. Fruit cracking in pomegranate and litchi is associated with temperature aberrations coupled with fluctuation in moisture.

The prolonged cold spell causes large-scale damage to agricultural and horticultural crops. When the temperature of plant tissue falls below critical values, sensitive perennial crops such as grapevines and tender tree fruits can suffer irreversible cold injury, causing malfunction or death of plant cells. It was noticed that due to cold wave, the plant mortality in mango varieties was highest in Dashehari, followed by Amrapali and least in Langra with 18 to 48 per cent flowering damage in parts of Jammu, Punjab, Haryana, Chandigarh and Himachal Pradesh. The mortality rate is still higher in the case of papaya ranging from 40 to 83 per cent in the Shiwalik region, plains of Uttar Pradesh, Bihar and the northeast.

Hailstorm

The development of hailstones typically occurs 5 to 7 km/hr above the earth’s surface. Its size and shape depend on how fast the storm is moving and how strong the updrafts are inside the storm. A typical hail streak is about 1.5 km wide and 8 km in length. Hail can severely damage all plants. Hailstorm causes primary injuries due to direct impact of hails which causes heavy defoliation, shredding of leaf blades, breaking of branches and tender stems, lodging of plants, peeling of bark, stem lesions, cracking of fruits, heavy flower and fruit drop, etc. This is followed by secondary injuries which are nothing but the manifestations of primary injuries like dieback or wilting of damaged plant parts, loss of plant height, staining, bruises, discoloration of damaged parts like leaves and fruits affecting their quality and rotting of damaged fruits and/or tender stems and branches due to fungal and bacterial infections. Prevalence of cloudy weather coupled with increased atmospheric humidity and wet foliage conditions during the hails storm, the plants that suffered from hail damage were likely to be affected severely with sucking pests like thrips, jassids, mites, and diseases like powdery mildew, leaf blights, fruit and flower rot, etc. Thus, appropriate treatment should be done as per the recommendation (Bal et al., 2017).

Meteorological drought

Drought results in wilting, reduction in photosynthesis, disturbances in physiological processes, cessation of growth, or even death of the plant or plant parts which ultimately reduce the potential yield. With the change in climate patterns, the occurrence and impact of drought on the production of fruit and vegetable crops are becoming more frequent. Water stress during the production phase of crops may affect their physiology and morphology in such a manner as to influence susceptibility to weight loss in storage (Sureshkumar et al., 2014). Crops start to show the symptoms of drought whenever the short supply of water to roots or heavy loss of water through evapotranspiration. However, the severity of the damage is driven by factors like rainfall patterns, moisture holding capacity of the soil, and water losses through evapotranspiration. The primary effects of long-term drought include dieback of branches and death of the plant as the plant’s capacity to absorb water is damaged. Secondary effects of drought lead to susceptibility to disease infections and insect invasion is heightened as the plant's ability to ward off these problems is diminished. Among the types of diseases likely to occur in response to drought- related stress are root rots, cankers, wood rots, and wilt.

Severe storms

As per the IPCC report, the warming climate is likely to increase the length and frequency of severe thunderstorm especially during summer season. However, projection about thunderstorms is very difficult because of their localized nature. Storm damage in orchards is determined by storm severity and crop maturity. A severe storm close to harvest is more serious than a less severe storm earlier in the season. Fruit damage depends on fruit maturity, size and texture of hailstones, and the speed and force of hail as it hits fruit. Later season damage can vary from bruised fruit to broken skin and holes in the fruit flesh. Fruit can also be stripped from the trees by the force of wind. Damage in mature fruit quickly becomes focal points for brown rot (stone fruit, cherries), blue rot (apples) and grey rot (all fruit). While the disease may initially be limited to damaged tissue, it can quickly spread to intact fruit in warm, humid conditions. Structured netting (with posts and tensioning wires) is the most expensive option and requires seasonal checking and adjustment. Throw-over netting can provide similar levels of protection but makes orchard management difficult and may need to be removed in summer for pruning and harvest. Both systems have advantages and orchardists need to investigate their options.

Achieving sustainable horticulture production through AAS

Setting up long-term goals through a set of management practices is very important aspect of sustainable development. Complete understanding of the limitations of the horticultural ecosystem and its relationships with weather and climate is essential to develop sustainable production strategies. Though there is substantial improvement in the weather services to the farmers, still the availability of information is not enough for unreached and poor farmers in the villages/hilly terrains/remote areas, especially in the wake of climate change. Providing accurate and locally-appropriate climate and weather information through Agromet Advisory Services plays a vital role in sustainable production and well as to increases the resilience of farming communities to biotic and abiotic stresses. A new initiative, the Global Framework for Climate Services (GFCS) by World Meteorological Organization, is working to enhance the capability of many countries to provide these services, so that they can adequately plan for the future. Over the period of years, IMD strengthened the AAS in terms of observation, seamless weather forecast, manpower, real-time information flow, research and development (R&D), dissemination etc in collaboration with AICRP of Agrometeorology, ICAR and SAUs. To meet the end user’s requirements in both the irrigated and rainfed systems, development and dissemination of AAS at block level has been started in some of the states with the aim to extend these services at the village level in the ensuing future.

Conclusion

India with diverse soil and climate comprising several agro-ecological regions provide ample opportunity in our country to grow a variety of horticultural crops comprising of fruits, vegetables, flowers, medicinal and aromatic plants, spices, condiments, plantation crops and mushrooms. It is known fact that climate change would be severe in most developing countries and would directly hit the agri-horti production system in these countries. As climate change will amplify the atmospheric stressors, especially temperature and rainfall variability in the case of horticultural crops strategies to improve the input use efficiency and development of location- specific adaptation measures should be planned to meet the future productivity demands in a sustainable manner. In this aspect, accurate forecasts and their timely dissemination via AAS would aid to curtail crop losses due to inclement weather. At the same time, losses were also reported due to wrong weather forecasts. The methodology adopted for block-level AAS can be up-scaled to the national level by utilizing the already established infrastructure and human resource by establishing linkage with line departments and state agricultural universities andKVKs established in the country.

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WATER MANAGEMENT SYSTEMS AND TECHNIQUES FOR HORTICULTURE CROPS

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Sprinkle and trickle irrigation together represent the broad class of "Pressurized Irrigation" methods, in which water is carried through a pipe system to a point near where it will be consumed. This is in contrast to surface irrigation methods, in which water must travel over the soil surface for rather long distances before it reaches the point where it is expected to infiltrate and be consumed. Thus, surface irrigation methods depend on critical uncertainties associated with water infiltration into soil while being conveyed, as well as at the receiving site.

In sprinkler irrigation, water is jetted through air to spread it from the pipe network across the soil surface. This adds uncertainty to sprinkle irrigation, as wind and other atmospheric conditions affect system application efficiency. The main goal of sprinkle system is uniform watering of an entire field. With trickle irrigation, the distribution of the water after it leaves the pipe network depends only on localized lateral movement above or on the soil surface or in the soil profile. Thus, water is conveyed through the pipe system almost directly to each plant, and only the soil immediately surrounding each plant is wetted. This leads to the potential high application efficiency associated with trickle irrigation.

Soil-Water-Plant relations:

Understanding basic soil-water-plant relations is central to the ability to design and manage trickle and sprinkle irrigation systems.

Water Holding Capacity:

Soils of various textures have varying abilities to retain water. Except for required periodic leaching, any irrigation beyond the field capacity of the soil is an economic loss. Table 1 gives typical ranges of available water holding capacities of soils of different textures. The listed averages may be used for preliminary design, but final designs should be based on actual field data.

Root Depth

The total amount of soil water available for plant use in any soil is the sum of the available water holding capacities of all horizons occupied by plant roots. Table 2 gives information on effective root depth for different crops.

Consumptive Use and Design

Deciding how much water a system should be able to deliver to a crop over a given period is ultimately a question of selecting a capacity that over the life of the system, will maximize profits to the farmer. To address this question of system capacity, it is necessary to know how much water a crop will use, not only over the entire growing season, but also during the season when water use is at its peak. This peak consumptive use should be the criterion for determining the rate of water to be delivered to the field.

Table 7.1. Range in available water holding capacity of soils of different texture

Soil texture	Water holding capacity	
	Range mm/m	Average mm/m
1. Very coarse texture- very coarse sands	33 to 62	42
2. Course texture-course sands, fine sands and loamy sands	62 to104	83
3. Moderately coarse texture-sandy loams	104 to145	125
4. Medium texture- Very fine sandy loams, loams and silt loam	125 to 192	167
5. Moderately fine texture-clay loams, silty clay loams and sand clay loams	125 to 208	183
6. Fine texture- sandy clays, silty clays and	133 to 208	192
clays	167 to 250	208
7. Peats and mucks		

Table 7.2. Effective crop root depths that would contain approximately 80% of the feeder roots in a deep, uniform, well drained soil profile

CROP	ROOT DEPTH (m)	CROP	ROOT DEPTH (m)
Alfalfa	1.2 to 1.8	Onion	0.3 to 0.6
Apple	0.8 to 1.2	Pastures	0.3 to 0.8
Avocado	0.6 to 0.9	Peanuts	0.4 to 0.8
Banana	0.3 to 0.6	Pepper	0.6 to 0.9
Barley	0.9 to 1.1	Plum	0.8 to 1.2
Beans(Dry)	0.6 to 1.2	Potato	0.6 to 0.9
Beans(Green)	0.5 to 0.9	Pumpkin	0.9 to 1.2
Berries	0.6 to 1.2		
Broccoli	0.6 to 1.2	Radish	0.3
Cabbage	0.6	Safflower	0.9 to 1.5
Carrot	0.4 to 0.6	Sorghum (Grain)	0.6 to 0.9
Cauliflower	0.6	Sorghum (silage)	0.9 to 1.2
Cherry	0.8 to 1.2	Soy bean	0.6 to 0.9
Citrus	0.9 to 1.5	Strawberry	0.3 to 0.5
Coffee	0.9 to 1.5	Sugarcane	0.5 to 1.1
Corn(grain & silage)	0.6 to 1.2	Sudan grass	0.9 to 1.2
Cotton	0.6 to 1.8	Tobacco	0.6 to 1.2
Cucumber	0.4 to 0.6	Tomato	0.6 to 1.2
Grapes	0.5 to 1.2	Watermelon	0.6 to 0.9
		Wheat	0.8 to 1.1

Percentage of Area Shaded and Wetted

Another factor determining system capacity for trickle irrigation is that trickle systems need to supply water only to the immediate vicinity of each plant being irrigated, unlike sprinkle systems, which are designed to wet an entire field. Thus , trickle systems can satisfy crop water requirements without unnecessarily large amount of water being evaporated from the soil surface. Because of this, trickle system capacity is not a function of water consumption over the entire field, but only over that portion of the field actually receiving irrigation water.

Soil Moisture Management

A general thumb rule for many field crops in arid and semi arid regions is that the soil moisture deficit, SMD, within root zone should not fall below 50% of available water holding capacity. This is a management allowed deficit (MAD). Because it is also desirable to bring the moisture level back to field capacity with each irrigation, the depth of water applied at each irrigation is constant through out the growing season. This means that duration of irrigation is also constant, although the frequency of application varies as a function of changes in the rate of water use over the growing season. In humid regions, it is necessary to allow for rains during irrigation.

Soil management, water management and economic considerations determine the amount of water used in irrigating and the rate of water application. The standard design approach has been to determine the amount of water needed to fill the entire root zone to field capacity. Table 3 gives information on selection of management allowed deficit for near optimum production of field crops. As indicated, for crops having high market values, it is often profitable to irrigate before 50% of the soil moisture in the root zone has been depleted.

Table 7.3.Guide for selecting management allowed deficit (MAD) values for various crops

MAD, %	Crops and root depth
25-40	Shallow rooted, high value fruit and vegetable crops
40-50	Orchards,* vineyards, berries and medium rooted row crops
50	Forage crops, grain crops and deep rooted row crops

*Some fresh fruit orchards require lower MAD values during fruit finishing for sizing.

Irrigation Scheduling

Irrigation depth and frequency are to be estimated by using the following formulae:

$$d_n = MAD * W_a * Z/100 \qquad (1)$$

Where,

d_n = maximum net depth of water to be apllied per irrigation, mm
MAD = management allowed deficit, %
W_a =available water holding capacity of the soil, mm/m
Z = effective root depth, mm

$$f' = d_n / U_d \qquad (2)$$

Where,

f ' = irrigation interval or frequency, days

U_d = estimated average daily crop water requirement or use rate \` during the month of peak consumption, mm/day

Management and Scheduling

Generally, irrigation systems are designed to meet average peak water use requirements. Sometimes, to reduce costs or to stretch limited water supplies, systems are designed to optimize production per unit of water applied. In such cases, systems can be designed to apply only about 80% of peak water requirement and obtain 95% of optimum yield.

Sprinkler Systems

There are ten major types of sprinkle systems. These are divided into two basic groups, namely set systems that operate with sprinklers in a fixed position and two, continuous move systems that operate while the sprinkler is moving through the field.

Set systems:

Periodic move systems

- Hand move lateral system
    - ♦ Used for all crops and requires high labor
- End toe lateral system
    - ♦ Laterals are towed lengthwise over the mainline from one side to the other in ‘S’ fashion. These systems are used for irrigating grasses, legumes and other close growing crops.
- Sides roll lateral system
    - ♦ These are similar to hand move systems. Lateral pipes are rigidly coupled and a large wheel supports each pipe joint. They are best adopted to rectangular plots with fairly uniform topography without obstruction.

- Side move laterals

  ♦ These are periodically moved across the field similar to side roll laterals. The difference in this system is ‘A’ frame instead of wheels supports laterals. These are suitable for most of field and vegetable crops.

- Gun and boom sprinklers

  ♦ These will have 16 mm or more dia. nozzle attached to long discharge tubes and rotated by rocker arm drive and can be set to irrigate part circle. Boom sprinklers have rotating arms 18 to 36 m in length. Water is discharged through nozzles strategically positioned along the arms and are supported by cable suspension system. These are high discharge and high energy systems and suitable for irrigating irregular fields.

- Fixed sprinkler systems

  ♦ All the system components are fixed in the field with sequential on-off valves fixed at various points of irrigation outlets involves high investment.

Continuous move systems

- Traveling sprinkler

  ♦ It is a high capacity sprinkler fed with water through a flexible hose. It is mounted on self propelled chassis and travels along a straight line while watering. With discharge rate of 32 l/s , the sprinkler can irrigate more than 120 m dia. in the field.

- Center – Pivot

  ♦ It sprinkles water from a continuously moving lateral pipeline. The self propelled lateral is fixed at one end and rotates to irrigate a large circular area. A fixed end of a lateral, called pivot point , is connected to water supply.

- Linear moving laterals

  ♦ Self propelled, linear moving laterals combine the structure and guidance system of a center pivot lateral with a traveling water feed system similar to a traveling sprinkler. For efficient operation, linear moving laterals require rectangular fields with no obstruction.

Application efficiencies of sprinkler systems

Table 4 gives information on well-managed sprinkler systems. These efficiency values can be used in preliminary designs.

Table 7.4 . Typical application efficiencies for well managed sprinkle systems

Systems and environmental conditions	Efficiency, %
Moving and set systems with excellent uniformity in cool and low wind conditions	85
Set systems with medium to high application rates and good uniformity in most climates and low winds	80
Moving systems in desert climates and high winds	75
Set systems with high application rates in desert climates with high winds, travelers	70
Set systems with moderately low application rates in desert climates and high winds	65
Set systems with low application rates with small drops operating in low desert climates and medium to high winds; Gun or Boom sprinklers	60

Application rates	**Wind speed**
Low: 2.5 to 5 mm/hr	low: 0 to 8 km/hr
Medium: 5 to 10 mm/hr	medium : 8 to 16 km/hr
High: > 10 mm/hr	high: 16 km/hr

Design Procedures for Sprinkle Systems

The first activity in design process is to collect basic farm resource data, which include topographic map showing obstacles and farm boundaries, as well data on water quality, quantity, weather, crops and soils. These preliminary data lead to determining peak use rate, infiltration capacity, maximum depth of application per irrigation, application rate and system capacity.

Checklist for design

1. Make an inventory of available resources and operating conditions. Include information on soils, topography, water supply, and source of power, crops and farm operation schedules.
2. Using actual field data, local irrigation guides, estimate depth or quantity of water to be applied at each irrigation.
3. Determine the average peak period, daily consumptive use rates and the annual irrigation requirements for the crops under consideration.
4. Determine design use frequency of irrigation or the length of shortest irrigation period.
5. Determine capacity requirements of the system
6. Determine optimum water application rates. Maximum rates are often obtainable from local irrigation guides
7. Consider several alternative types of sprinkler systems keeping views of the owner
8. For periodic move and fixed sprinkle systems, determine:
    a) The sprinkler spacing, discharge, nozzle sizes, and operating pressure for the optimum application rate
    b) The number of sprinklers that must be operated simultaneously to meet system capacity requirements
    c) The best layout of main and lateral lines for simultaneous operation of the approximate number of sprinklers required.
    d) Final adjustments to meet layout conditions
    e) Required sizes of lateral pipe and
    f) Maximum total pressure required for individual lateral lines
9. Determine required sizes of main pipeline
10. Check mainline pipe sizes for power economy

11. Determine maximum and minimum operating (pressure and discharge) conditions
12. Select the pump and power unit of for maximum operating efficiency within the expected range of operating conditions
13. Prepare plans, schedules, and instructions for proper layout and operation

Characteristics Of Sprinkler Heads

The hardware design process should begin with the sprinkler selection, continue with the system layout, and end with the design of the lateral, main line, and pumping plant. Sprinklers are classified according to their operating pressure range and their position in relation to irrigated crops. The general layout of sprinkle system is given in fig.1.

Precipitation Profiles and Recommended Spacing.

In choosing a sprinkler, the aim is to find the combination of sprinkler spacing, operating pressure, and nozzle size that will most nearly provide the optimum water-application rate with greatest degree of uniformity of distribution.

Each type of sprinkler has certain precipitation profile characteristics that vary with nozzle size and operating pressure and result in an optimal range of operating pressures for each nozzle size. In selecting nozzle sizes and operating pressures for a required sprinkler discharge, the designer should know that different pressures affect the profiles as follows:

1. At lower side of the specified pressure range for any nozzle, the water remains in large drops. When pressure falls too low, the water from the nozzle concentrates in a ring a distance away from the sprinkler, giving a poor precipitation profile.
2. On the high side of the pressure range, the water from the nozzle breaks up into fine drops and settles around the sprinkler. Under such conditions, wind movement easily distorts the profile: and
3. Within the desirable range, the sprinkler should produce a precipitation profile.

At a given pressure, large drops are obtained from large nozzles and fine sprays from small ones. All manufacturers of revolving sprinklers recommended operating pressures or ranges of pressures that will result in the most desirable application pattern for each combination of sprinkler and nozzle size.Wind distorts the application pattern, and the higher the wind velocity, the greater the distortion. This distortion must be considered when selecting the sprinkler spacing.

The depth of water applied to an area surrounding a revolving sprinkler varies as the distance from the sprinkler increases. Thus, to obtain a reasonably high degree of uniformity of application, water from adjacent sprinklers must be added. Manufacturers of sprinklers specify a wetted diameter for all nozzle-size and operating –pressure combinations for each type of sprinkler in their lines. As it is common for sprinkler-spacing recommendations to be made on the basis of these diameters, the planner must carefully consider them. The precipitation profile is also important when making sprinkler-spacing recommendations.

Sprinklers operating in low winds produce characteristic precipitation profiles. Conditions that affect both the diameter and profile of a sprinkler's precipitation pattern are: direction and velocity of wind measured from the ground level to the top of the jet trajectory; height and angle of risers; turbulence in the stream of water entering and leaving the nozzle; pressure of the nozzle; and size of the nozzle. Characteristics of the sprinkler itself that affect its performance are the angle of the stream trajectory and the design of the driving mechanism that determines the speed and uniformity of rotation. With such a complex set of conditions, the practical way to determine a sprinkler's profile type and diameter is to place catch gauges in the precipitation area and record and evaluate the results.

As a general recommendation, moderate and intermediate pressured sprinkler should be spaced as follows:

1. For a rectangular spacing, use 40 by 67 % of the effective diameter based on the average wind speed during the setting

2. For a square spacing, use 50% of the effective diameter based on average wind speed during the setting

3. For an equilateral triangle spacing, use 62% of the effective diameter based on average speed during the setting.

Nozzle size and Pressure

In general, the relationship between pressure and discharge from a sprinkler can be expressed by orifice equation:

$$q = K_d \sqrt{p} \qquad (3)$$

Where,

Q = sprinkler discharge, l/min
K_d = appropriate discharge coefficient for the sprinkler and nozzle combined and the specific units used.
P = sprinkler operating pressure, kPa
H = sprinkler operating pressure head, m

System Capacity Requirements

The capacity of system can be computed by the formula:

$$Qs = K\,Ad / fT \qquad (4)$$

Where,

Qs = system discharge capacity, L/s
K = conversion constant, 2.78 for metric units
A = design area, ha
d = gross depth of application, mm
f = operating time allowed for completion of one irrigation, days
T = average actual operating time per day, hr/day

Intake and Optimum Application Rates

The rate at which water should be applied depends on the following:

- The infiltration characteristics of the soil, the field slope, and the crop cover ;

- The minimum application rate that will produce a uniform sprinkler distribution pattern and satisfactory efficiency under prevalent wind and evaporative demand conditions; and
- The coordination of the lateral moves for periodic-move systems with over operations on farm.

Computing Set Sprinkler Application Rates

The average application rate from a sprinkler is computed by using the formula given below and suggested maximum application rates of sprinklers are given in Table 5 for various slopes.

$$I= K_q/(S_e \text{ x } S_l) \qquad (5)$$

Where,

I = average application rate, mm/hr
K = conversion constant, 60 for metric units
q = sprinkler discharge, L/min
Se = spacing of sprinklers along the laterals, m
S_l = spacing of laterals along the main line, m

TRICKLE IRRIGATION SYSTEM

Types and Components of Trickle System

Emitter

This is an applicator used in drip, subsurface, bubbler irrigation. Emitters are designed to dissipate pressure and to discharge a small uniform flow or trickle of water at a constant rate that dose not vary significantly because of minor differences in pressure.

Different types of emitters are often classified according to the mechanism each uses to dissipate pressure. For example, long-path emitters use as a long, capillary-sized tube or channel to dissipate pressure, but orifice emitters rely on individual or a series of orifices, and vortex emitters employ a vortex effect. Flushing emitters are designed to have a flushing flow of water to clear the discharge opening every time the system is turned on. Continuous-flushing emitters permit continuous passage of large solid particles while operating at a trickle or drip flow; this reduces requirements for filter fineness. Compensating emitters discharge water at a constant rate over a wide range of lateral line pressures. Multioutlet emitters supply water to two or more points through small diameter auxiliary tubing.

Emission Point

This is a point on or beneath the ground surface where water is discharged from an emitter. Trickle irrigation with water discharged from emission points that are rather widely spaced, usually 1 m or more, is called point-source application. When water is discharged from more closely spaced outlet, it is called line source application.

Line-Source Tubing

There are three types of line-source tubing. Single-chamber tubing is a small diameter (less than 25 mm) hose that has orifices punched or more complex emitters fabricated or inserted at intervals of 0.6 m or less. Double chamber tubing is a small diameter (less than 25 mm) hose that has both a main and an auxiliary bore separated by a single wall. Porous-wall tubing is small diameter (less than 25mm) hose that has a uniformly porous wall. The pores are of capillary sizes and ooze water when under pressure.

Sprayers

These small applicators (also called aerosol emitters, foggers, splitters, misters, micro sprayers, or miniature sprinklers) used in spray irrigation. They are designed to dissipate pressure and discharge a small uniform spray of water to cover an area of 1 to 10 $^{m2.}$ Ideally sprayers should apply a relatively depth of water to the area wetted and should have a single large-flow cross section and a low water trajectory angle.

Emitter Flow and System Relations

The following relations characterize the interaction between pressure variations due to friction loss and elevation differentials and emitter discharge. Usually trickle irrigation systems are provided with some means for regulating pressure, flow, or both. The area served downstream from each pressure or flow regulation point is called a subunit.

Emission Uniformity

Emission uniformity, EU, is a measure of the uniformity of emissions from all the emission points within an entire trickle irrigation system. For field tests:

$$EU = 100\ q'n / qa \qquad (6)$$

Where,

EU' = field test emission uniformity, %
q'n = average rate of discharge of the lowest one-forth of the field data emitter discharge readings, L/hr
q_a = average discharge rate of all the emitters checked in the field, L/hr

System Layout and Pipe Network

The pipe network should be designed to deliver water to emitters at the appropriate pressure. The general layout of trickle system is given in fig 2. It should be designed to optimize cost-effectiveness for the particular application. In designing pipe networks for trickle irrigation systems, the life-cycle costing techniques should be used. This should be done to achieve the minimum total costs of operation, maintenance, and capital at the desired rate of return over the presumed economic life of the system.

Emitters require a supply of clean water. Once water has left the filter, recontamination must be avoided. The components of the pipe network must be no corrosive and no scaling and otherwise highly reliable against failure. The most widely used pipe materials are polybutylene, polyethylene, or PVC for laterals; and PVC or polyethylene for manifolds and main line; however, other materials now being used for main lines include filament-wound epoxy pipe, epoxy-coated steel pipe, and asbestos-cement.

Basic Components

Control Head

The most important components of a main control head for a trickle irrigation system are the chemical injector, controller, and filter necessary for continuous operation. Injectors are used to put fertilizer, systemic insecticides, algaecides, acids, and other liquid materials into the irrigation water. Piston type injectors or venturi injectors that create a pressure drop across an orifice to siphon the chemical solutions from a tank are most commonly used. Automatic controllers provide a signal to actuate the main pump, the automatic manifold valves, or both. Filters that remove debris that might clog or otherwise foul the emitters or sprayers are essential on most systems.

Main Pipelines

Normally, pressure-control or adjustment points are provided at manifold inlets. A manifold, with its attached laterals is the basic system subunit. Upstream from pressure-control points the allowed pressure variation for the subunit does not affect pipe-size selection. Therefore, the selection of pipe sizes for the main water supply lies should be based primarily on the economic tradeoff between power costs and costs for pipe and installation. Because normal operating pressures are low, the lowest pressure class available for each pipe size is often suitable for trickle irrigation system.

Manifolds and Headers

A manifold (with or without headers) is the portion of the pipe network between the main line and the laterals. It is usually buried but can also be on the surface. The allowable pressure loss for manifolds, header, or both depends on the topography, lateral losses, and total allowable pressure variation for the emitters chosen. Once these limits have been established, standard calculations for hydraulic pipelines that have multiple outlets may be used.

Laterals

Point-source emitters are systematically spaced along the lateral and are connected to lateral by various means. Types of lateral lines that themselves function as emitters include single-or dual-chamber line-source tubing as described earlier. Tapered laterals have two or more pipe sizes beginning with the larger pipe at the inlet end where flows are largest. They take advantage of the progressively decreasing flow by using smaller pipe sizes where flow rates permit this reduction.

Emission Point Layouts

For wide spread crops double laterals or two laterals per row are sometimes used to provide more emission points per tree. Other methods of providing more emission points per tree are: to zigzag, snake, or loop the lateral around or between the trees; to use short pigtail lines looped around each tree; or to use multioutlet emitters with small-diameter tubing to distribute the water.

Pressure Control and Regulation of Flow

System controls should either be volumetric or should incorporate volumetric monitoring with time sequencing. This is important because it is impossible to precisely control emitter discharges because of temperature and pressure fluctuations and aging, plugging, and slow clogging of the emitters.

Flow Regulation

Adjusting the pressure at the manifold inlets controls the flow rate in most systems. Either automatic does this or manual valves that are set to balance flow rates between the subunits.

Control Valves

The principal valves used for the control, management, and operations of trickle irrigation systems include the valves located at the control head, manifold valves, riser (or header) valves, and flush-out valves.

Operating Controls

Even without automation, trickle irrigation system requires relatively little labor. The main activities of the irrigator are to schedule water and chemical applications and to see that filters are kept clean and the emitters are not plugged.

Partial Automation

Partial automation can be achieved by volumetric valve, mechanically or electronically timed valves.

Full Automation

Full automation can be achieved by several ways. It can be done with accurate electronically timed clock valves, a central controller, Controllers are available that can be set to actuate the irrigation cycle in practically any desirable manner.

System Capacity

Daily water requirement can be calculated by using the formula given below and to obtain the system capacity, this is to be multiplied with number of emitters per plant.

$$V= K_p . K_c. E_p. S_p.S_r. P_w/ E_s \qquad (7)$$

Where,

V= Volume of water, l/day/plant
Kp= Pan co efficient (0.7 to 0.85),
Kc= crop co efficient,
Ep= pan evaporation, mm/day
Sp= plant to plant spacing, m
Sr= row to row spacing, m
Pw= percentage wetting (%), (33% < Pw< 66%)

Computing Percentage Wetted Area

The percentage area wetted, P_w, is the average horizontal area wetted in the top 15 to 30 cm of the crop root zone as a percentage of the total crop area. The estimated values are given in Table 6 for different soil types.

Emitters spacing, S_e, is the spacing between emitters along a lateral line, m Optimal emitter spacing, S'_e is the drip emitter spacing, which is 80% of the wetted diameter estimated from field tests (m).

For straight single-lateral systems with $S_e \leq S'_e$, the percentage wetted can be computed as:

$$P_w = [N_p S_e w / S_p \text{ x } S_r] \text{ x } 100 \qquad (8)$$

Where,

P_w = percentage of soil area wetted along a horizontal plane 30 cm (12 in.) below the soil surface, %,

N_p = number of emitters per tree, and

S_px S_r = tree spacing, m x m

If $S_e > S'_e$, then S_e in above equation must be replaced by S'_e

For double-lateral system, the two laterals should be placed S'_e apart. This is done to maximize the wetted area without leaving extensive dry area between the lines.

$$P_w = \frac{N_p S'_e (S'_e + w)/2}{S_p \text{ x } S_r} \text{ x } 100 \qquad (9)$$

Maintenance of the trickle system:

Clogging is a major problem in the micro irrigation systems. In spite of filtration units installed in the system in control head, presence of algae and slimes are common in water if the surface water is used. Both algae and slime can be controlled by chlorination. It can be done by injecting sufficient chlorine to bring the concentration between 10 to 20 ppm during the last 20 min. of irrigation cycle. Otherwise, continuous concentration of chlorine between 0.5 to 1.0 ppm at the end of laterals. This should be followed by flushing of pipe network with min. velocity of

0.3 m/s to remove fine particles deposited at the end of both laterals and sub mains. Maintenance of filtration units are also important in order to have higher trap efficiency. Maximum recommended pressure drop across sand filter is 70 kPa. Whenever the pressure drop exceeds this limit, the sand filter should be back flushed either manually or automatically. The mesh filter must be cleaned whenever the pressure drop ranges between 20 to 35 kPa.

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Improve management practices for dryland horticulture crops.

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Introduction

Dryland horticulture not only provides higher income to the farmers, but also more stable returns, besides utilizing the off-season precipitation. Therefore dry land horticulture is taken up in small land holdings and in water scarcity lands. Importance of fruit plant:- Perennial fruit crops grown in all season or fruit crop which grows and yields without wasting any available rain water, nutrient from soil is selected and cultivated. Several farmers are evincing keen interest in cultivating Dryland horticulture crops like grapes, ber, pomegranate, custard apple, amla, guava, tamarind, karonda, tomatoes, pumpkins, beans, and other summer crops. These crops grow using the winter water stored in the soil, rather than depending on rainfall during the growing season.

Dry land horticulture has a special significance, especially when there is a renewed emphasis on increasing the productivity of marginal lands. At present, the productivity of these lands is very low as most of these lands are located in either semiarid or arid areas. Most of these lands are not fit for crop farming, and crop farming on such lands is also very risky and is not remunerative. The cultivation of fruit crops in this region with conventional methods is not going to be a paying preposition. It is only by adopting farming system approach the cultivation of fruit crops can be successful in these regions.

Improve management practices for dryland horticulture crops.

1) Development of water harvesting module
2) Orchard floor management
3) Protected cultivation
4) Fruit-based cropping models for crop diversification
5) High-density planting and canopy management
6) Integrated nutrient management
7) Mulching
8) Organic farming
9) Value addition

1. Development of water harvesting system

Investments are needed in institutional and human capacities to plan and manage water for rainfed horticulture at the catchment scale. Local runoff water resources can be diverted, stored, and managed. Under dryland conditions, tapping the potential lies in the availability of an adequate but erratic water resource provided by the rain. The major water-related challenges for rainfed horticulture in semi-arid regions are the extreme variability in rainfall, characterized by few rainfall events, high-intensity storms, and high frequency of dry spells and droughts. It is therefore critical to understand how hydroclimatic conditions and water management affecting yields in rainfed horticulture. However, construction of earthen and concrete check dam according to the catchment area, development of micro catchment module, full moon, half-moon terracing, and the help of Horti-Silvi-pastoral system, water loss could be minimized under dryland conditions.

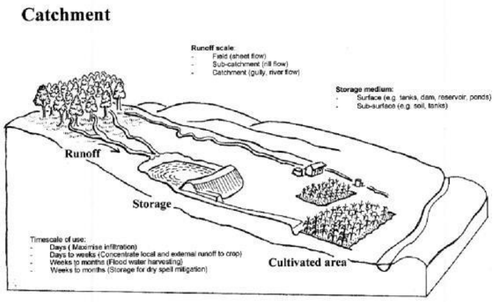

Fig. 8.1:water harvesting system

2. Orchard floor management

Under dryland condition, inter cropping during initial years of orchard of bael, aonla and jamun had no adverse effects on plant growth for up to 7 years. However, intercropping in the orchard spaced at 10m x10m can be done for up to 10 years. Intercropping of guar, cucurbits, okra, and leguminous vegetable crops increased the income 2-3 times. Cultivation of guar in orchards gave the additional advantage of seed yield than cowpea. Cover cropping with lobia, moth bean was found to increase the water-holding capacity of light soils due to increased organic carbon content in these regions. Among the different cucurbits tried as intercrops, aonla + bottle gourd fetches more net economic return under rainfed conditions. Intercropping is economically viable for increasing productivity per unit area and minimizes crop failure during drought years.

Fig. 8.2: Orchard floor management in fruit crops

3. Protected cultivation

High input costs and low-cost structures can be raised to grow crops during the off-season. Due to harsh environmental conditions, protected cultivation is useful to increase production and income by growing high-value crops in dryland conditions. Vegetables like cucumber, capsicum, tomato, and flowers like gerbera, orchids, etc., can be grown year-round and income can be enhanced manifold with proper management.

Fig. 8.3: Protected cultivation in vegetable crops

4. Fruit-based cropping system for crop diversification

Various fruit crop models can be adopted under dryland conditions to minimize risk and enhance productivity. Bael, aonla, and jamun based cropping models are beneficial in terms of improved yield and income. Bael + aonla + karonda + drumstick, bael + chironji + fig + custard apple, bael+khirni+phalsa +wood apple cropping models are useful to enhance the productivity of dryland tracts of the country. Layout and plantation of these crops should be done at closer spacing with proper canopy management to double productivity and income.

Fig. 8.4: Fruit-based cropping system

5. High-density planting and canopy management

India is the homeland of many semi-arid, drought hardy fruit crops like bael, aonla, acid lime, charoli, mahua, etc. However, the productivity of all these fruits in India is very low (4-5 t/ha) compared with other major fruit crops grown in India. Many reasons may be attributed to low productivity. A need to develop high yielding varieties/hybrids resistant to biotic and abiotic stresses having dwarf stature and responding to the pruning to solve this problem. By adopting the scientific practices of canopy architecture management and high-density planting, yield can be doubled in lesser time and from the more secondary area. High-density orcharding results in early bearing, helping to minimize weed problems. High-density planting at a spacing of 5 m x5 m in bael, aonla, jamun, chironji, and mahua has been found to double the yield and reduce the traditional planting system's harvesting. However, crops like phalsa, pomegranate and karonda can be accommodated at lesser spacing with the help of proper training and pruning. By adopting a double hedgerow system of planting, the productivity and income per unit area can be enhanced to 2-2.5 times over the conventional square system of planting under the rainfed condition. Bael, ber, and aonla are recommended for planting at 5mx5m distance under semi-arid conditions. However, a high-density plantation study revealed that maximum plant height was noticed in 2.5 x 2.5m planting distance and tripled the yield over the traditional planting system(5mx5m).

Fig. 8.5: High-density planting in fruit crops

6. Integrated nutrient management

India's soils of semi-arid regions are poor in organic carbon, nutrients, and water holding capacity. Soil depths of the soil in these regions are less, and nutrient management becomes difficult due to the presence of calcium carbonate layer at a lower depth. Improved fertilizer management is required to grow crops successfully on such soils. To avoid ammonia volatilization, fertilizers containing ammonium-N or urea should be moved into the root zone with rainfall or irrigation or be incorporated into the ground. Band placement of P minimizes soil contact, thus reducing or delaying the formation of insoluble Ca and Mg phosphates. Crops planted on calcareous soils may require above-average levels of K and Mg fertilizer for satisfactory nutrition. Using tolerant root stocks and varieties reduces the severity of nutrient-related disorders. The deficiency of micro nutrients can be corrected through foliar application of chelates. Adequate K supply and organic matter application in the form of cakes, FYM, and organic wastes can improve micro elements' availability.

Fig. 8.6: Integrated nutrient management in fruit crops

7. Mulching

Continuous use of organic mulches helps improve the soil physic-chemical properties, microbial flora, earthworm population, and soil aeration and moisture holding capacity, which ultimately resulted in better growth and yield of the plant. Under dryland conditions, the application of organic mulch (paddy straw, grasses, maize straw, etc.) in three basins is beneficial for the successful cultivation of fruit crops like bael, jamun, aonla, custard apple. It reduces the moisture loss from the soil, enhances the rate of rain water absorption in the soil, and controls weed growth. Mulching can be done with any locally available organic material. Mulching with paddy straw, maize straw, grasses, and rice husk reduces the weed population and conserves the soil's moisture. Mulches should be applied in the tree basin (20 cm thick) after the rainy season, and non-decomposed organic mulches should be incorporated and mixed with the soil of the tree basin in the forthcoming monsoon. Organic mulches improve the soil properties and moisture-holding capacity, reduce soil temperature (2 to 8 C) during summer, and increase the yield of 20-25 percent under dryland conditions.

Fig. 8.7: Field day mulching demonstration

8. Organic farming

Most of the minor horticultural crops of India's semiarid regions are often available only in the local markets and are practically unknown in other parts of the world. Today, consumers are becoming increasingly conscious of the health and nutritional benefits of their food basket. The minor horticultural crops are rich in minerals, vitamins, therapeutic values, and they can serve this purpose as they are growing naturally; therefore, they are free from toxic chemicals. To achieve this, these fruits need to be popularized in national and international markets. Practically, it can be achieved by developing suitable processing and marketing strategies for minor horticultural crops. In this regard, attempts have been made as aonla, pomegranate, guava, karonda, and bael and aonla based organic products are becoming more popular in the domestic markets. The growing of crops through organics not only hikes the price of products but also improves soil health. At CHES, Godhra, among the different combinations of an organic source of nutrients; the treatment combination FYM + neem cake +CPP and FYM + Azotobactor + VAM recorded 63.45kg and th 67.12kg/tree in NA-7aonla during 8 year with improved TSS, total sugar, vitamin C and total phenols.

Fig. 8.8: Organic farming in potato crop

9. Value addition

Malnutrition in resource-poor areas of drylands is a significant problem, particularly in pregnant women and children. Fruits like aonla, custard apple, bael, khirni, karonda, pomegranate, and ber are a rich source of vitamins, minerals, and dietary fibers. Ber fruits contain higher protein than even apples. Fruits like wood apple and custard apple are rich in carbohydrates and minerals, vital for maintaining the body. These fruits are highly perishable, the marketing of which is a significant problem, e.g.,custard apple get spoiled within 2–3 days of harvesting,if not consumed.Also,with the glut in the market,these fruits' prices drop down drastically, making it uneconomical for the farmers to sustain production; the result is that the farmers uproot the trees.

To avoid the situation, there is a need to extend these fruits' shelf life and develop post-harvest value addition technologies that are simple and adaptable at the farm level. This will result in developing small scale industries and employ the rural masses throughout the year, resulting in an increased income of both farmers and workers. Efforts made at the station were successful and many products, viz., dried and dehydrated fruits,RTS,squash,fruit bars, candies, fruit concentrates, powders, wines, and condensed fruit juices through solar drying, were prepared. Pomegranate varieties with dark red arils are preferred in making fruit juice and carbonated drinks. The tamarind pulp is pressed and preserved in large masses, and in dry conditions, the pulp remains good for about 1 year. There is tremendous scope for preparing beverages from the ripened fruit of chironji. Kernels are being used for the preparation of different kinds of sweets. The products like squash, RTS, and nectar may be prepared from the pulp of the fruit.

Fig. 8.9: Amla squash

Fig. 8.10: Bitter gourd RTS

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Integrated Pest Management (IPM) in Horticultural Crops

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Introduction

Indian horticulture sector plays a key role in ensuring nutritional security of the nation. It provides alternate rural employment opportunities, diversification in farm activities, and enhanced income to farmers. Agriculture is the most important and diversified industry of India which contributes about 18.5 per cent of the national income and gives employment to 52 per cent of its population (Anonymous, 2007). Horticulture sector is most vibrant sector for economic development which cover 18.98 million hectares (13.27% of total cultivated area) and contribute 28 per cent of the gross domestic product in agriculture (Mittal, 2007). India is currently producing about 320.48 million tones of horticulture produce with an area of 25.66 million ha. India's share in world fruit and vegetable production is 12.6 per cent and 14.0 per cent respectively. India ranks first in the production of mango, banana, guava, papaya, sapota, pomegranate, lime and aonla and is the second largest producer of fruits and vegetables. However, the productivity is low due many abiotic and biotic constraints. Among biotic constraints, insect pest damage causes considerable yield losses. Integrated Pest Management (IPM) system is the best effective sustainable approach of protecting crops from the ravages of insect pests towards achieving the goal of food sufficiency. IPM helps minimize reliance on chemical pesticides leading to elimination of several pesticide associated problems such as environmental pollution, killing of beneficial and non-target organisms, pesticide residue problem, health hazards, development of resistance in insect population, resurgence of pests and secondary pest outbreak. Sustainability in crop production and protection can only be achieved by developing technologies that are based on locally available, easily acceptable and cost-effective inputs. The estimated crop losses due to major insect pests are given in Table 1.

Table 9.1. Yield losses due to major insect pests of vegetables in India

Crop/Pest	**Yield losses (%)**	**Crop/Pest**	**Yield losses (%)**
TOMATO		CHILLIES	
Fruit borer (*Helicoverpa armigera*)	24-65	Thrips (*Scirothrips dorsalis*)	12-90
CABBAGE		CUCURBITS	
DBM (*Plutella xylostella*)	17-99	Mites (*Polyphagotarsonemus latus*)	34
Cabbage borer (*Hellula undalis*)	30-58	Fruitfly (*Bactrocera cucurbitae*)	
Cabbage leaf webber (*Crocidolomia binotalis*)	28-51	OKRA	
Cabbage caterpillar (*Peiris brasicae*)	69	Leafhopper (*Amrasca biguttula biguttula*)	54-66
BRINJAL		Shoot and fruit borer (*Earias vittella*)	23-54
Fruit and shoot borer (*Leucinodes orbonalis*)	11-93	Whitefly (*Bemisia tabaci*)	54

Average losses : 40%

Before we initiate the pest control or IPM practices, it is better to understand the nature of damage caused by pests and their typical symptoms and identification of pests are the key ones. Better comprehension of insect pest will facilitate and offer effective implementation of specific pest management. The information on major insect pests of vegetable crops, fruit crops symptoms of damage and specific management practices is given Table 2 and 3.

Table 9.2. Major insect pests of vegetable crops, symptoms of damage and specific management practices

Insect pest	**Damage Symptoms**	**Specific Management practices**
Brinjal fruit and shoot borer, *Leucinodes orbonalis*	Larva bores into tender shoots resulting in drying of tip • It bores into developing fruits and bore hole plugged with excreta • Damaged fruits unfit for marketing	Cultivation of resistant varieties such as Pusa Purple Round and Punjab Neelam • Installation of pheromone traps for monitoring and mass trapping • Removing and destroying affected shoots and fruits • Avoid continuous cropping of brinjal • Need based application of indoxacarb or carbaryl
Fruit borer, *Helicoverpa armigera*	Caterpillars in the initial stages feed on the leaves and later bore into the fruits	Grow resistant varieties • Growing of African marigold as trap crop • Use of pheromone traps (4 traps/acre) for monitoring • Setting of bird perches @ 10 / acre • Spray of Ha - NPV @ 250 LE / ha • Spray of B.t.k @1.5 kg/ha • Release parasitoids like *Trichogramma* spp. @ (50,000 / acre), *Bracon* spp. and *Campoletis* spp.
Potato tuber moth, *Phthorimaea operculella*	Mines on leaves and bore holes on tender shoot and tubers	Use of pest free seed material • Earthing up the tuber crop • Removing and destruction of infested tubers • Installation of pheromone traps @10/ha for monitoring • Release of *Bracon gelichiae*, *Copidosoma koehleri* and egg larval

		parasitoid. *Chelonus blackburni* • Need based spray of malathion
Whitefly, *Bemisia tabaci*	Nymphs and adults suck the sap from the under surface of the leaves and excrete honeydew • Leaves appear sickly and get coated with sooty mold • Stunted plant growth, shedding of fruits • It transmits yellow vein mosaic virus	Setting of yellow sticky traps, which are coated with grease / sticky oily materials • Growing of tolerant varieties • Avoid using of synthetic pyrethroids • Spray trizophos (2.5 ml/l) or prophenophos
Chilli thrips, *Scirtothrips dorsalis* *Thrips parvispinus*	Adults and nymphs lacerate the leaf tissue and suck the sap • Upward curling of leaves • Attacked plants are stunted, leaves drop, fresh buds become brittle and drop down	Destruction of affected plants • Release of predators such as *Chrysoperla* or coccinellid beetles • Setting of yellow sticky traps @20 / acre • Need based spray of acephate or fipronil
Diamond back moth, *Plutella xylostella*	Mining and skeletanization of cabbage leaves • Larvae also feeds on cabbage	Growing bold seeded mustard as trap crop • Installation of pheromone traps for monitoring and mass trapping • Release of parasitoids such as *Apanteles plutellae* and *Diadegma semiclausum* • Remove and destroy all the remnants and stubbles after the harvest of the crop • Need based spray of quinalphos or fenvalerate
Cucurbit fruit flies, *Bactrocera*	Maggots feed on the pulp and seeds inside • The affected fruits	Deep ploughing for killing of pupae • Removal and destruction of infested

cucurbitae	may fall prematurely • Infested fruits become soft and rotten	fruits • Setting of baits mixed with insecticides

Table 9.3: Major insect pests of fruit crops, symptoms of damage and specific management practices

Insect pest	**Damage Symptoms**	**Specific Management Practices**
Mango stem borer, *Batocera rufomaculata*	•Grubs bore into the wood and make irregular tunnels and feed on the vascular tissues •Bore holes on the mango stem, oozing of sap and protrusion of frass from the bored holes and drying of branches or entire tree	• The affected portions with grubs and pupae removed and destroyed. • A swab of cotton wool soaked in chloroform or petrol 5ml or carbon disulphide or kerosene oil or dichlorvos 10ml/l inserted in to the hole and sealed with mud. • Methyl parathion 1 ml/l poured in to the hole or tablet of aluminium phosphide inserted into the hole to kill the grub. • When burrows are superficial, extract the grubs with stiff hooked wire and paint bordeaux paste.
Mango mealy bugs (*Drosicha mangiferae*)	•The newly hatched nymphs start crawling on trees and settle on inflorescence causing flower drop and affecting fruit set. •Severe infestation results in drying of leaves and	Deep ploughing of orchard immediately after harvest or during summer months to expose eggs and pupae of mealy bugs to natural enemies and sun heat. Raking of soil around the tree trunk and mixing with methyl parathion

	inflorescence.	2% dust @ 250 g per tree Release of important predators such as *Cryptolaemus montrouzieri*, *Menochilus sexmaculatus*, *Rodolia fumida* and *Sumnius renardi* Put a heap of fine sand around the tree trunk so that the mealybug crawlers cannot climb on the trees
Banana Rhizome weevil, *Cosmopolities sordidus*	•Grubs bore into the pseudostem and rhizome and make tunnels by feeding and presence of bore holes • Adults bore into the suckers, the central shoots gets killed • Plants show premature withering and suckers get killed	•Drenching of soil with chlorpyrifos before planting • Planting of healthy suckers • Clean cultivation • Removal of pseudostems below ground level • Trimming the rhizome • Trapping of adults using yellow traps • Use of carbofuran or phorate granules for soil incorporation at time of planting
Citrus fruit sucking moth, *Othreis fulonica* *O.materna*, *O.ancill*	•Adults suck the juice from ripening fruits resulting in dropping • Shedding of fruits with feeding punctures	Destruction of weed hosts •Smoking below the trees to scare away the moths • Bagging of fruits with polythene or paper cover to avoid damage by adults •Destruction of the fallen and decaying fruits • Setting of light and placing of water mixed with kerosene below
Pomegranate butterfly / Anar butterfly *Deudorix isocrates*	•Caterpillar bore holes on the pomegranate fruits surrounded by faecal matter and feeds on inner contents (pulp)	Destruction of fallen infested fruits checks the spread. Removal of flowering weeds Bagging of fruits with polythene or paper bags or cloth bags soon after

		the fruit se Chemical control by application of dichlorvos @ 1 ml. /L or carbaryl 3g /l.
Tea mosquito bug, *Helopeltis antonii*	•Corky out growth or scab formation • Drying of shoots, inflorescence and dropping of the flowers and young fruits	Nymphs are parasitized by the mermithid, *Agamermis paradecaudata* Application of recommended dose of fertilizers. Spray application of monocrotophos 1.6ml/l or dimethoate 2ml/l at fortnightly interval during the fruit development
Grapevine stem girdler, *Sthenias gresator*	Spiral cut on the grapevine stem (ringing the vine)	•Cutting and burning of attacked branches below the girdling point • Hand collection and destruction of beetles
Papaya mealybug *Paracoccus marginatus*,	•Initially the affected portion will be cholotic, later changed to brown and dry away. •These bugs excrete honey dew and as a result infested portion becomes shiny and moist and to this, secondary infection by sooty fungus, *Capnodium* occurs results in black covering the affected parts.	Release of *Cryptolaemus montrouzieri* @ 10 per tree Conserve coccinellid predators Spray chlorpyriphos 20EC @2.5 m;/l or buprofezin 25EC @ 2 ml/l

Invasive insect pests:

Thrips parvispinus in Chilli crop

1. *Thrips parvispinus* is reported as an invasive insect pest in 2015 from India and is polyphagous in nature.
2. It is the most damaging species of thrips on papaya (in Hawaii and Indonesia), pepper and other solanaceous crops (in Indonesia) and ornamentals (in Europe and Indonesia). And mostly it is not a vector for virus transmission.

The damage symptoms are noticed on leaves and floral parts.

i. On leaves, adjacent Portions to veins are preferred areas for colonizing and feeding .
ii. Deep punctures and scratches on the underside of the leaves.
iii. Yellowish and blotchy appearance in upper surface respective to feeding sites.
iv. Reddish brown discolouration on under the surface of the leaves.

South American tomato leaf miner, *Tuta absoluta*

South American tomato leaf miner, *Tuta absoluta* (Meyrick) and is lepidopteran insect pest (Lepidoptera: Gelechiidae) is key and invasive pest of Tomato. The most distinctive symptoms of damage done by the tomato leaf miner (*Tuta absoluta*) are the blotch-shaped mines in the leaves. Caterpillars prefer leaves and stems, but they may also occur underneath the crown of the fruit and even inside the fruit itself.

The easiest, most accurate way to identify leaf miners is to look for their damage to host plants. Since the larvae feed within the plant's leaves or needles, they produce either large blotches or tunnels that wander under the surface of the leaf.

Integrated Pest Management (IPM)

Integrated Pest Management (IPM) involves a combination of various measures to ensure effective pest management without disturbing the ecosystem, reducing environmental pollution and eliminate direct and indirect health hazards to human beings. Integrated Pest Management (IPM) is a sustainable approach to managing pests by combining biological, cultural, mechanical and chemical tools in a way that minimizes economic, health and environmental risks. The IPM concept is based on the principle that it is not necessary to eliminate all the pests but to suppress the pest population to a level at which these pests do not cause significant losses.

COMPONENTS OF IPM

The different components of IPM are

- Monitoring
- Resistant varieties
- Cultural control
- Mechanical control
- Bio - rationals
- Biological control
- Regulatory control
- Chemical control

Monitoring: Keep tracks of the pests and their potential damage. This provides knowledge about the current pests and crop situation and is helpful in selecting the best possible combinations of the pest management methods.

Resistant varieties: Cultivation of plant varieties which are less prone to pest attack. The resistant varieties reduce production cost. Use of Bt transgenic crops reduce the incidence of lepidopteran pests. Breeding for pest resistance is a continuous process. These are bred and selected when available in order to protect against key pests.

Cultural control: It includes crop production practices that make crop environment less susceptible to pests. Cultural methods such as deep ploughing and burning of crop residues, soil solarization, synchronous planting of crop fields, planting trap crops, intercropping, crop rotation, tillage, and use of pest free seeds and planting material are effective methods to reduce pest load. Cultural methods are based on pest biology and development.

Mechanical control: These are based on the knowledge of pest behaviour. Mechanical methods such as hand picking, installation of bird perches and mulching reduce the pest buildup. Physical methods of pest control involve manipulation of temperature, humidity, use of energy and sound.

Bio - rationals: Biorationals include plant products such as neem and bio - pesticides such as nuclear polyhedrosis virus and Bacillus thuringiensis. Non chemical methods for pest control, such as use of sex attractants or pheromones, insect growth regulators and repellants.

Biological control: These includes augmentation and conservation of natural enemies of pests such as insect predators, parasitoids, pathogen and weed feeders. In IPM programes, native natural enemy population are conserved and non-native agents are released with utmost caution.

Regulatory control: Quarantine laws to prevent the entry of pest from other areas or other countries.

Chemical control: Pesticides are used to keep the pest population below economically damaging levels when the pests cannot be controlled by other means. It is applied ONLY when the pest's damaging capacity is nearing to the threshold. The economic threshold levels (ETLs) of major pest of vegetable crops and fruit crops are given in Table 4 and 5.

Table 9.4: Economic Threshold Levels (ETLs) of major insect pests of vegetable crops

Major Insect Pest	**ETL**
BSFB (*L.orbonalis*)	5% fruit damage, 8-10 moths/ day/ trap
Tomato fruit borer (*H. armigera*)	1 larva/ plant or 2% fruit damage
Spodoptera litura	1-5 % incidence
Dimond back moth (DBM) of cabbage (*P. xylostella*)	10 larvae/ plant at seedling stage, 1-5 % damage
Cauliflower aphids	30 aphids/plant
Chilli mites (*P. latus*)	Single mite/ leaf
Chilli thrips (*S. dorsalis*) New Invasive trhirps -*T. parvispinus*	2-5 thrips/ leaf or 10% infected plants
Whitefly (*B. tabaci*) in brinjal	5-10 flies/leaf
Leaf hopper	2-5 nymphs/leaf
Okra fruit borer (*E. vittella*)	5 % of fruit infestation
Pea aphids (*Acyrtosiphon pisum*)	3-4 aphids/stem

Table 9.5: Economic Threshold Levels (ETLs) of major insect pests of fruit crops

Major Insect Pest	**ETL**
Phytophagous mites, *Panonychus ulmi*	5 - 10 % foliage infestation
Mealybug, *Maconellicoccus hirsutus*	1 % bunch infestation
Thirps, *Retithrips syriacus*	5 thrips / young leaf
Mango leaf webber, *Orthaga exvinacea*	10 % incidence
Mango hopper, *Amritodes atkinsoni*	5 adults / panicle
Mango stem borer, *Batocera refomaculata*	Appearance of pest
Grapes flea beetle, *Scelodonta stricollis*	2 % foliar damage
Ber fruit fly, *Carpomyia vesuviana*	1 - 2 % incidence
Citrus caterpillar, *Papilio demoleus*	20 - 30 % foliar damage

Integrated Pest Management Strategy

- While developing IPM strategy one has to select different components that are readily available, economical and applicable at field level

- To cater the needs for location specific cropping systems the suitable technologies should be developed by research workers from time to time

- The research findings that are practically implementable should be popularized by the Extension workers through education to farming community. Farmers have to be trained in scouting, diagnosis of pest infestation and arriving ETLs for need based chemical application in time

- Farmers should also be trained in selection of suitable pesticide, use of proper lethal dose and proper coverage of foliage to avoid risks of resistance, resurgence and residues. Farmers training is a continuous process and is an important integrated part for successful implementation of IPM

- An healthy, meaningful co - operation is very much needed from corporate pesticide industry to make IPM successful at farmers level. The pesticide industry should not wield enormous financial power and maintain market dominance against ecological and environmental safety.

According to Metcalf and Luckmann (1994) the principals and concepts of IPM are given below

Principals of IPM	**Concepts of IPM**	**Tools/Methods of IPM**
Subsistence phase	Understanding of agricultural eco-system	Cultural control
Exploitation phase	Planning the agricultural ecosystem	Physical control
Crisis phase	Cost/Benefit and Benefit/Risk	Mechanical control
Disaster phase	Tolerance of pest damage	Biological control
Integrated management phase	Leaving pest residue	Genetic control
	Timing treatments	Legal control
	Public understanding and acceptance	Chemical control

The step-by-step procedures for developing an IPM program/strategy are given below (Norris et al. 2002; Pedigo and Rice 2009)

- Identify all insect pests, their life stages as well as their natural enemies in the system.
- Establish first crude and then refines as well as improved monitoring and pest scouting guidelines
- Establish injury levels and action threshold for each pest species in the system
- Establish a record keeping system for evaluating and improving any IPM program
- Develop a list of acceptable management strategies for each pest preferably the preventive strategies and then therapeutic strategies.
- Develop a specific criterion for the selection of pest management methods like; i) least destructive to natural control and beneficial fauna, least hazardous to human health, least toxic to non-target organisms, exhibit sustainable reduction of pest population, easy to carryout in the system and most cost-effective in the short- and long-term situation.
- Develop guidelines for the selection of pesticide every time.
- Evaluate the sustainability of the IPM program

The general IPM strategy for horticultural crops

- Deep summer ploughing to expose resting stages of insect pests
- Removal of weeds / alternate host plants such as *Hibiscus*, *Parthenium* etc. on the bunds and adjoining areas
- Adopt proper crop rotation
- Grow resistance or moderately resistance varieties
- Select healthy planting materials/ seeds for planting
- Sowing should be done timely
- For vegetable crops, seed treatment with imidacloprid @ 5g/kg against sucking insect pests
- Grow trap crops on the borders
- Removal of effected plant parts and destroy the same
- Avoiding the movement of planting material from infested areas
- Erection of bird perches @ 10 / acre
- Installation of yellow sticky traps for aphids, leaf hoppers and whiteflies @20 per acre
- Installation of pheromone traps @ 10 / ha for monitoring
- Bagging of fruits with polythene to avoid damage by fruit sucking moth and fruit flies
- Destruction of fallen and decaying fruits
- Conservation of these natural enemies such as ladybird beetles, lacewings, hover flies, spiders, certain hymenopteran and dipteran parasitoids
- Soil application of neem cake @ 250 kg / ha and three sprays of neem seed kernel extract (NSKE) @ 5 % against sucking pests
- Application of HaNPV 250 LE /ha or *Bacillus thuringiensis* formulation @ 1.5 kg/ha for management of *Helicoverpa* at 10-15 days interval
- Need based application of recommended dose of pesticides
- Avoid repeating the use of the same chemical insecticide to avoid development of resistance

Conclusions:

IPM is a knowledge driven and labour intensive strategy and adoption of the same has to be promoted. Despite increasing emphasis on research and extension of IPM technologies, there are still some knowledge and information gaps that need to be filled for enhancing the adoption of IPM technologies. The adoption of different components of IPM was found to be varying. On the whole the cultural components of IPM such as proper pruning and training and collection of affected branches are easy to adopt. The adoption of biological components such as NPV, Bt was observed to be limited because of the constraints in availability as well as the lack of proper understanding on the application methods and efficacy of these components. Use of pheromone traps and sticky traps and fruit fly traps are to be promoted. Adoption of IPM was observed to be more in case of all commercial crops like grapes, mango and tomato and chilli crops. The adoption of IPM was found to lead to reduction in use of insecticides, reduced cost of cultivation and increased net returns.

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Bioinoculants for horticultural production systems

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Introduction

India is the 2nd largest producer of fruits and vegetables. It is also the largest producer of mango, papaya, pomegranate, cashew etc. It is estimated that, total horticulture production in 2020-21 would reach 319.57 Million Tonne. The horticulture sector has become important factor for economic development and contributes 30.4 % to GDP of agriculture.

Impacts of chemical fertilizers

Though use of chemical fertilizers helped to improve the yield of crops, their excessive and indiscriminate use has resulted in several environmental problem besides deteriorating soil health. Over the years their cost has also been increased several folds. Manufacturing of chemical fertilizers requires of lots of fossil fuels, which in turn cause emission of GHGs and thereby contributing to climate change.

Bioinoculants

Bioinoculants are beneficial microorganisms which improve plant growth, development and also soil health through several mechanisms. These microorganisms play a key role in organic matter decomposition, biogeochemical cycling of C, N, P and S, mobilization and solubilization of nutrients, removal of toxic pollutants, management of various pest and diseases. Biofertilizers are ecofriendly, cost effective and renewable. Use of bioinoculants is one of the best option to reduce harmful agrochemicals usage in agriculture.

The bioinoculants such as *Azotobacter*, phosphorus solubilizing bacteria, mycorrhiza and biocontrol agents can be used in different horticultural production systems. By utilizing nitrogen fixing organism such as *Azotobacter*, it is possible to reduce the requirement of chemical nitrogenous fertilizers up to 20 % besides improving the crop yield by 10-20% (Pathak et al. 2017). Phosphorus solubilizing bacteria like *Bacillus polymyxa*, *Pseudomonas striata*, *Aspergillus niger* and others solubilize fixed phosphorus by secreting various organic acids such as gluconic acid, 2 ketogluconic acid etc. and make it available for plant uptake. They also help in reducing the requirement of phosphatic fertilizers up to 40 %. The arbuscular mycorrhizal genera such as *Glomus*, *Acaulospora, Scutellospora, Gigaspora*, etc. mobilizes plant nutrients such as P, K, Zn, Fe and provides for plant uptake. They also help in enhancing the tolerance level of plants to several biotic and abiotic stresses (Baum et al. 2015). The biocontrol agents through various mechanisms such as secretion of antibiotics, competition for nutrients and space, parasitism etc. inhibit the growth of pathogenic microorganisms.

Bioinoculants for horticultural crop production

Mango

Use of *Azotobacter* 50 g per plant + PSB 50 g per plant + 3 kg vermicompost per plant significantly enhanced growth and development of mango cv. Dasheri and also improved soil health (Poonia et al. 2018). Application of 250 g each of *Azotobacter* + VAM along with recommended dose of NPK recorded highest yield (93.5 kg/plant) of mango cv. Amrapali as compared to 60 kg/plant in 100% NPK treated trees (Kundu et al. 2011).

Guava

Application of FYM 26 kg/plant +*Azotobacter* 100 g/plant +PSB 100 g/plant +potash mobilizers 100 g/plant applied in two split doses, once in January and again in August resulted in maximum yield (114 kg/plant) of guava cv. Sardar (Devi et al. 2012). Use of phosphatic biofertilizers @ 200 g/tree/year along with 20 kg farmyard manure significantly influenced the fruit weight of guava (Dey et al. 2005). Application of 150 g of *Azospirillum brasilense* + arbuscular mycorhizal fungi and 5 kg of FYM in two split application (one at January and other during August) recorded highest fruit yield (41.3 kg plant^{-1}) (Das et al. 2017).

Custard apple

Application of 50 % recommended dose of chemical fertilizers (25 g urea, 100 g SSP, 25 g MOP) + 50 % N through vermicompost (766.5 g/plant) + *Azotobacter* 50 g/plant + PSB 50 g/plant +Mycorrhiza 20 g/plant significantly enhanced growth and development of custard apple cv. Arka Sahan (Sharma et al. 2014).

Sapota

Application of 1125:750:375 g NPK/plant+ 15 kg vermicompost+250 g *Azotobacter*+250 g PSB/plant recorded maximum yield of 197.53 kg/plant (Baviskar et al. 2011). Use of *Azospirillum* (200 g/plant) + PSB (200 g/plant) along with 100 % NPK (1000:500:500 g NPK per plant) recorded highest yield of 53.33 kg/tree in sapota cv. Kalipatti (Manjare et al. 2018).

Papaya

Application of 75 % recommended dose of chemical fertilizers (187.5:187.5:187.5 NPK/plant/year) + *Azotobacter* 50 g/plant + PSB 50 g/plant+ *Azospirillum* 50 g/plant significantly enhanced growth and development of papya cv.Red Lady (Jadia et al. 2019). Use of 75% NP (150g N:150 g P) 100% K (200 g K) + *Azotobacter* + PSB significantly improved vegetative growth of papaya seedlings (Mamta et al. 2017).

Tomato

Use of *Azotobacter* along with recommended dose of fertilizers (120:100:100 kg NPK per hectare) recorded highest fruit yield of 693.32 q/ha in tomato (Kamal et al. 2018).

Chilli

Application of biofertilizers such as *Azospirillum* + AMF (*Glomus fasiculatum*) + potash mobilizer (*Fraturia aurantia*) in addition to recommended dose of fertilizers i.e.,150:80:80 NPK kg/ha resulted in maximum yield of chilli cv. Beldanga (Kumbar et al. 2017).

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Soil Based Crop Suitability Assessment for Alternate Land-use Planning

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Land evaluation is the process of assessing the potential of land for one or more kinds of use. Land resource surveys and land use planning is linked with each other through land evaluation (Deckers et al. 2004).The land or land resources, taken in the broader sense– includes climatic, soil, water and biological resources that are used to support human activities. It takes the biophysical inventory of these resources a step beyond in interpreting their suitability for specific targeted uses. It's a process of relating, or matching, the characteristics and qualities of land with the requirements of existing or intended uses. In its simplest form, land evaluation involves the assessment of selected biophysical characteristics that are relevant for particular purposes. Land evaluation for different uses, irrigability classification and capability classification are the systematic appraisal of land and their distribution by classes on the basis of similar physical and chemical properties with respect to their suitability for their sustainable production. FAO Framework of Land Evaluation is most widely used for assessing the suitability of soils for various kinds of Land Utilization Types (LUTs). Land Suitability may be defined as "the fitness of a given type of land for a specified kind of land use" (FAO, 1983). It is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. Suitability is assessed for each relevant use and each land unit identified in the study. Land suitability assessment in developing countries where data insufficiency often constrains modeling (Stomph et al. 1994), suitability analysis can answer the question (what is to grow where?). In order to define the suitability of an area for a specific practice, several criteria need to be evaluated (Belka, 2005). Land suitability is the fitness of a given piece of land for a well specified land use (Dengiz and Usul 2018, Girmay et al. 2018). Traditional classification is now found inadequate in view of the complex nature of climatic and edaphic factors influencing the productive potential of different subregions within the rain-fed agro-ecosystem. It is an expression of how well a land unit matches the requirements of the land utilization type. It consists of 4 chief stages (Girmay et al. 2018):

1. Determination of the land use requirements and the corresponding land attributes
2. Characterization or quantification of the land attributes
3. Comparison of the land use with the land, and

4. Determination of the real and potential land suitability class

Each plant species requires definite soil and site conditions for its optimum growth. Although some plants may be found to grow under different soils and extreme agro-ecological conditions, yet not all plants can grow on the same soil and under the same environment. The conspicuous absence of Pinus species in inter-tropical and of eucalyptus in the temperate (cold) regions are examples. Since the availability of both water and plant nutrients is largely controlled by the physicochemical and micro environment of soils, the success and/or failure of any plant species, in a particular area, is largely determined by these factors. The deep rooted forest or orchard plantations respond differently to soil depth and soil texture (Mishra and Sahu,1991) than the shallow-rooted arable crops such as rice, wheat, green gram, black gram, pigeon-pea, groundnut etc. Several soil-site studies for different plant species have been reported in the literature. These illustrate how soil depth, (sub) soil texture, salinity and drainage conditions are related to soil-site quality. The objective of various soil-site evaluation studies has been to predict and classify land for plant growth (Sehgal1996). Observations on growth inhibiting

factors for certain species and tolerance of others to extremely adverse conditions have been evaluated by many scientists.

Suitability Criteria:

Most of the plant species need well drained, moderately fine to medium texture soils, free of salinity and having optimum physical environment. Soil resource maps based on several parameters, can aid in predicting the behaviour and suitability of soils for growing field crops, horticultural crops, forest species and other plantation crops once the suitability criteria is established (Pushpanjali, 2014). Within limits, it may also find application in transfer of technology to other areas with comparable soil-site characteristics. Several systems of land evaluation have been proposed for use in different regions, the important being that of Storie (1954) and Ricquier et al(1970).

The FAO land suitability classification system has four different categories: Orders, Classes, Subclasses and Units. There are two orders(S and N) which reflect the kind of suitability (S for suitable and N for unsuitable land).

Order "S" -Suitable land

Land on which sustained use for the defined purpose in the defined manner is expected to yield benefits that will justify required recurrent inputs without unacceptable risk to land resources.

Order "N"-Unsuitable land

Land having characteristics which appear to preclude its sustained use for the defined purpose in the defined manner or which would create production, upkeep and/or conservation problems requiring a level of recurrent inputs unacceptable at the time of interpretation.

Land Suitability Classes:

The framework at its origin permits complete freedom in determining the number of classes within each order. However, it has been recommended to use only 3 classes within order S and 2 classes within order N(Table 1). The class will be indicated by an Arabic number in sequence of decreasing suitability within the order and therefore reflects degrees of suitability within the orders.

Table 11.1: Guidelines to define the suitability classes (Sys 1975)

Suitability class		
	productivity	Viability to use land for agriculture purpose
S1	high	Not Practical+ viable
S2	moderate	practical + viable
S3	marginal	practical + restricted viability
N1	not actually, nut potentially suitable	major land improvements
N2	actually & potentially unsuitable	not practical nor viable

No firm criteria are given for defining the classes; this permits complete freedom in choice of the criteria in order to elaborate the degrees of suitability within the orders. For each specific case a specific method is to be suggested. Appraisal can be done according to an evaluation of land limitations.

Land Suitability Sub classes:

The sub classes reflect kinds of limitations or main kinds of improvement measures required within classes. They are indicated in the symbol using lower case letters.

Table 11.2 : Sub classes with limitation

	Subclass symbol	Interpretation
1	c	Climatic conditions
2	t	Topographic limitations
3	w	Wetness limitations
4	n	Salinity(and/or alkalinity) limitations
5	f	Soil fertility limitations not readily to be corrected
6	s	Physical soil limitations (influencing soil/ water relationship and management).

Source: (Ziadat 2007, AbdelRahman et al. 2016)

Land suitability units:

This grouping is used to identify land development units having minor differences in management requirements. This can indicate the relative importance of land development works. It is indicated by Arabic numerals, enclosed in parenthesis, following the subclass symbol.

The whole unit is indicated by a symbol; for example: S2w (2). Here "S" represents Order (Suitable); the number 2 after the letter S represents Class 2(moderately suitable); "w" represents Subclass (wetness limitation); and (2) represents Unit 2.

Sys and Verheye (1975) proposed the following capability index (Ci) based on nine parameters for crop production in the arid and
semi-arid regions.

Ci =A.B.C.D.E.F.G.H.I.

Where,

A = rating for soil texture

B = rating for calcium carbonate

C = rating for gypsum

D = rating for salinity

E = rating for sodium saturation

F = rating for drainage

G = rating for soil depth

H = rating for epipedon and weathering stage

I = rating for profile development

The limitation approach has been successfully used to provide a qualitative land evaluation based on general characteristics which are made available after a quality soil survey and general study of other soil resources in the area. The soil-site parameters considered for the purpose of evaluating land for agriculture, forestry and for plantation crops and for defining suitability classes are:

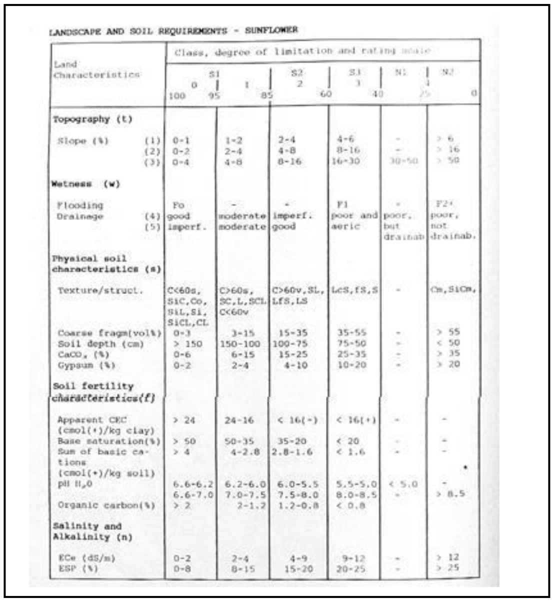
	Soil-Site Characteristics Related Land Quality
Climate (c)	-Available moisture Topography and Landscape(t) - Resistance to erosion Wetness (w) conditions - Available moisture - Drainage - Flooding
Physical conditions(s) of soil	-Texture - Water availability - Gravels/Stoniness Availability of foot-hold for (Surface and subsoil) root development - Depth - Availability of foot-hold for plant growth - Calcium carbonate - Nutrient availability - Gypsum - Source of nutrient sulphur
Soil fertility (f)	-Organic matter - Cation Exchange Capacity (CEC) - Base Saturation - Nutrient availability
Salinity and Alkalinity (n)	- Salinity - Groundwater depth and its quality - Alkalinity/Sodicity

Soil-Crop Suitability Maps

Many of GIS-based land suitability analysis approaches are recently developed such as Boolean overlay and modelling for land suitability analysis.Where the criteria for the optimum growth of various crops or groups of crops to be evaluated is known, then a soil-crop suitability table can be prepared and used as a legend on the map. This is most useful for planners as it gives at a glance a comparative suitability of the soils for better crop planning. For example Parseoni village, Parseoni Taluk, Maharashtra, with rainfall of 1150 mm, Typic Haplusterts temperature 32°C with latitude- longitude of 21.39027778 and 79.15527778 Was being studied for soil based crop suitability for sunflower (Figure 1 and 2) and chilli crops(Figure 3).

Table 11.3: example of Soil Properties used for one location

	Values
PH	8.22
EC ((dS m$_{-1}$))	0.22
OC **(%)**	0.43
Clay **(%)**	53.50
CEC (**Cmol (p+)kg^{-1})**	46.02
BD**(Mg m^{-3})**	0.18
COLE	12.83
AWC **(%)**	39.21
BS (%)	113.02
ESP (%)	2.49



LANDSCAPE AND SOIL REQUIREMENTS - SUNFLOWER

Land Characteristics	Class, degree of limitation and rating scale					
	S1 0	S1 1	S2 2	S3 3	N1	N2 4
	100–95	95–85	85–60	60–40	40–25	25–0
Topography (t)						
Slope (%) (1)	0-1	1-2	2-4	4-6	-	> 6
(2)	0-2	2-4	4-8	8-16	-	> 16
(3)	0-4	4-8	8-16	16-30	30-50	> 50
Wetness (w)						
Flooding	Fo	-	-	F1	-	F2+
Drainage (4)	good	moderate	imperf.	poor and aeric	poor, but drainab	poor, not drainab.
(5)	imperf.	moderate	good			
Physical soil characteristics (s)						
Texture/struct.	C<60s, SiC,Co, SiL,Si, SiCL,CL	C>60s, SC,L,SCL C<60v	C>60v,SL, LfS,LS	LcS,fS,S	-	Cm,SiCm,
Coarse fragm(vol%)	0-3	3-15	15-35	35-55	-	> 55
Soil depth (cm)	> 150	150-100	100-75	75-50	-	< 50
CaCO$_3$ (%)	0-6	6-15	15-25	25-35	-	> 35
Gypsum (%)	0-2	2-4	4-10	10-20	-	> 20
Soil fertility characteristics(f)						
Apparent CEC (cmol(+)/kg clay)	> 24	24-16	< 16(-)	< 16(+)	-	-
Base saturation(%)	> 50	50-35	35-20	< 20	-	-
Sum of basic cations (cmol(+)/kg soil)	> 4	4-2.8	2.8-1.6	< 1.6	-	-
pH H$_2$O	6.6-6.2 6.6-7.0	6.2-6.0 7.0-7.5	6.0-5.5 7.5-8.0	5.5-5.0 8.0-8.5	< 5.0 -	- > 8.5
Organic carbon(%)	> 2	2-1.2	1.2-0.8	< 0.8		
Salinity and Alkalinity (n)						
ECe (dS/m)	0-2	2-4	4-9	9-12	-	> 12
ESP (%)	0-8	8-15	15-20	20-25	-	> 25

Figure 11.1: Location and soil requirement for Sunflower Source: Sys 1985

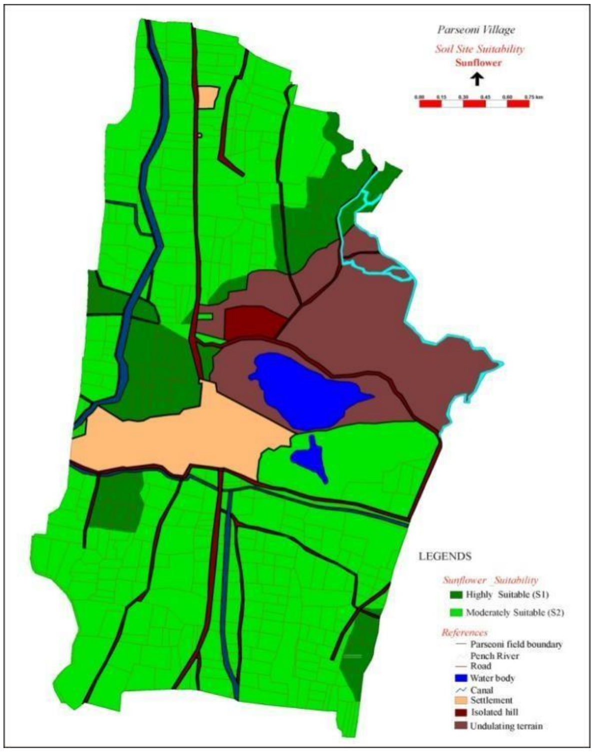


Figure 11.2: Soil site suitability based map for sunflower

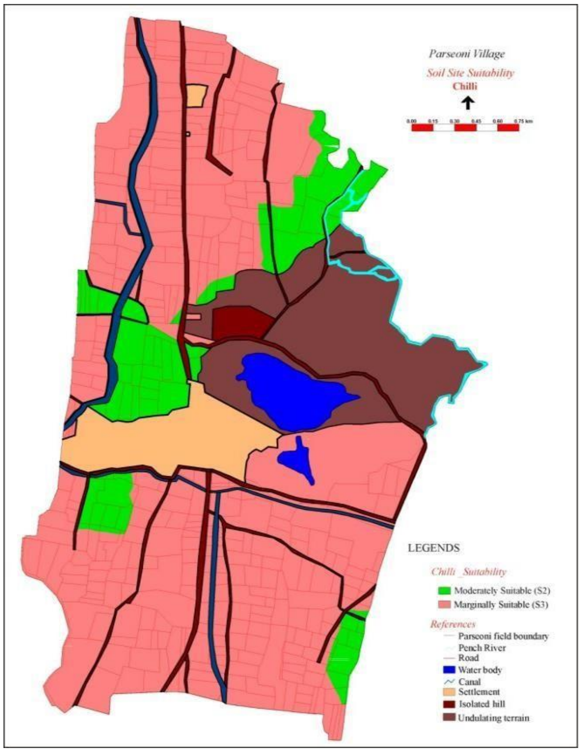


Figure 11.3: Soil site suitability based map for Chilli

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