Agroforestry Opportunities

for Enhancing Resilience to Climate Change in Rainfed Areas

Editors: G Rajeshwar Rao, M Prabhakar, G Venkatesh, I Srinivas, K Sammi Reddy

ICAR - Central Research Institute for Dryland Agriculture

National Innovations in Climate Resilient Agriculture

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FOREWORD

The growing population and the diversified food requirements of the country calls for enhancing food production substantially in the years to come in spite of several limitations such as land degradation, declining productivity and soil health and growing concerns of climate change. Farmers in rainfed regions depend extensively on natural resources for food, fodder and fuel wood and may experience greater levels of poverty and hunger as their sources of livelihood become increasingly exposed to climate-related risks. Climate change is expected to increase temperature, greater variability and erratic rainfall regimes, increased frequency and intensity of extreme events which may lead to greater vulnerability of rainfed agriculture. This will have serious economic, social, and ecological consequences for agriculture and food security particularly in rainfed regions.

Agroforestry provides a unique opportunity to achieve the objectives of enhancing the productivity and improving the soil quality. Tree systems can also play an important role towards adapting to the climate variability and important carbon sinks which helps to decrease the pressure on natural forests. Realizing the importance of the agroforestry in meeting the twin objectives of mitigation and adaptation to climate change as well as making rainfed agriculture more climate resilient, the ICAR-CRIDA has taken up the challenge in pursuance of National Agroforestry Policy 2014, in preparing a book on *Agroforestry Opportunities for Enhancing Resilience to Climate Change in Rainfed Areas* at ICAR-CRIDA to sharpen the skills of all stakeholders at national, state and district level in rainfed areas to increase agricultural productivity in response to climate change. The efforts made by the reviewers and editors in compiling and editing the chapters and bringing them in the form of a book are commendable. I am sure that this publication will be of great use in providing information regarding the agroforestry practices and procedures to be followed in making rainfed agriculture climate resilient.

22-03-2018
New Delhi

(Dr. K. Alagusundaram)

PREFACE

This book deals with importance of opportunities for enhancing resilience to climate change in rainfed areas through agroforestry. It is great privilege for us to express our profound sense of gratitude to Indian Council of Agriculture Research (ICAR), New Delhi and National Innovations in Climate Resilient Agriculture for sponsoring to bring out this publication on *Agroforestry Opportunities for Enhancing Resilience to Climate Change in Rainfed Areas.* We profusely thank DDG (Natural Resource Management), I/c, ICAR for their kind encouragement by supporting this publication. The encouragement, support and guidance received from Dr. K Sammi Reddy, Director, ICAR-CRIDA, is sincerely acknowledged. We express sincere thanks to all the authors who had contributed in time and sharing their knowledge. We thank all the staff of ICAR-CRIDA who helped directly or indirectly in bringing out this publication in time. We firmly believe that this publication will be highly useful, in one way or other, for researchers, academicians, extension workers, policy makers, planners, officials in development institutions/agencies, producers, farmers and students of rainfed areas.

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Chapter 1

Climate Change and Agriculture: Global and Local Perspectives

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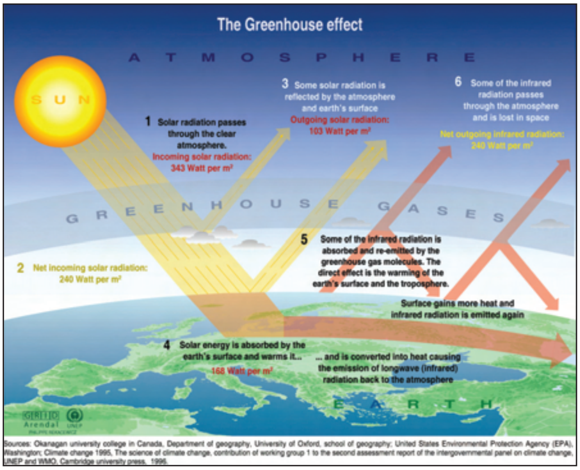
Introduction

Climate change is a long-term shift in the statistics of the weather (including its averages). For example, it can be seen as a change in climate normal (expected average values for temperature and precipitation) for a given place and time of year, from one decade to the next. It has been found that the global climate is currently changing. The last decade of the 20th Century and the beginning of the 21st have been the warmest period in the entire global instrumental temperature record, starting in the mid-19th century. Enormous progress has been made in increasing our understanding of climate change and its causes, and a clearer picture of current and future impacts is emerging. Research is also shedding light on actions that might be taken to limit the magnitude of climate change and adapt to its impact. There is consensus among the majority of climate scientists agree that human activities, especially the burning of fossil fuels (coal, oil, and gas), are responsible for most of the climate change currently being observed.

Global Climate Change: Concepts and Effects

What is Climate Change?

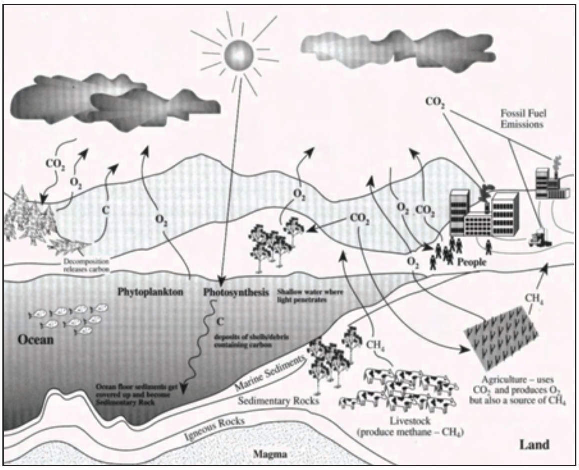
Before we go into what exactly is climate change is it important to understand what the difference between weather and climate is. Many people use the words weather and climate as if they mean the same thing, but they are not the same. It is important to understand the difference in order to appreciate the idea of climate change. Weather is what is going on in the atmosphere at a particular place and time. Weather is measured in terms of windspeed, temperature, humidity, atmospheric pressure, cloudiness and precipitation. In most places, weather changes from hour-to-hour, day-to-day, and season-to-season. Climate on the other hand is the weather conditions prevailing in an area in general or over a long period. The word climate refers to the average pattern of weather in a region.



Climate change denotes long term changes in climate including mean temperature and precipitation. Shifting weather patterns results in changing climate, this sort of change threatens food production through increased unpredictability of precipitation, rising sea levels contaminate coastal freshwater reserves and increase the risk of catastrophic flooding. A warming atmosphere aids the pole-ward spread of pests and diseases once limited to the tropics. Green house effect is one of chief causes of climate change on earth. The greenhouse effect is a process by which thermal radiation from earth's surface is absorbed by atmospheric greenhouse gases (GHG) and is re-radiated in all directions, the main greenhouse gases in the earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone. Since part of this re-radiation is back towards the surface, it results in an elevation of the average surface temperature above normal. The greenhouse effect plays an important role in regulating the climate of the earth. In the absence of this greenhouse effect earth's surface temperature would be far below freezing. However, an increase of these GHGs could result in increased trapping of heat and rising global temperatures.

Carbon dioxide the Primary Culprit

Carbon dioxide (CO_2) is one of the important GHGs which contribute to this change in climate. The concentration of carbon dioxide (CO_2) in Earth's atmosphere has reached 395 ppm (parts per million) by volume as of June 2012. The current level is the highest in the past 650,000 years. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change concludes, "that most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." Natural sources of atmospheric carbon dioxide include volcanic outgassing, the combustion of organic matter, wildfires and the respiration processes of living aerobic organisms; man-made sources of carbon dioxide include the burning of fossil fuels for heating, power generation and transport, as well as some industrial processes. It is also produced by various microorganisms from fermentation and cellular respiration. Plants convert carbon dioxide to carbohydrates during a process called photosynthesis. They gain the energy needed for this reaction through the absorption of sunlight by pigments such as chlorophyll. The resulting gas, oxygen, is released into the atmosphere by plants, which is subsequently used for respiration by heterotrophic organisms and other plants, forming a cycle. Most sources of CO_2 emissions are natural, and are balanced to various degrees by natural CO_2 sinks. For example, the natural decay of organic material in forests and grasslands and the action of forest fires results in the release of about 439 gigatonnes of carbon dioxide every year, while new growth entirely counteracts this effect, absorbing 450 Gigatons per year. Although the initial carbon dioxide in the atmosphere of the young earth was produced by volcanic activity, modern volcanic activity releases only 130 to 230 Mt of carbon dioxide each year, which is less than 1 per cent of the amount released by human activities (at approximately 29,000 Mt). These natural sources are nearly balanced by natural sinks, physical and biological processes which remove carbon dioxide from the atmosphere. For example, some is directly removed from the atmosphere by land plants for photosynthesis and it is soluble in water forming carbonic acid. There is a large natural flux of CO_2 into and out of the biosphere and oceans. In the pre-industrial era these fluxes were largely in balance. Currently about 57 per cent of human-emitted CO_2 is removed by the biosphere and oceans. The ratio of the increase in atmospheric CO_2 to emitted CO_2 is known as the airborne fraction; this varies for short-term averages but is typically about 45 per cent over longer (5 year) periods. Estimated carbon in global terrestrial vegetation increased from approximately 740 billion tons in 1910 to 780 billion tons in 1990. While CO_2 absorption and release is always happening as a result of natural processes, the recent drastic rise in CO_2 levels in the atmosphere is known to be entirely due to human activity such as burning fossil fuels like coal and petroleum which is the leading cause



of increased anthropogenic CO_2; deforestation is the second major cause, as a result, carbon dioxide has gradually accumulated in the atmosphere, and as of 2009, its concentration on is 39 per cent above pre-industrial levels. Carbon dioxide has deleterious long-term effects on climate change that are largely irreversible; hence it is important to check the increase in CO_2 concentration in order to combat climate change.

Natural Variability and Climate Change

The climate varies naturally from one year to the next. Climate can also vary on much longer timescales, from decades to centuries. Climate change refers to the shift in the mean state of a particular climate parameter, such as temperature or precipitation. Natural climate variability refers to the variation in climate parameters caused by other than human forces. There are two types of natural variability the first type are those that are external and those that are internal to the climate system. Variations in the Sun, volcanic eruptions, and changes in the orbit of the Earth around the Sun exert an external control on climate variability. These processes are the driving force behind changes that occur over long time periods, such as oscillations between ice ages and interglacial periods. On the other hand, natural variability is also influenced by processes internal to the climate system that arise, in part, from interactions between the atmosphere and ocean, such as those occurring in the tropical Pacific Ocean during an *El Nino* event. These changes occur over shorter time periods, from months to decades. In any given year, natural variability may cause the climate to be different than its long-term average. The Intergovernmental Panel on Climate Change (IPCC) uses the phrase “climate change” to refer to any climate change that has occurred or will occur, whether from natural variability or human activity. In popular use, however, the phrase is often synonymous with the phrase “global warming,” which is used to describe the world’s ongoing temperature rise as it relates to society’s emissions of greenhouse gases.

Interconnected Factors in Climate Change

The climate system is interconnected and contains relationships in which an event in one geographic area causes changes in another area, which may be a long distance away. The best example for this is the *El Nino* effect. These long distance interconnections are a natural consequence of the chaotic atmospheric system but have a recurring pattern that can be observed over periods of weeks to years. Although many interconnections have been recognized, combinations of only a small number of patterns can account for much of the interannual variability in the climate. These natural cycles create variability in the weather and climate that at times may accentuate the warming caused by the enhanced greenhouse effect or may suppress, and even override, human-caused warming. El Nino-Southern Oscillation (ENSO) is the most important source of interannual connections across the globe and causes large changes in climate. It is characterized by a temperature change in tropical Pacific sea surface temperatures that alters the strength and direction of atmospheric trade winds. In addition to this radiative effects are also envisaged. Radiative effects measures the influence that climate-altering factors have on the energy balance of the earth. Examples of factors that can alter the Earth’s energy balance include atmospheric concentrations of greenhouse gases, aerosols from volcanoes and air pollution, and the amount of solar radiation delivered to the Earth by the Sun.

Observed Climate Change Impacts

Rising temperatures due to increasing greenhouse gas concentrations have produced distinct patterns of warming on Earth’s surface, with stronger warming over most land areas and in the Arctic. There have also been significant seasonal differences in observed warming. Global warming is also having a significant impact on snow and ice, especially in response to the strong warming across the Arctic. It has been observed that snow and ice are melting and frozen ground is thawing, hydrological and biological systems are changing and in some cases being disrupted, migrations are starting earlier, and species' geographic ranges are shifting towards the poles. For terrestrial biological systems, changes documented in the database include shifts in spring events (*e.g.*, earlier leaf unfolding, blooming date, migration, and timing of reproduction), species distributions, and community structure. Because CO_2 reacts in seawater to form carbonic acid, the acidification of the world's oceans is another certain outcome of elevated CO_2 concentrations in the atmosphere. Extreme weather includes unusual, severe or unseasonal weather; weather at the extremes of the historical distribution-the range that has been seen in the past. Often, extreme events are based on a location's recorded weather history and defined as lying in the most unusual ten percent. In recent years some extreme weather events have been attributed to human-induced global warming, with studies indicating an increasing threat from extreme weather in the future. Although it is difficult to attribute the cause of any one event to global warming, there is solid theoretical justification for expecting the frequency and/or magnitude of some extreme events to increase in the future. It is also likely that while some events will become more common and powerful, others will become less frequent and intense, like in the temperature example mentioned above.

Local Climate Change

The effects of global warming on the Indian subcontinent vary from the submergence of low-lying islands and coastal lands to the melting of glaciers in the Indian Himalayas, threatening the volumetric flow rate of many of the most important rivers of India and South Asia. In India, such effects are projected to impact millions of lives. As a result of ongoing climate change, the climate of India has become increasingly volatile over the past several decades; this trend is expected to continue. Climate change is impacting the natural ecosystems and is expected to have substantial adverse effects in India, mainly on agriculture on which 58 per cent of the population still depends for livelihood, water storage in the Himalayan glaciers which are the source of major rivers and groundwater recharge, sea-level rise, and threats to a long coastline and habitations. Climate change will also cause increased frequency of extreme events such as floods, and droughts.

Extreme Heat

India is already experiencing a warming climate, unusual and unprecedented spells of hot weather are expected to occur far more frequently and cover much larger areas. Under 4°C warming, the west coast and southern India are projected to shift to new, high-temperature climatic regimes with significant impacts on agriculture.

Changing Rainfall Patterns

A decline in monsoon rainfall since the 1950's has already been observed. The frequency of heavy rainfall events has also increased. A 2°C rise in the world's average temperatures will make India's summer monsoon highly unpredictable. At 4°C warming, an extremely wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century. An abrupt change in the monsoon could precipitate a major crisis, triggering more frequent droughts as well as greater flooding in large parts of India. India's northwest coast to the south eastern coastal region could see higher than average rainfall. Dry years are expected to be drier and wet years wetter.

Droughts

Evidence indicates that parts of South Asia have become drier since the 1970s with an increase in the number of droughts. Droughts have major consequences. In 1987 and 2002-2003, droughts affected more than half of India's crop area and led to a huge fall in crop production. Droughts are expected to be more frequent in some areas, especially in north-western India, Jharkhand, Orissa and Chhattisgarh. Crop yields are expected to fall significantly because of extreme heat by the 2040's.

Ground Water

At 2.5°C warming, melting glaciers and the loss of snow cover over the Himalayas are expected to threaten the stability and reliability of northern India's primarily glacier-fed rivers, particularly the Indus and the Brahmaputra. The Ganges will be less dependent on melt water due to high annual rainfall downstream during the monsoon season. The Indus and Brahmaputra are expected to see increased flows in spring when the snows melt, with flows reducing subsequently in late spring and summer. Alterations in the flows of the Indus, Ganges, and Brahmaputra rivers could significantly impact irrigation, affecting the amount of food that can be produced in their basins as well as the livelihoods of millions of people (209 million in the Indus basin, 478 million in the Ganges basin, and 62 million in the Brahmaputra basin in the year 2005).

Climate Change and Indian Agriculture

Agricultural productivity is sensitive to two broad classes of climate-induced effects, one is the direct effects due to changes in temperature, precipitation, and carbon dioxide concentrations and the other is the indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases. The main direct effect is generally seen on the duration of the crop. Duration of crop growth cycles are related to temperature. Therefore an increase in temperature will speed up development. In the case of an annual crop, the duration between sowing and harvesting will shorten, for example, the duration in order to harvest a maize crop could shorten between one and four weeks. The shortening of such a cycle could have an adverse effect on productivity because senescence would occur sooner. In India impact of 1-2^{o}C increase in mean air temperature is expected to decrease rice yield by about 0.75 t/ha in efficient zones and 0.06 t/ha in coastal regions and impact of 0.5^{o}C increase in winter temperature is projected to reduce wheat yields by 0.45 t/ha. Furthermore, crops may experience both low and high weather extremes like drought and flood, heat and chilling etc. in a single cropping season and such changes will have varying and complex impacts on agricultural production. Reductions in yields as a result of climate change are predicted to be more pronounced for rainfed crops in comparison with irrigated crop and under limited water supply situations because there are no coping mechanisms for rainfall variability. Crop growth and yield can be impaired in diverse ways by either high day or high night temperatures and in addition, to this soil temperatures also play an important role in the response of crops to heat stress (Table1.1). Additional challenge to temperature increase stems from the fact that higher temperatures will increase the rate at which plants lose moisture resulting in increased transpiration and water loss. Temperature affects the stages of development of crops during its progress to physiological maturity, the main stages in food grain crops that are sensitive to temperature are (i) germination (ii) canopy and leaf area development (iii) flowering and reproductive development (v) grain development - anthesis to maturity. In Eastern regions of India it is predicted that crops will be most impacted by increased temperatures and decreased radiation, resulting in relatively fewer grains and shorter grain filling durations. However, the potential reductions in yields due to increased temperatures in Northern India can be caused by higher radiation which can induce decreased photosynthesis and increased transpiration and stomatal conductance. On the other hand, Increased CO_2 is expected to have positive physiological effects by increasing the rate of photosynthesis and elevated CO_2 causes crops to produce more number of mesophyll cells and chloroplasts as well as longer stems and extended large roots with altered branching patterns, but this may increase the need for fertilizers and may not be a very desirable effect. Studies at Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad with various rainfed cereals, pulses and oilseed crops at elevated levels of CO_2 in open top chambers revealed that the genetic variability was highest in pulses followed by cereals. Similarly the response of pulses for elevated CO_2 was more favourable followed by cereals. Pulses recorded the highest response of total biomass and the response was significantly high for root biomass, whereas the response was highest for leaf biomass in cereal crop.

Agricultural production in India will be adversely affected not only by an increase or decrease in the overall amount of rainfall, but also by shifts in the timing of the rainfall. The best example for this has been seen in Chhattisgarh region which received less than its share of pre-monsoon showers. These showers are important to ensure adequate moisture in fields being prepared for paddy cultivation. Effects will also be seen in the coastal regions of Gujarat and Maharashtra, where fertile areas are vulnerable to inundation and salinisation. Standing crops in these regions are also more likely to be damaged due to cyclonic activity. In Rajasthan, a rise in temperature by 2°C was estimated to reduce production of pearl millet by 10-15 per cent.

Further, climate change will indirectly affect crop productivity by changing pest and disease dynamics. Direct effects of pathogens or other organisms can be the induction of resistance or susceptibility and its associated cost or benefit to the host plant. The likelihood of most damaging impacts of diseases and pest can be expected in especially cereals like wheat and rice. These are likely to have a large impact in terms of food security under climate change scenarios as seen in the case of wheat. Changes in levels of CO_2, ozone and UV-B will have an influence on diseases by modifying host physiology and resistance mechanisms. Furthermore, changes in temperature, precipitation and the frequency of extreme events will influence disease epidemiology. An acute change that may arise in the host as an outcome of climate change and the subsequent indirect effects on the pathogen is a possible outcome. Changes in geographical distribution will possibly alter the comparative importance and range of diseases and may give rise to new disease complexes. Evolution of pathogen populations may hasten from enhanced UV-B radiation and increased fecundity under elevated CO_2. Consequently, host resistances may be overwhelmed more swiftly, specifically increases in leaf waxes and epidermal thickness as a result of increased CO_2 atmospheres can result in the host exhibiting higher physical resistance to some pathogens. Carbon dioxide induced alterations in the architecture of a crop, could lead to increased humidity inside the canopy and can create additional favourable condition for pathogen survival. In addition to this High speed winds and cyclones can contribute to increased dispersal of airborne plant pathogens such as rusts, splash-borne pathogens such as bacteria, and windborne insects and vectors such as aphids and psyllids.

Table 1.1 Vulnerability of crop production to possible effects of climate change in India

Crops / Regions	Possible effects
Wheat	Decline of 600-650 grains m^{-2}
Rice Wheat Northern India and Coastal regions	• 2^0C increase in mean temperature could decrease rice yield by about 0.75 ton/ha in high yield areas and 0.06 ton/ha in the low yield coastal regions. • 0.5^0C increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 ton/ha, and 10 per cent reduction in wheat production in the high yield states of Northern India.
Rice- irrigated yield -Uttarakhand	Pantnagar-Uttarakhand-rice production would be positive in the absence of nutrient and water limitation
Wheat at three levels of Production (potential, irrigated and rain fed) - Northern India	• Wheat yield at all three levels of production (potential, irrigated and rain fed) increased significantly. • Northern India, a 1^0C rise in mean temperature had no significant effect on potential yield but irrigated and rainfed yields increased in most places. • An increase of 2^0C, reduces potential wheat yields at most places • The effect on irrigated and rainfed productivity varied with location • Evapotranspiration reduced in irrigated as well as rainfed environments

Crops / Regions	Possible effects
Wheat	Wheat yield decreased due to the adverse effect of temperature during filling and maturity stages of the growth
Wheat at three levels (potential, irrigated and rainfed) - Northern India, Central India, High latitudes, lower latitude, tropical, subtropical	• At 425 ppm CO_2 and no rise in temperature, grain yield at all levels of production increased significantly at all places. • 1^0C rise in mean temperature, no significant effect on potential yields, Irrigated yields increased in most places where current yields were greater than 3.5 t/ha. Significant Rainfed yields • 2^0C rise, reduced potential yield at most places. Less magnitude at places with low potential productivity • Sub-tropical region (above 23^0N), decrease of 1.5 to 5.8 per cent) but in tropical locations the decrease was 17-18per cent • High latitudes (above 27^0N)-slightly increased, lower latitude-High decreased • No significant effect of climate change in Northern India but yields were reduced in Central India by 10-15 per cent
Sorghum (Jowar) in three diverse Sorghum growing regions, *i.e.*, Hyderabad, Akola and Solapur	• In Hyderabad and Akola, yield declined in rainy season Sorghum • Post rainy season sorghum at Solapur on stored soil water showed a marginal increase in yield. • The positive effects of CO_2 were neutralized by adverse effects of increase in temperature resulting in shortened crop growing season.
Rice	• Predicted increase in rice production under the GCM (Global Circulation Model) scenario • This is due to increase in yield of main season crops where the fertilizing effect of the increased CO_2 is able to compensate the crop for any detrimental effects of increased temperature • However large decreases were predicted for second season crops due to high temperature but overall impact on rice production is low as relatively low proportion of total rice produced in this season
Brassica crop (an oilseed crop), in the Northern belt of the Indian subcontinent	The production of *Brassica* crop is likely to increase and is likely to extend to some more relatively drier regions than where it is grown presently.
Wheat, rice, maize and groundnut in Punjab using crop simulation model	• Reduce grain yield of studied crops (increase of 1, 2 and 3^0C) • Wheat: reduction by 8.1, 18.7 and 25.7 per cent respectively • Rice: reduction by 5.4, 7.4 and 25.1 per cent respectively • Maize: reduction by 10.4, 14.6 and 21.4 per cent respectively • Groundnut seed yield: reduction by 8.7, 23.2 and 36.2 per cent respectively
Vulnerability of wheat and rice crops -Northwest India -through sensitivity experiments	Northwest India Doubling CO_2: Rice and Wheat- yield of rice and wheat increased significantly (15 and 28 per cent respectively), however 3^0C temp for wheat and 2^0C temperature for rice cancelled out the positive effects of increased CO_2
Rice, India	• Impact: 3.94 per cent during 1966-84 and 10.6 per cent during 1985-98 • Reduction of ABC and GHG, increase in rice-6.18 per cent and 14.4 per cent

Crops / Regions	Possible effects
Sorghum	• Observed increased temperature would decrease the Sorghum yields in present day condition • Increase in temperature by 1 and 2^0C, Sorghum yields decrease by 7 to 12 per cent, further temperature increase, drastically reduced the yields by 18 to 24 per cent . There is no large interaction effect between yearly climatic variation and increase in temperature as the decline of production was proportional to the increase in temperature in most years. • Increase in 50 ppm CO_2-only 0.5 per cent increase in yield, but this was nullified when the temperature Increased only by 0.08^0C. • The beneficial effect of 700 ppm CO_2 was nullified by an increase of only 0.9^0C temperature
Chickpea Pigeon pea	*Chickpea* • Observed temperature increase of up to 2^0C did not influence potential yield of chickpea. Pre-anthesis and total crop duration reduced by 10-12 days with 20C rise of temperature • Irrigated yield increased with temperature rise up to 2^0C crop duration reduced by only 4 days • Nitrogen uptake and total water use (as evapo-transpiration) were not significantly different up to 2^0C rainfed crop yield was much lower but the effect of temperature rise on crop growth processes and yield were same as observed in irrigated crop • increase in CO_2-increased yield under potential, irrigated and rainfed conditions *Pigeon pea* • 1^0C increase in temp has great impact on Pigeon pea production
Soybean Central India	• Doubling of CO_2 will lead to 50 per cent increase in Soybean yield in central India while 3^0C temp almost wipes out the positive effect of doubling of CO_2 by reducing the duration of crop and inducing early flowering and shortening the grain fill period • decline in daily rainfall amount by 10 per cent restricts the grain yield to about 32 per cent • In future, in spite of elevated CO_2, acute water shortage due to dry spell in monsoon could be a critical factor for the Soybean productivity
Maize Irrigated and rainfed	• Rise in temperature decreased the maize yield in both irrigated and rainfed conditions • CO_2 350 ppm, yield decrease continuously with temperature rise till 4^0C where the yield decreased by about 30 per cent over the present day condition • At CO_2 700 ppm, maize yield increase by about 9 per cent over the present day condition but rise in temperature decreases the yield (8 per cent yield decrease per rise of 1^0C in temperature • The effect of elevated CO_2 is lower in the case of Maize as compared to wheat, chickpea and mustard crop • The beneficial effect of 700 ppm CO_2 was cancelled out by rise of only 0.6^0C temperature • IPCC scenario, (rise of 1.8^0C temp for India and 425 ppm CO_2 by the year 2030), potential maize yield would be severely affected by about 18 per cent
Rice Kerala Sensitivity experiment	• Rise in CO_2 leads to increase in rice production in Kerala due to fertilisation effect and also enhances water use efficiency • Tested up to 5^0C temp, there is a continuous decline in rice yield • For 1^0C temp increase there is decline in production of about 6 per cent.

Crops / Regions	Possible effects
Farm level net revenue	• Increase in 2^0C temperature and 7 per cent increase in precipitation are negative and about 8.4 per cent of the total farm level net-revenue for India • Northern State like Haryana, Punjab, Western Uttar Pradesh where wheat is dominant crop in winter experience most negative effects along with coastal districts of Tamil Nadu • However, the Eastern district of West Bengal and part of Bihar seem to benefit from the changes in future
Rice Central, South and Northwest India	• Middle of the 21^{st} Century in central and south India, rice production will increase • Under climate change, Northwest rice production would decrease significantly under irrigated condition as a result of decrease in rainfall during monsoon season • Reduction in crop duration may occur at all location in India due to increase in temperature associated with the build-up of GHGs in the atmosphere
Rice Northern, Southern, Western and Eastern India -Current level of management (150 Kg) N/ha doses and frequent Irrigation	• Without increase in CO_2 and Rise in temperature of $1\text{-}2^0C$ and, showed a decrease of 3-17 per cent in rice production in different regions • Extent of effect of temp rise on Rice production: • Eastern and Western: Less affected • Northern: Moderate • Southern: Severely affected • With CO_2 increase: production increased in all regions • Doubling CO_2: 12-21 per cent increase in production in different regions • Beneficial effect of 450 ppm CO_2 was nullified by an increase of $1.9\text{-}2^0C$ in Northern and eastern regions and by $0.9\text{-}1^0C$ in Southern and Western regions • Increase of 1-40 temp without increase in CO_2: 5-30 per cent decrease in grain yield in different regions • A 28-35 per cent increase in yields of rice as CO_2 doubled • The beneficial effect of 450 ppm CO_2 was nullified by an increase of $1.2\text{-}1.7^0C$ in Northern and Eastern regions and by $0.9\text{-}1^0C$ in Southern and Western regions

Source: The Institute for Social and Economic Change, Bangalore

Climate Change and Rainfed Agriculture

There is now adequate evidence about the impending climate change and the consequences thereof. The fourth assessment report of IPCC observed that 'warming of climate system is now unequivocal, as is now evident from observations of increases in global air and ocean temperatures, widespread melting of snow and ice, and rising global sea level. Though climate change is global in its occurrence and consequences, it is the developing countries like India that face more adverse consequences.

Climate change projections made up to 2100 for India indicate an overall increase in temperature by $2\text{-}4^0C$ with no substantial change in precipitation quantity (Table 1.2). However, different regions are expected to experience differential change in the amount of rainfall in the coming decades. The Western Ghats, the Central Indian and North Eastern parts of the country are projected to receive higher amount of rainfall. Another significant aspect of climate change is the increase in the frequency of occurrence of extreme events such as droughts, floods and cyclones. All these changes will have adverse impacts on climate sensitive sectors such as agriculture, forest and coastal ecosystems and also on availability of water for agriculture.

Table 1.2 Projected changes in climate in India: 2070-2099

Region	January - March	April - June	July – Sept.	October – Dec.
Change in temperature (^{0}C)				
Northeast	4.95	4.11	2.88	4.05
Northwest	4.53	4.25	2.96	4.16
Southeast	4.16	3.21	2.53	3.29
Southwest	3.74	3.07	2.52	3.04
Change in precipitation (per cent)				
Northeast	-9.3	20.3	21.0	7.5
Northwest	7.2	7.1	27.2	57.0
Southeast	-32.9	29.7	10.9	0.7
Southwest	22.3	32.3	8.8	8.5

Source: Kavikumar (2010)

Within agriculture, it is the rainfed agriculture that will be most impacted for two reasons. First, rainfed agriculture is practiced in fragile, degraded and slopy lands which are thirsty as well as hungry and prone to erosion. Second, the people dependent on rainfed agriculture are also less endowed in terms of financial, physical, human and social capital limiting their capacity to adapt to the changing climate.

The following are some of the challenges that the changing climate will pose to rainfed agriculture:

Temperature is an important weather parameter that will affect productivity of rainfed crops. Last three decades saw a sharp rise in all India mean annual temperature. Though most rainfed crops tolerate high temperatures, rainfed crops grown during *rabi* are vulnerable to changes in minimum temperatures. Analysis of data for the period 1901-2005 by IMD suggests that annual mean temperature for the country as a whole has risen to 0.51^{o}C over the period. It may be mentioned that annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across the country, over a larger part of the data set. However, since 1990, minimum temperature is steadily rising and rate of rise is slightly more than that of maximum temperature. Apart from direct impacts, higher temperatures also increase the water requirements of crops putting more pressure on the availability of water.

According to Indian Meteorological Department (IMD), no significant trend is observed in the summer monsoon rainfall over the country on all India basis. However, significant changes were noted at the sub-divisional level. Three sub divisions, *viz.,* Jharkhand, Chhattisgarh and Kerala show significant decreasing trend and eight subdivisions *viz.,* Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka show significant increasing trends. A study carried out by CRIDA based on rainfall trends from 1901-2004 indicated that significant increase in rainfall is likely in West Bengal, Central India, Coastal regions, south Western Andhra Pradesh and Central Tamil Nadu. Significant decreasing trend was observed in central part of Jammu and Kashmir, northern MP, central and western part of UP, northern and central part of Chhattisgarh (Fig 1.1). In some areas, both the rainfall and number of rainy days are decreasing which is a cause of concern. It is to be noted here that the negative deviations in the monsoons are accompanied by a fall in food grain production in India.

The extent to which rainfall and temperature patterns and the intensity of extreme weather events will be altered by climate change remains uncertain, although there is growing evidence that future climate change is likely to increase the temporal and spatial variability of temperature and precipitation in many regions (IPCC, 2007). More than seasonal rainfall, the distribution is more important for dryland crops grown during *kharif*. Long dry spells have significant negative impact on fodder and grain production indirectly affecting the livestock production. Extreme events such as cold waves, heat waves, floods and high intensity single day rainfall events are on increasing trend during the last decade. For example, the 2002 drought across the country during *kharif*, the heat wave of May 2003 in AP, extreme cold winter in North during 2002-03, prolonged dry spell during July in 2004, abnormal temperatures during March, 2004 and January, 2005 in North, floods during 2005, cold wave during 2005-06, unusual floods in Rajasthan desert and drought in North-East 2006 and abnormal temperatures during January-February, 2007 in North and country wide drought during 2009 and floods in Andhra Pradesh and Karnataka are some extreme weather events which had significantly impacted agriculture.

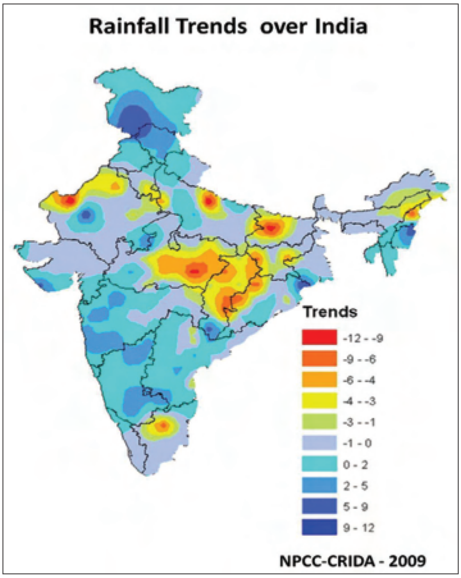


Fig. 1.1 Rainfall trends over India from 1901 to 2004

Source: CRIDA Annual report (2009-10)

To sum up, expansion of rainfed agriculture as more and more regions become arid and semi-arid, increased risk of crop failures and climate-related disasters and decreased yields are the important challenges that the changing climate will lead to. These will result in further deepening of poverty and food insecurity and loss of livelihoods in the rainfed regions.

Conclusions

Even though climate change in India is now a reality, a more certain assessment of the impacts and vulnerabilities of agriculture sectors including livestock and fisheries is needed. A comprehensive understanding of adaptation options across the full range of warming scenarios and regions would go a long way in preparing the nation for climate change. A multi pronged strategy of using indigenous coping mechanisms, wider adoption of the existing technologies and or concerted Research and Development efforts for evolving new technologies are needed for adaptation and mitigation. Policy incentives will play crucial role in adoption of climate ready technologies in all sectors. The state agricultural universities and regional research centres will have to play major role in adaptation research which is more region and location specific while national level efforts are required to come up with cost effective mitigation options, new policy initiatives and global cooperation.

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Chapter 2

Agroforestry in Indian Perspective

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Introduction

Agroforestry plays a vital role in the Indian economy by way of tangible and intangible benefits. In fact, agroforestry has high potential for simultaneously satisfying three important objectives *viz.*, protecting and stabilizing the ecosystems; producing a high level of output of economic goods; and improving income and basic materials to rural population. It has helped in rehabilitation of degraded lands on one hand and has increased farm productivity on the other. At present agroforestry meets almost half of the demand of fuel wood, 2/3 of the small timber, 70-80 per cent wood for plywood, 60 per cent raw material for paper pulp and 9-11 per cent of the green fodder requirement of livestock, besides meeting the subsistence needs of households for food, fruit, fiber, medicine etc. Agroforestry is also playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular. Changing priorities in avenues like green energy, employment generation, carbon sequestration and optimization of farm productivity are now being focused through agroforestry. It is also realized that agroforestry is the only alternative to meet the target of increasing forest cover to 33 per cent from the present level of less than 25 per cent. A major role for agroforestry in near future will be in the domain of environmental services such as climate change mitigation (carbon sequestration), phytoremediation, watershed protection and biodiversity conservation, and above and all in meeting the targets of reducing the emission intensity through creation of additional carbon sink for carbon di-oxide by increasing tree and forest cover as per INDC by 2030. However, this will need the development of mechanism to reward the rural poor for the environmental services that they provide to society.

Agroforestry has traditionally been a way of life and livelihood in India for centuries. The origin of agroforestry practices in India *i.e.* growing trees with food crops, grasses and other components is believed to have started during *Vedic* era, though agroforestry as a science evolved in recent years. The long history and diversity of agroforestry system and practice in the country have been widely reviewed (Tejwani, 1994; Pathak *et al.*, 2000; Sharda *et al*., 2001; Prasad and Dhyani, 2010; Kumar *et al.*, 2012.) Agroforestry is now understood as a science of designing and developing integrated self sustainable land management systems which involve introduction and /or retention of woody components such as trees, shrubs, bamboos, canes, palms along with agricultural crops including pasture/ animals, simultaneously or sequentially on the same unit of land and time, to satisfy the ecological as well as socio-economic needs of the people (Dhyani *et al*., 2009). The commonly used definition of agroforestry is “Agroforestry is a collective name for land use system in which woody perennials (tree, shrubs etc.) are grown in association with herbaceous plants (crops, pastures) or livestock, in spatial arrangement, a rotation or both; there are usually both ecological and economic interactions between the trees and other components of the system” (Lundgren, 1982). In general there are 4 or 5 basic sets of components which are managed in all agroforestry system. Structurally, the system can be grouped as:

1. Agrisilviculture system
2. Agrihorticulture system
3. Silvipastoral system
4. Agri-silvipastoral system
5. Other or specialized systems

On the basis of nature of components the following are common agroforestry systems found in different agro-ecological regions of India:

1. Agrisilviculture (trees + crops)
2. Boundary plantation (tree on boundary + crops)
3. Block plantation (block of tree+ block of crops)
4. Energy plantation (trees + crops during initial years)
5. Alley cropping (hedges + crops)
6. Agrihorticulture (fruit trees + crops)
7. Agrisilvihorticulture (trees + fruit trees + crops)
8. Agrisilvipasture (trees + crops + pasture or animals)
9. Silvi-Olericulture (tree + vegetables)
10. Horti-Pasture (fruit trees + pasture or animals)
11. Horti-Olericulture (fruit tree + vegetables)
12. Silvi-Pasture (trees + pasture/animals)
13. Forage Forestry (forage trees + pasture)
14. Shelter-belts (trees + crops)
15. Wind-breaks (trees + crops)
16. Live Fence (shrubs and under- trees on boundary)
17. Silvi or Horti-sericulture (trees or fruit trees + sericulture)
18. Horti-Apiculture (fruit trees + honeybee)
19. Aqua-Forestry (trees + fishes)
20. Homestead (multiple combinations of trees, fruit trees, vegetable etc).

Agroforestry Research in India

Agroforestry research in India is more than 100 years old. However, agroforestry was incorporated into national agricultural and forestry research agendas when ICAR launched an All India Coordinated Research Project (AICRP) on Agroforestry with 20 centers in 1983 followed by the establishment of National Research Centre on Agroforestry (NRCAF) on 8th May, 1988 at Jhansi, U.P. The Centre is now upgraded as Central Agroforestry Research Institute (CAFRI) from 1st December, 2014. At present there are 37 centers of AICRP on Agroforestry located in 27 State Agricultural Universities (SAUs), 09 in ICAR and 01 in ICFRE Institutes representing all agro-climates of the country. In addition to ICAR, Indian Council of Forestry Research and Education (ICFRE) also conducts agroforestry research through its research institutes and advanced research centers in different parts of the country (ICFRE 2011). Recognizing agroforestry as a viable venture, many business corporations, limited companies such as ITC, WIMCO, West Coast Paper Mills Ltd., Hindustan Paper Mills Ltd., and other institutions initiated agroforestry research with emphasis on production of improved planting material of the fast growing species (Dhyani *et al.*, 2015) with an objective to meet the demand of wood based industries. The agroforestry research through the AICRP on Agroforestry was conceptualized with the following six projects:

i Diagnostic survey and appraisal of existing farming system and agroforestry practices including farmers' preference.

ii Collection and evaluation of promising tree species, cultivars of fuel, fodder and small timber for agroforestry interactions.

iii Studies on management practices of agroforestry systems.

iv Analyze economical relation of agroforestry systems.

v Explore the role of agroforestry in environment protection, and

vi Studies on post-harvest technology, fishery, apiculture, lac, etc. in relation to agroforestry systems.

The diagnostic survey and appraisal of existing agroforestry practices in the country revealed that there are a number of agroforestry practices prevalent in different agro-ecological zones (Table 2.1). The survey indicates that agroforestry systems or practices are widely based on nature and arrangement of the components and ecological or socio-economic criteria. In the documented agroforestry practices trees serve as wind breaks and shelterbelts, delineate boundaries, and provide shade, ornamentation and seclusion around homesteads. They supply not only poles, stakes, timber and fuel, but also cash crops, fodder, fruits and nuts, dyes, gums, resins, fiber and medicines. Fodder and food trees provide balanced diets during dry seasons, when other foods are scarce. Trees, with their deep rooting systems, consume moisture and nutrients from higher depth in the soil than arable and pastoral crops, and thus there is least competition among the different components. Thus the value of trees on farmland may considerably exceed than that offered by woodlands and plantations (Singh, 1987).

The second major thrust of the agroforestry research was collection and evaluation of promising tree species/ cultivars of fuel, fodder and small timber. A large germplasm of important agroforestry trees has been collected and evaluated in arboretum established by the Centers of the AICRP (Handa *et al.*, 2015). About 184 promising tree species have been determined based on growth performance trials at these centers. The results indicate that the safest choice of agroforestry species have come from the native vegetation, which has a history of adaptation to local precipitation regimes. There are a number of tree crop combinations, which in turn reflect the differences in the climates and soil fertility of various regions in the country. The examples of major trees in agroforestry practices are (1) *Grewia optiva*, *Ulmus wallichiana*, *Morus alba* and *Robina pseudoacacia* in Western Himalayan region; *Acacia auriculiformis, Alnus nepalensis,* Bamboos, *Parasarianthes falcataria* and *Gmelina arborea* for Eastern Himalayan region; (2) Poplars, *Eucalyptus*, *Acacia* and *Dalbergia sisoo* in Indo-gangetic region: (3) *Dalbergia sissoo, Acacia tortilis, Acacia nilotica*, *Ailanthus excelsa, Prosopis cineraria*, *Leucaena leucocephala* and *Azadirachta indica* for arid and semi arid regions; (4) *Acacia nilotica*, *Prosopis cineraria* and *Ziziphus* in Western India: (5) *Tectona grandis*, *Tamarindus indica,* Para rubber (*Hevea brasilensis*) and cashew nuts: in southern region and (6) *Albizia spp. Gmelina arborea, Gliricidia*, *Acacia auriculiformis*, *Acacia mangium* for humid and sub humid regions; (7) *Artocarpus*, *Pongamia*, *Casuarina equisetifolia, Grevillea robusta* and bamboos in Coastal and Island region. This would correspond to the high rainfall levels and long rainy seasons in the south, with drought periods comparatively longer for the regions to the west, Indo-gangetic and central (Dhyani *et al*., 2003). The efforts made so far has created voluminous database, which is a great strength. The information collected may be utilized for creating local and regional volume tables.

On the basis of identification and evaluation of promising trees and D and D survey of the existing systems, agroforestry interventions were initiated in different agro-climatic regions. Primarily these systems are put in different categories such as agrisilviculture, agri-horticulture, agri-horti-silviculture, hortipastoral, silvipastoral, and specialized systems. Among these systems, agrisilviculture followed by agrihorticulture, are the most prominent being practiced and advocated for the majority of the agroclimatic zones. Home gardens, block plantation, energy plantation, shelterbelts and shifting cultivation are some of the specialized agroforestry systems developed by the research institutions with the knowledge gained by documenting and analyzing the traditional systems (Table 2.2 and 2.3). However the agroforestry systems developed and recommended (Table 2.3) by these institutions are location specific.

Table 2.1 Prominent agroforestry systems in different regions of country

Agroclimatic zone/region	Agroforestry system					
	Agri-silvi-culture	Agri-horti-silvi culture	Agri-horti culture	Horti-pastoral	Silvi-pastoral	Specialized
Western Himalayan	4	4	5	4	4	-
Eastern Himalayan	5	3	5	4	3	Jhum (shifting cultivation)
Lower Gangetic plains	5	-	3	2	2	Energy
Middle Gangetic plains	4	-	2	-	-	Homestead
Upper Gangetic plains	5	-	5	-	-	Agri horticulture
Trans-Gangetic plains	5	-	5	-	-	Agri-horti-silviculture
Eastern plateau and Hills	5	-	4	3	4	Block plantation
Central plateau and Hills	4	-	5	4	4	Block plantation
Western plateau and Hills	4	-	5	2	4	-
Southern plateau and Hills	5	-	3	2	4	-
East Coast plateau and Hills	4	5	4	4	2	Home garden/ shelterbelt
West Coast plains and Ghats	4	5	4	2	2	Home garden
Gujarat plains and Hills	4	2	4	3	5	Block plantation
Western dry area	5	3	4	-	5	Shelterbelt
The Islands	4	5	4	1	2	Home garden

(Nos. 1-5 indicate the priority practiced mode; 1= least and 5 = highest)
Source: Solanki (2006)

The Research and Development efforts undertaken during the last more than three decades have clearly demonstrated the potential of agroforestry for resource conservation, improvement of environmental quality, rehabilitation of degraded lands and providing multiple outputs to meet the day to day demand of the rural population (Dhyani *et al.*, 2008). The current area under agroforestry in India is estimated as 25.32 Mha, or 8.2 per cent of the total geographical area of the country (Dhyani *et al*., 2013). As such on an average 14.19 per cent of total cultivated land has agroforestry in one form or other, which includes 11.23 per cent in irrigated and 16.54 per cent in rainfed areas. The accurate assessment of area under agroforestry systems in different agro-climatic regions of India is being done with integrated use of spatial technologies like, Geographical Information System (GIS), Remote Sensing (RS) and Geographical Positioning System (GPS). The methodology (Rizvi *et al.*, 2011) developed is being tested/replicated under National Initiative of Climate Resilient Agriculture (NICRA) project for assessment and estimation of area under agroforestry systems (NRCAF, 2013a).

Agroforestry Contribution

Agroforestry plays a vital role in the Indian economy by way of tangible and intangible benefits. It has helped in rehabilitation of degraded lands on one hand and has increased farm productivity on the other. At present agroforestry meets almost half of the demand of fuel wood, 2/3 of the small timber, 70-80 per cent wood for plywood, 60 per cent raw material for paper pulp and 9-11 per cent of the green fodder requirement of livestock, besides meeting the subsistence needs of households for food, fruit, fiber, medicine etc. Agroforestry is also playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular. Industries have taken up poplar, *Eucalyptus*, bamboos, *Acacia*, *Casuarina*, *Ailanthus* and teak for commercial agroforestry due to their great market potential. Genetically improved clonal planting stock of eucalypts, poplars and acacias has transformed the productivity and profitability of plantations. Average yields from such clonal plantations are 20 to 25 times higher compared to the average productivity of forests in India. Almost 50 million plants of improved *Eucalyptus* are being planted every year (Dhyani *et al.*, 2013). In fact, agroforestry has high potential for simultaneously satisfying three important objectives *viz.*, protecting and stabilizing the ecosystems; producing a high level of output of economic goods; and improving income and basic materials to rural population. Besides, agroforestry is capable of conserving natural resources under different agro-climatic regions and is the only option to increase the forest/tree cover from present less than 25 to 33 per cent in the country.

Constraints in Promotion of Agroforestry

During last more than three decades many agroforestry technologies have been developed and demonstrated by various research organizations. But most of them have not reached to farmer's field for want of awareness, inadequate infrastructure and lack of policy support. Therefore, the desired impact has not been observed in terms of adoption of technology. The major reason for this is that agroforestry sector is disadvantaged by adverse policies, legal constraints and lack of coordination between the government sectors to which it contributes *viz.*, agriculture, forestry, rural development, environment and trade. Absence of appropriate policy and institutional arrangement to provide farmers with clear incentives to plant and protect trees that contribute to both ecosystem function and rural livelihoods is a great hurdle. Existing rules and regulations are greatest obstacles in felling, transport and marketing of agroforestry products and they vary from state to state. Agroforestry has to be declared at par with agriculture in availing credit and other subsidies by poor farmers (Dhyani *et al.*, 2013). The agroforestry technologies have been successful in the areas where farmer's got incentive in terms of quality planting material and assured market for example in case of *Poplar, Leucaena* and *Eucalyptus*. Availability of quality planting material of trees is one of the major concerns and need to be addressed urgently.

Agroforestry and Ecosystem Services

Agroforestry has the potential to provide most or all the ecosystem services. The Millennium Ecosystem Assessment (2005) has categorized the ecosystem services into provisioning service (*e.g.*, fuel-wood, fodder, timber, poles etc.), regulating service (hydrological benefits, micro-climatic modifications), supporting service (nutrient cycling, agro-biodiversity conservation), and cultural service (recreation, aesthetics). Agroforestry is playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular. Agroforestry land use increases livelihood security and reduces vulnerability to climate and environmental change. There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, and carbon sequestration potential of an agroforestry system is generally greater than that of an annual system (Dhyani *et al*., 2009a). Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. It also provides for ecosystem services - water, soil health and biodiversity (NRCAF, 2013b). However, long term studies on quantification of the ecosystems services from agroforestry are yet to be initiated. Some of the contributions of agroforestry for the ecosystem services are presented here.

Agroforestry for Food and Nutritional Security

The country's food production has increased many folds since independence but recent improvements in food supply have been insufficient to fulfill the nutritional needs of the common person in an ever increasing population of the country. Agroforestry with appropriate tree- crop / legume combination is one option in this regard. The different agroforestry systems provide the desired diversification options to increase the food security and act as a insurance against the low production during drought and other stress conditions. Agroforestry also provides nutritional security because of diverse production systems which include fruit, vegetables, legumes, oilseed crops, medicinal and aromatic plants in addition to normal food crops grown by the farmers. With the rapid growth of urbanization and economic growth in the country, farming community have witnessed unprecedented opportunities for moving beyond subsistence farming to supplying products needed by urban population. Agroforestry products such as timber, fruit, food, fiber, fodder, medicine and others are progressively meeting the subsistence needs of households and providing the platform for greater and sustained productivity. Thus, agroforestry systems offer opportunities to farmers for diversifying their income and to increase farm production. Research results from different agroclimatic regions of the country show that financial returns generated from agroforestry systems vary greatly but are generally much higher than returns from continuous unfertilized food crops. The higher returns associated with agroforestry can translate into improved household nutrition and health, particularly when women control the income.

Agroforestry has proven as an important tool for crop diversification. By virtue of diversity of the components of the agroforestry systems like fruits, vegetables, nutritional security to the communities could be ensured. In agroforestry, the potentially higher productivity could be due to the capture of more growth resources e.g. light or water or due to improved soil fertility. The best example is of poplar (*Populus deltoides*) - a popular species in agroforestry system in the Upper Indo-Gangetic region. Poplar was a best choice as it was fast growing, compatible with wheat and other crops and has industrial use. Therefore, poplar (*Populus spp.*) based agroforestry in northern India made rapid strides. Woodlots of other fast growing trees such as *Eucalyptus spp.*, *Leucaena leucocephala, Casuarina equisetifolia, Acacia mangium, Acacia auriculiformis, Ailanthus*, teak and *Melia dubia* are also becoming increasingly popular among the farmers in several parts of the country due to their great market potential.

Agroforestry for Fodder Production

Trees and shrubs often contribute substantial amount of leaf fodder in arid, semi arid and hill regions during lean period through lopping/pruning of trees, popularly known as top feed. The leaf fodder yield depends on species, initial age, lopping intensity and interval as well as agroclimatic conditions. Silvipastoral system is the most appropriate land use system for degraded lands. The top feeds are also considered very important in vegetation stabilization and sustained productivity of rangelands (Dhyani, 2003). They also play an important role as windbreaks and by providing shade for the grazing animal. The important ones are *Prosopis cineraria, Albizia lebbeck. Acacia spp., Leucaena leucocephala, Dalbergia sissoo, Ailanthus excelsa, Azadirachta indica, Acacia leucopholea etc.* for the arid and semi –arid region and *Grewia optiva, Morus alba, Celtis australis, Albizia*, Oaks, *Ficus etc.* for the hilly regions. Bamikole *et al*. (2003) reported that feed intake, weight gain, digestibility and nutrient utilization can be enhanced by feeding *Ficus religiosa* in mixture with *Panicum maximum*, and it can be used in diet mixtures up to 75 per cent of Dry Matter fed. Dagar *et al*. (2001) reported that for silvipastoral system on alkali soils *Prosopis juliflora, Acacia nilotica* and *Tamarix articulata* are the most promising trees and *Leptochloa fusca*, *Chloris gayana* and *Brachiaria mutica* most suitable grasses. *Leptochloa fusca* in association with *Prosopis juliflora* produced 46.5 tha^{-1} green fodder over a period of four years without applying any amendments and fertilizer.

Agroforestry for Energy Security and Biofuel Production

A large part of India's population mostly in rural areas, does not have access to the conventional source of energy even today. The main biomass energy sources in rural areas include wood (from forest, croplands and homesteads), cow dung and crop biomass. Among the sources 70-80 per cent energy comes through biomass from trees and shrubs. Due to the agroforestry initiatives large amount of woods are now being produced from outside the conventional forestlands. Small landholdings and marginal farmers, through short rotation forestry and agroforestry practices are now providing the bulk of country's domestically produced timber products. Ravindranathan *et al*. (1997) reported for a Karnataka village that 79 per cent of all the energy used came mainly from trees and shrubs. *Prosopis juliflora* due to high calorific value of over 5000 Kcal is the major source of fuel for the boilers of the power generation plants in Andhra Pradesh. About Rs.700-1300/t is the price offered for *Prosopis juliflora* wood at factory gate depending on the season and moisture content. An estimated 0.51 Mha area is under *Prosopis juliflora*. Research and Development can help in enhancing productivity and assisting the power plants in captive plantation management on degraded lands. Promoting bioenergy through *Prosopis juliflora* also encourages tremendous employment generation to the tune of 6.34 million man days and 7.03 million woman days for fuel making in Tamil Nadu alone.

The fuel wood potential of indigenous (*Acacia nilotica, Azadirachta indica, Casuarina equisetifolia, Dalbergia sissoo, Prosopis cineraria* and *Ziziphus mauritiana*) and exotics (*Acacia auriculiformis, Acacia tortilis, Eucalyptus camaldulensis* and *Eucalyptus tereticornis*) trees was studied by Puri *et al.* (1994). The calorific value ranges from 18.7 to 20.8 MJ/kg for indigenous tree species and 17.3 to19.3 MJ/kg for exotics. Pathak (2002) opined that species such as *Casuarina equisetifolia*, *Prosopis juliflora, Leucaena leucocephala* and *Calliandra calothyrsus* have become prominent due to their potential for providing wood energy at the highest efficiency, shorter rotation and also their high adaptability to diverse habitats and climates.

Further the Indian scenario of the increasing gap between demand and domestically produced petroleum is a matter of serious concern. In this connection, fuels of biological origin have drawn a great deal of attention during the last two decades. Biofuels are renewable liquid fuels coming from biological raw materials and has proven to be good substitute for oil in the transportation sector as such biofuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The potential tree borne oilseeds (TBOs) holding promise for biofuel are *Jatropha curcas*, *Pongamia pinnata*, *Simarouba*, *Azadirachta indica*, *Madhuca* spp., etc. These biofuel species can be grown successfully under different agroforestry systems (Dhyani *et al.*, 2011).

ICAR institutes *viz.*, Central Agroforestry Research Institute (CAFRI) and Central Institute for Dryland Agriculture (CRIDA) Hyderabad have conducted projects and involved in research on Tree Borne Oilseeds (TBOs) *e.g.*, *Jatropha curcas, Pongamia pinnata* and *Simarouba glauca* since 2003. The National Policy on Biofuels identified sweet sorghum as one of the candidate crops for augmenting biofuel production in the country. ICAR-Indian Institute of Millets Research (IIMR), Hyderabad has been engaged in sweet sorghum research since 1989 and it has developed sweet sorghum varieties and hybrids. ICAR-

Indian Institute of Sugarcane Research (IISR), Lucknow, is engaged in Research and Development for developing biological protocols for ethanol production from sugarcane and sugar beet and maintenance of sugar beet germplasm.

At National level, the Research and Development efforts on TBOs were mainly focused on collection, evaluation and conservation of germplasm, understanding breeding behavior, standardization of nursery and propagation techniques, development of cultivation packages for different soil and climatic conditions. However, at present the Research and Development funding for biofuel is not available. NOVOD which was earlier funding for biofuel research is now closed. The main stumbling block is yield levels of biofuel tree crops and the targeted areas of their cultivation. In India as per BIOFUEL POLICY the cultivation of biofuel species has to be taken up on non-arable lands to avoid food vs. fuel crisis. The existing policies for Research and Development for promoting bioenergy and biofuels do not permit use of edible oilseed and other crops for biofuel production. Production currently limited to first-generation biofuels, namely molasses-derived ethanol and tree-borne oilseed (TBO) biodiesel. Recently the Government of India through 335th Amendment Rules, 2017 allocated Overall coordination concerning bio-fuels to the Ministry of Petroleum and Natural Gas (MoPNG) from earlier Ministry of New and Renewable Energy (MNRE).

Agroforestry for Soil Conservation and Amelioration

Agroforestry plays a key role in keeping the soil resource productive which is one of the major sustainability issues. Closely spaced trees on slopes reduce soil erosion by water through two main processes: first as a physical barrier of stems, low branches, superficial roots and leaf litter against running water and secondly as sites where water infiltrates faster because of generally better soil structure under trees than on adjacent land.

Agroforestry systems on arable lands envisage growing of trees and woody perennials on terrace risers, terrace edges, field bunds, as intercrops and as alley cropping in the shape of hedge row plantation. Integrating trees on the fields act as natural sump for nutrients from deeper layers of soil, add bio-fertilizer, conserve moisture and enhance productivity of the system. The alley cropping with leguminous trees such as *Leucaena leucocephala* has been most widely used on field bunds for producing mulch material for moisture conservation and nutrient recycling. Alley cropping with *Leucaena leucocephala* was effective for erosion control on sloping lands up to 30 per cent. Reduction in crop yield could be minimized by shifting the management of trees to contour hedge rows. The sediment deposition along the hedge and tree rows increased considerably with consequent reduction in soil loss. Inclusion of trees and woody perennials on farm lands can, in the long run, result in marked improvements in the physical conditions of the soil, e.g. its permeability, water-holding capacity, aggregate stability and soil-temperature regimes. Although these improvements may be slow, their net effect is a better soil medium for plant growth. Experimental evidences give a very clear picture about agroforestry system that increased soil organic carbon and available nutrients than growing sole tree or sole crop. An increase in organic carbon, available N, P and K content in Khejri based silvipastoral system over control, advocating retention/plantation of Khejri tree in pasture land to get higher fodder production and to meet requirement of food, fodder, fuel and small timber is one such example. Similarly, an increase in soil organic carbon status of surface soil under *Acacia nilotica* + *Sacchram munja* and under *Acacia nilotica* + *Eulaliopsis binata* after five years was observed. It was found that *Acacia nilotica* + *Eulaliopsis binata* are conservative but more productive and less competitive with trees and suitable for eco-friendly conservation and rehabilitation of degraded lands of Shiwalik foot hills of subtropical northern India. Rehabilitation of degraded forests is possible through afforestation by adopting integrated land use planning with soil and water conservation measures on watershed basis. CAFRI observed that in agrisilviculture growing of *Albizia procera* with different pruning regimes, the organic carbon of the soil increased by 13-16 per cent from their initial values under different pruning regimes which was five to six times higher than growing of either sole tree or sole crop.

Agroforestry systems have been developed using local resources and conservation-based measures in the North Eastern Hill (NEH) region. Suitable alternate land use systems involving agriculture, horticulture, forestry and agroforestry have been designed with the support of local natural resources for almost identical hydrological behavior as under the natural system. Under agri-horti-silvipastoral systems, the reduction in runoff was 99 per cent and in soil loss 98 per cent. Combining fine-root system of grasses and legumes, such as *Stylosanthes guyanensis*, *Panicum maximum*, *Setaria* etc. and deep-root system of fodder trees, such as alder (*Alnus nepalensis*) in a silvipastoral system stabilizes terrace risers and provides multiple outputs. In depth evaluation of soil chemical properties of traditional agroforestry system in northeastern region indicated a spectacular increase in soil pH, organic-C, exchangeable Ca, Mg, K, and build up of avai1able P (Bray's P_2-P) under different agroforestry practices (AFP) within 10-15 years of practice. The exchangeable Al, potential cause of infertility of these lands disappeared completely within 10-15 years of agroforestry practice (Singh *et al.,* 1994; Dhyani *et al.,* 1994).

The use of trees as shelterbelts in areas that experience high wind or sand movement is well-established example of microclimate improvement that resulted in improved yields. Increased agricultural production due to windbreaks and shelterbelts in India has been well demonstrated. Establishment of micro-shelterbelts in arable lands, by planting tall and fast-growing plant species such as castor bean on the windward side, and shorter crop such as vegetables in the leeward side of tall plants helped to increase the yield of lady's finger by 41 per cent and of cowpea by 21 per cent over the control. In general, the use of shelterbelts brought about a 50 per cent reduction in the magnitude of wind erosion. In studies carried out in an agroforestry system, *Acacia tortilis* (7 yr old) and guar crop at Jodhpur indicated that relative humidity recorded beneath the tree canopy during the active cropping season of guar was found to be 7 per cent more than in the open. This will, in turn, help for better growth of the crops.

Agroforestry practices have been developed for arable lands and non-arable degraded lands, bouldery riverbed land, torrent control, landslide and landslip stabilization, abandoned mine-spoil area rehabilitation and as an alternative to shifting cultivation. Also, agroforestry systems have proven their efficacy in prevention of droughts, reclamation of waterlogged areas, flood control, rehabilitation of wastelands, ravine reclamation, sea erosion control, control of desertification and mine-spoil rehabilitation and treatment of saline and alkaline lands. Agricultural use of salt affected lands and water resources increases due to increasing demands of food and fodder is yet another example where agroforestry played great role in enhancing the productivity of land and also address the environmental issues. Removal of salts from the soil surface is neither possible nor practical; therefore attempts have been made to minimize adverse effect of salts on crop by developing agro techniques. Central Soil Salinity Research Institute, Karnal (Haryana) has developed special planting techniques for sodic and saline soil for better establishment and growth of multipurpose trees. The technique ensures more than 80 per cent tree survival even after ten years in highly alkali soil. A study by CAFRI indicated scaling-up of integrated watershed management in drought prone rainfed areas with enabling policy and institutional support would promote equity and livelihood along with strengthening various ecosystem services while reducing poverty and building resilience in semi-arid tropics.

Bio-diversity Conservation through Agroforestry

Agroforestry innovations contribute to bio-diversity conservation through integrated conservation-development approach. Forest degradation has caused immense losses to the bio-diversity, which can be conserved through agroforestry by adopting a strategy of conservation through use. The biodiversity shall help in the development or improvement of new varieties or populations. It will further help in enhancing the availability of improved planting material, which is a key to the increase in productivity and production at farm level. Swaminathan (1983) has pointed out that biodiversity is the feed stock for a climate resilient agriculture. Agroforestry with components like trees, agricultural crops, grasses, livestock, etc. provides all kinds of life support system. Trees in agro ecosystems in Rajasthan and Uttarakhand have been found to support threatened cavity nesting birds and offer forage and habitat to many species of birds. Traditional agroforestry systems are excellent examples of agro-biodiversity conservation. The best examples are the tropical home gardens of Western Ghats (India) and north-eastern hill region. Nonetheless, agroforestry may not avert all species losses, but with divergent life forms such as trees, agricultural crops, grasses, livestock, etc., it may act as an effective buffer to prevent such losses, especially in the smallholder land use systems where there are a variety of species than in the larger ones.

Agroforestry for Livelihood Security and Employment Opportunities

Agroforestry systems due to diverse options and products provide opportunities for employment generation in rural areas. Dhyani *et al.* (2003) have highlighted the role of agroforestry products and environmental services to meet the subsistence needs of low income households and providing a platform for greater and sustained livelihood of the society. Increased supply of wood in the market has triggered a substantial increase in the number of small-scale industries dealing with wood and wood based products in the near past. Such industries have promoted agroforestry and contributed significantly to increasing area under farm forestry. Recognizing agroforestry as a viable venture, many business corporations, limited companies such as ITC, WIMCO, West Coast Paper Mills Ltd., Hindustan paper Mills Ltd., financial institutes such as IFFCO have entered into the business and initiated agroforestry activities in collaboration with farmers on a large scale. Besides the existing agroforestry practices, there is a tremendous potential for employment generation with improved agroforestry systems to the tune of 943 million person days annually from the 25.4 Mha of agroforestry area (NRCAF, 2007). Dhyani *et al.* (2005) have indicated the potential of agroforestry for rural development and employment generation to the tune of 5.763 m human days/yr from Indian Himalayas alone.

Sericulture is being practiced in different parts of the country since time immemorial. Dhyani *et al.* (1996) successfully developed and demonstrated mulberry and muga sericulture based agroforestry systems for the north-eastern hill region. Sericulture with fruit plants and grass model was highly preferred by farmers, followed by sericulture with field (uplands) crops. Now, tasar sericulture is being promoted in different districts of Bundelkhand region. For this, tasar sericulture insect *Antheria mylata* is being reared on arjun (*Terminalia arjuna*) which is common tree species of the forest area in this area. Arjun can also be cultivated under dense plantation (2800 plants per ha at 2 x 2 m spacing) and intensive management for economic tasar cultivation. The plantation is ready for rearing tasar silkworm within 3-4 yrs. As per the information of Sericulture Directorate, Uttar Pradesh, one ha dense plantation of arjun can generate an income of Rs. 30,000 to 50,000 from tasar cultivation. There is scope of tasar sericulture under agroforestry. To promote livelihood opportunities for the farmers, CAFRI introduced lac based agroforestry system for the semi-arid Bundelkhand region on palas (*Butea monosperma*) and ber trees which are very common in this region. Success of lac cultivation in *katki* crop (rainy season) was observed in the region. The preliminary results indicate good possibility to promote livelihood through lac cultivation in the region. Similarly, there is scope for augmenting income of farmers by collecting gum and resins from trees. CAFRI identified suitable trees for gum and resin in different agro-climatic regions for development under agroforestry.

New Initiatives

Agroforestry, evergreen agriculture, and smallholder production systems have attracted considerable attention around the world, of late, and tree-based production systems are being promoted, the world-over (Kumar *et al.*, 2012). In fact the agroforestry momentum is getting a good response in India. As per the latest FSI report (ISFR, 2015), there is an increase of 110.34 M cu m in total growing stock of the country as compared to last assessments (ISFR, 2013). The noteworthy feature of this is the healthy contribution of 88.66 M cu m from the tree outside forests, which indicates agroforestry contribution. The potential of agroforestry to contribute to sustainable development has been recognized in many international policy declarations also. For example, the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) acknowledged it as a component of climate-smart agriculture and is frequently mentioned as having a strong potential for climate change adaptation and mitigation. The United Nations Convention to Combat Desertification (UNCCD) acknowledges agroforestry's potential to control desertification and rehabilitation. It is also seen as an important element in the ecosystem approach promoted by the Convention on Biological Diversity (CBD) for agro biodiversity conservation.

National Agroforestry Policy

In India, agroforestry has been receiving greater attention by researchers, policy-makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality. Agroforestry is now recognized as an important part of the 'evergreen revolution' movement in the country. India launched National Agroforestry Policy (http://www.indiaenvironmentportal.org. in/content/389156/ national-agroforestry-policy-2014/) in 2014 and became the first country in the world to have a National Agroforestry Policy (http://ccafs.cgiar.org/publications/ indias-new-national-agroforestry-policy). The policy is not only seen as crucial to India's ambitious goal of achieving 33 per cent tree cover but also to mitigate GHG emissions from agriculture sector.

After launching the NAP in 2014, considerable progress has been made in terms of putting it into practice. Department of Agriculture Cooperation and Farmers Welfare (DAC and FW) under the Ministry of Agriculture and Farmers Welfare (MOA and FW) is also playing a significant role in the promotion of agroforestry. It has taken a policy decision to include trees in all its programmes, and this will significantly increase tree-planting on farms, especially under schemes funded by the National Mission on Sustainable Agriculture (NMSA). This has so far approved the funding for 80,000 ha of new agroforestry projects (pers. comm.). Efforts are on to issue guidelines on the production and supply of high-quality planting material and accreditation of nurseries producing MPTS planting material.

Until recently, the felling, transit and processing of trees grown on farms required approvals and permits from government agencies, and this was a significant impediment to establishing agroforestry systems. In order to promote agroforestry, 20 multipurpose tree species (MPTS) which are commonly grown by the farmers were prioritized which can be exempted from the regulatory regime. On 18th November, 2014, Ministry of Environment, Forest and Climate Change (MoEFCC) issued fresh guidelines to all State/UT governments for simplification of felling and transit regulation of tree species grown on non-forest/private lands. So far 17 states have de-notified a number of tree species from felling and transit regulations, and this will make it much easier for landowners and farmers to practice agroforestry (pers. comm.). At the same there is a strong political support for agroforestry. The Prime Minister frequently uses the phrase *Har Med par Ped*, which means "trees on every field bund / boundary". A Sub-Mission on Agroforestry (SMAF) with an outlay of Rs. 940 crores has recently been initiated. The Mission is expected to assist all the states to scale up agroforestry in a targeted manner.

Post 2020 Climate Action Plan

India intends to reduce the emissions intensity of its GDP by 33 to 35 per cent by 2030 from 2005 level and to create an additional carbon sink of 2.5 to 3 billion tons of CO_2 equivalent through additional forest and tree cover by 2030. Agroforestry will play a crucial role in meeting the India's Intended Nationally Determined Contribution (INDC) targets as there is no further scope to put more areas under forest land.

The major share of the land to be brought under agroforestry will come from fallows, cultivable fallows, pastures, groves and through rehabilitation of problem soils. In addition bunds on agriculture lands are another potential area for agroforestry.

Corporate Social Responsibility and Agroforestry

The Corporate Social Responsibility (CSR) laws of India were modified on 1st April, 2014 and notified by the Ministry of Corporate Affairs through Section 135 and Schedule VII of the Companies Act, as well as the provisions of the Companies (Corporate Social Responsibility Policy) Rules, 2014. Accordingly, agroforestry became a legitimate part of the recognized CSR activities, number 6 (Ensuring environmental sustainability, ecological balance, protection of flora and fauna, animal welfare, agroforestry, conservation of natural resources and maintaining quality of soil, air and water) (http://finance.bih.nic.in/Documents/CSR-Policy.pdf.).

Carbon Sequestration Potential of Agroforestry

Agroforestry has importance as a carbon sequestration strategy because of C storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. Agroforestry can also have an indirect benefit on C sequestration when it helps to decrease pressure on natural forests, which are the largest sinks of terrestrial C. Another indirect avenue of C sequestration is through the use of agroforestry technologies for soil conservation, which could enhance C storage in trees and soils. For increasing the C sequestration potential of agroforestry systems practices such as- Conservation of biomass and soil carbon in existing sinks; improved lopping and harvesting practices; improved efficiency of wood processing; fire protection and more effective use of burning in both forest and agricultural systems; increased use of biofuels; increased conversion of wood biomass into durable wood products are advocated to be exploited to their maximum potential. Agroforestry thus contributes to the resilience of agriculture by adaptation and mitigation of climate change effects. In India, evidence is now emerging that agroforestry systems are promising land use system to increase and conserve aboveground and soil carbon stocks to mitigate climate change (Dhyani *et al.*, 2009). Earlier average sequestration potential in agroforestry in India has been estimated to be 25 t C/ha over 96 Mha (Sathaye and Ravindranath, 1998).

CAFRI, Jhansi initiated estimation of carbon sequestration potential (CSP) of existing agroforestry systems (AFS) in the country. In first step it has surveyed in 26 districts of ten selected states of India. At the country level, observed number of trees per hectare on farmers' field varied from 1.81 to 204 with an average value of 19.44 trees. The total biomass (tree and crop) ranged from 4.96 to 58.96 Mg DM/ha and the soil organic carbon ranged from 4.28 to 24.13 Mg C/ha. The average estimated carbon sequestration potential of the agroforestry systems (AFS) representing varying edapho-climatic conditions on farmer's field at country level was 0.21 Mg C/ha/yr. At national level, existing AFS are estimated to mitigate 109.34 million tons CO_2 annually, which may offsets one-third (33 per cent) of the total GHG emissions from agriculture sector (Ajit *et al.*, 2016). However, the potential of agroforestry systems as carbon sink varies depending upon the species composition, age of trees, geographic location, local climatic factors and management regimes (Dhyani *et al.*, 2016).

Way Forward

The organized research efforts undertaken during the last more than three decades have clearly demonstrated the potential of agroforestry for resource conservation, improvement of environmental quality, rehabilitation of degraded lands and providing multiple outputs to meet the day to day demand of the rural population. However, the results obtained so far have to be validated on large scale and in farmer's fields. Also, the agroforestry models developed by the research institutions suitable for the diverse agro-climatic regions are to be scaled up and tested with sound database. The Research and Development on processing technologies for the agroforestry species is still lacking.

Therefore, in order to promote agroforestry, it will require appropriate research intervention, adequate investment, suitable extension strategies, providing incentives to marketing of agroforestry produce, harvest process technology development of new products and market infrastructure and above all taking forward the NAP to address these issues.

Agroforestry has shown its potential as a key path to prosperity for millions of farm families, leading to extra income, employment generation, greater food and nutritional security and meeting other basic human needs in a sustainable manner. As mitigation strategy to climate change as well as rehabilitation of degraded land, the conversion of unproductive grasslands and crop land to agroforestry is a major opportunity as it helps for carbon sequestration and makes land productive and reduces further soil degradation. By virtue of diversity of the components of the agroforestry systems like food grains, vegetables, fruits, nutritional security to the communities could be ensured. Induction of fodder cultivation under agroforestry land use will ensure production of milk, meat and animal products and also wide range of food crops, pulses and oil seeds can meet diverse needs of society. The analysis presented here gives a clear identification of the advances made in understanding and appreciation the potential of agroforestry. Owing to increased supply of wood in the market, there has been a significant increase in the number of factories /industries dealing with wood and wood based ventures. Such industries have promoted agroforestry and contributed significantly in increasing its area. On the whole, in addition to promoting indigenous agroforestry models, it appears that a great deal of research needs to be done to identify short rotation, high value species which suit the farmers' requirement of planting on marginal lands. It would probably be more realistic to select trees that could provide more cash benefit to farmers through their products, and to accept that in the longer term they will also provide environmental benefits arising from a more complex agro- ecosystem.

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Table 2.2 Major agroforestry systems and nature of their benefits in different agro-ecological zones of India

Agro-ecological zone		Major benefits	Examples
I.	**Himalayan Region**		
1.	Trees in agricultural fields / bunds (Agrisilviculture)	Production of food, fruits, fodder, etc. and stabilization of bunds.	*Grewia optiva* and other fodder trees in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and other North-Eastern hill region
2.	Intercropping in fruit orchards (Agri-horticulture)	Production of fruits, food etc	Orange and other citrus, and guava intercropped with cereals, tuberous and rhizomatous crops in Sikkim, Meghalaya and other North-Eastern states.
3.	Plantation crops under shade of trees (Multistoried / Specialized system)	Food, spices, fuel-wood, timber etc.	Large cardamom, coffee etc. under alder in Sikkim and Nagaland; tea under leguminous trees in Assam and West Bengal; betel vine and black pepper on arecanut and other trees in Meghalaya and other north-eastern States.
4.	Silvipasture	Fodder, fuel wood *etc.*	Tree leaf fodder from *Grewia, Celtis* and other species in the Himalayas.
II.	**Indo-Gangetic Plains**		
1.	Trees for soil Reclamation (sodic/ saline / degraded soil)	Reclamation of degraded lands	*Prosopis chilensis, Acacia nilotica, Parkinsonia aculeata* and other species for problem soils.
2.	Fodder trees in degraded grazing lands (Silvipasture)	Fuel, fodder,timber	*Albizia lebbeck, Bauhinia purpurea, Dalbergia sissoo* and other species on grazing lands.
3.	Trees in fields/bunds (Agrisilviculture)	Fuel, fodder, timber, shade, cash, minor products.	*Poplar, Tamarindus indica, Bombax ceiba, Eucalyptus, Dalbergia sissoo, Melia spp. etc.*
4.	Fodder banks and woodlots.	Fodder, soil conservation, fuel *etc.*	*Azadirachta indica, Melia azadirach, Albizia spp., Syzygium cuminii* etc. fodder trees. *Casuarina equisetifolia, Eucalyptus, Bamboos, Dalbergia sissoo etc.* woodlots.
III.	**Arid and Semi-arid Region**		
1.	Multipurpose trees in agricultural fields (Agrisilviculture)	Fodder, fuel wood, fruits, cash, shade and minor products.	Khejri *(Prosopis cineraria),* Ziziphus *spp., Acacia senegal, Ailanthus excelsa, Acacia nilotica, Acacia leucophloea* etc. tree species
2	Trees for reclamation of degraded soils.	Reclamation of soil, fuel, fodder, minor products.	*Albizia lebbeck, Casuarina sp., Acacia tortilis, Azadirachta indica* and other tree species.
3.	Windbreaks and shelterbelts.	Sand dune Stabilization	*Acacia nilotica, Acacia senegal,* other *Acacias, Azadirachta indica, Cassia spp., Prosopis chilensis, Tamarix spp. etc.*
4	Fodder banks and woodlots	Soil conservation, fodder, fuel, etc.	*Prosopis cineraria, Ziziphus nummularia, Salvadora persica, Salvadora oleoides, Acacia nilotica etc.*
5.	Trees on rangelands (silvipasture system)	Fodder, fuel shade, timber.	*Prosopis chilensis, Acacia senegal, Acacia tortilis, Prosopis cineraria, Ziziphus spp., Azadirachta indica etc.* in pasture lands.

IV.	**Humid and Sub- Humid Region**		
1.	Home gardens / Homesteads	Production of multiple outputs.	Home gardens in Kerala, Assam, West Bengal have a mixture of trees, shrubs, herbs etc. Coconut, Arecanut, *Erythrina*, *Gliricidia,* with black pepper, cacao, coffee, cassava and other cash crops.
2.	Multi-tier system or plantation crop combination	Cash, and multiple outputs.	Coconut, arecanut, *Erythrina* and other trees with coffee / banana, pineapple / papaya, cacao /coffee and black pepper / betel vine, large cardamom.
3.	Multipurpose trees in agricultural fields	Fodder, minor products	*Acacia auriculiformis, Aegle marmelos, Albizia spp., Anogeissus latifolia, Anthocephalus chinensis, Artocarpus, Casuarina equisetifolia, Diospyros melaxylon etc.*
V.	**Coastal and Island Region**		Coffee under *Erythrina lithosperma,* Cacao with coconut, black pepper on *Gliricidia, Grevillea robusta*, Cardamom under *Toona ciliata, Artocarpus etc*.
1.	Plantation crop combination, multi-storied	Production of multiple outputs, cash	Composite fish culture in ponds and multipurpose trees in homesteads.
2.	Trees with aquaculture	Fish, fuel, fodder, timber.	*Acanthus ilicifolius, Avicennia officinalis, Carbera odollam, Rhizophora conjugata etc.*
3.	Mangroves plantations as part of homesteads.	Shore protection, fuel, fodder, environmental protection.	*Azadirachta indica, Casuarina equisetifolia, Prosopis chilensis, Acacia senegal etc.*
4.	Shelter belts and wind breaks	Shore / beach stabilization.	*Aegle marmelos, Albizia spp., Azadirachta indica, Bamboos, Bombax malabaricum, Calliandra calothyrsus, Cassia spp. etc.*
5.	Trees on boundaries of agricultural fields (Agrisilviculture)	Fodder, fuel, shade, minor products	*Aegle marmelos, Albizia spp., Azadirachta indica, Bamboos, Bombax malabaricum, Calliandra calothyrsus, Cassia spp. etc.*

Table 2.3 Improved agroforestry systems for rainfed areas

Agro-climatic Zone	Agroforestry system	Tree Component	Crop / grass
Western Himalayas	Silvipasture	*Grewia optiva*	Setaria
		Morus alba	Setaria
Central Plateau and Hills	Agrihorticulture	*Emblica officinalis*	Black gram / Green gram
	TBOs	*Jatropha curcas*	-
Southern Plateau and Hills	Agrisilviculture	*Eucalyptus*	Cotton
	Silviculture	*Leucaena leucocephala, Eucalyptus*	-
East Coast Plains and Hills	Agrisilviculture	*Ailanthus excelsa*	Cow pea
West Coast Plains and Hills	Agrisilviculture	*Acacia auriculiformis*	Black Pepper
	Agrihorticulture	*Artocarpus heterophyllus*	Black Pepper
	Agrisilviculture	*Acacia auriculiformis*	Paddy
Western Dry Region	TBOs	*Jatropha curcas*	-

Chapter 3

Agroforestry in Arid Regions for Combating Climate Change

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Introduction

Arid Environment is extremely diverse in terms of their land forms, soils, fauna, flora, water balance and human activities. The binding element of all arid environments is aridity. The hot arid region of India is situated between 24^o and 29^{o}N latitude and 70^o and 76^{o}E longitude, and covers an area of 31.70 million hectares. The arid areas of western Rajasthan, Gujarat, Punjab and Haryana, together constitute the Great Indian Desert, better known as the *Thar* desert which accounts for 89.6 per cent of the total hot arid region of India. Out of total area of *Thar* desert, 68.1 per cent lie in Arid Western Rajasthan and thus, this part represents principal hot arid region of the country.

Climate change, the greatest global challenge, is already a reality for the farmers of arid regions of India. It is increasing the pressure on already scarce resources and if proper measures are not taken, migration towards the cities will soon reach new heights. According to the Rajasthan State Action Plan on Climate Change (RAPCC) report by the Rajasthan State Pollution Control Board prepared with the help of a multi-disciplinary team of experts from TERI with support from GIZ says, 'enough is already known to start action'. Given the fragility of the resource base in arid regions, agriculture is a high risk activity. Climate change poses formidable challenges to the animal husbandry sector as well. Yield-temperature response curves show that there is a decrease in grain yield of wheat in Rajasthan at the rate of 249 kg/ha/degree rise in seasonal temperature, similarly 92 kg/ha decrease in yield of mustard (GoR, 2013; Poonia and Rao, 2013).

Agroforestry has been a practice in arid regions of the country since time immemorial. Farmers cultivate crops with trees as most trees on account of their draught resistant capacity are still able to provide fuel, fodder, fruits and other miner tree products when the crops fail. Livestock is also an integral part of farming in this region. Thus, a great scope is there in this region to promote agroforestry on scientific management consideration to combat ill effects of climate change (Roy, 2016).

The Desert Regions

In the state of Rajasthan hot arid region is spared over in an area of 1, 96,150 km^2 involving 12 districts located in western and north western part. The production and life support systems in this region are constrained by environmental limitations such as low precipitation (100-420 mm/year), high temperature (45-50^{o}C), high wind speed (30-40 km/hr), and high evapo-transpiration (1500-2000 mm/year) and sandy-rocky gravely to saline soils having poor fertility and low water retention. Sand dunes are dominant formation of arid western Rajasthan.

Due to ever increasing human and livestock population the biotic stress in this part of country is of very high degree. The human population (17.44 million) in 1991 has increased to 27.50 million in 2011. Likewise, livestock population (ACU) of 9.6 million (in 1983) has increased to 11.3 million in 2003. In spite of inhospitable climatic conditions, poor soil structure and fertility and very high biotic stress, agriculture is the main stay of the rural population. Mixed crop- livestock, mixed livestock- crops and livestock farming form the spectrum of economic activities in this region (Shankarnarayan *et al.*, 1987).

Of the total area of the Arid Western Rajasthan, only 1.3 per cent is under forest cover. The net shown area increased by over 55 per cent from 1915 to early 1980s. This trend of growth in net sown area has further intensified and as a consequence barren, uncultivable waste lands, permanent pasture and fallow land have declined substantially. The present land use pattern in Arid Western Rajasthan is depicted in Table 3.1.

Table 3.1 Land use pattern in Arid Western Rajasthan

Major land use	Category	% of total area
Forest	-	1.3
Area not available for cultivation	Land put to non-agricultural use	4.6
	Barren / uncultivable lands	0.5
Other uncultivated lands	Permanent pastures / grazing lands + trees	4.7
Cultivated waste lands	Salt affected areas	0.6
	Water logged areas	0.4
	Highly sandy tracts	23.3
Fallow lands	Current fallows and others	18.0
Net sown area	-	46.6

Traditional Agroforestry Systems

The people of the region have evolved tree based farming systems or agroforestry systems as a drought protective mechanism based on centuries old experience, descending from one generation to other. At Central Arid Zone Research Institute (CAZRI), Jodhpur, research and development projects started long back in 1970s leading to identification of productive systems. The major components of traditional agroforestry systems in various districts of Arid Western Rajasthan is described in Table 3.2.

On the basis of rainfall, four types of major traditional agroforestry systems have been identified in upper transact of Arid Western Rajasthan extending from Danta-Ramgarh (transitional zone between arid and semi-arid region) to extreme western fringes of Bikaner/Ganganagar districts (Table 3.3) (Shankarnarayana, 1887).

Table 3.2 Components of traditional agroforestry systems in various districts of Arid Western Rajasthan

District	Main tree/shrub	Main crops*	Major grass
Ganganagar and Hanumangarh	*Prosopis cineraria, Acacia nilotica sub sp. indica, Acacia tortilis*	Pearl millet, moong bean and cluster bean (rainfed). Wheat, cotton, rice and moong bean (irrigated)	*Lasiurus sindicus*
Bikaner	*Prosopis cineraria, Ziziphus nummularia, Calligonum polygonoides, Acacia jacquemontii*	Moong bean, moth bean, cluster bean and pearl millet	*Lasiurus sindicus*
Jaisalmer	*Calligonum polygonoides, Ziziphus nummularia, Prosopis cineraria, Acacia senegal, Capparis decidua*	Moong bean, pearl millet and cluster bean	*Lasiurus sindicus*
Barmer	*Prosopis cineraria, Tecomella undulata, Ziziphus nummularia, Capparis decidua*	Pearl millet, Moon bean and cluster bean	*Lasiurus sindicus, Cenchrus ciliaris*

District	Main tree/shrub	Main crops*	Major grass
Jodhpur	*Prosopis cineraria, Ziziphus nummularia, Capparis decidua, Acacia senegal*	Pearl millet, moon bean and cluster bean (rainfed). Wheat, chilli, mustard and moong bean (irrigated)	*Cenchrus ciliaris*
Churu, Jhunjhunu and Sikar	*Prosopis cineraria, Gymnosporia montana, Ziziphus nummularia*	Pearl millet, moong bean and cluster bean	*Lasiurus sindicus, Cenchrus ciliaris*
Naguar	*Prosopis cineraria, Acacia nilotica*	Pearl millet and moon bean (rainfed). Wheat, moong bean and mustard (irrigated)	*Cenchrus ciliaris*
Jalore	*Prosopis cineraria, Salvadora persica, Salvadora oleoides, Acacia nilotica, Punica granatum* (fruit tree)	Pearl millet, moong bean, isabgol, sorghum and cumin	*Cenchrus ciliaris*
Pali	*Acacia nilotica subsp. indica, Acacia nilotica var. cupressiformis, Acacia leucopholea, Acacia catechu, Salvadora spp.*	Sorghum, pearl millet, moong bean and cluster bean	*Cenchrus ciliaris, Cenchrus setigerus*

(NOTE: *all the crops are rainfed, except otherwise indicated)

Table 3.3 Prominent trees and their density in upper transect of Western Rajasthan

Rainfall zone (mm)	Predominant Tree / Shrub	Trees / shrubs (Nos/ha)	Density of prominent species (%)
400	*Prosopis cineraria – Acacia nilotica*	31.4	80.5
300 – 400	*Prosopis cineraria*	14.2	80.0
200 – 300	*Zizyphus* spp. – *Prosopis cineraria*	91.7	95.0 (91.7 % *Zizyphus* spp.)
< 200	*Zizyphus* spp. – *Prosopis cineraria* – *Salvadora* spp.	17.2	87.2 (65 % *Zizyphus* spp.)

Over 400 mm rainfall zone pre-dominant system is *Prosopis cineraria – Acacia nilotica* based; between 300 and 400 mm rainfall zone. *Prosopis cineraria* based; between 200 – 300 mm rainfall zone *Ziziphus* spp. – *Prosopis cineraria* based; and in less than 200 mm rainfall zone *Ziziphus* spp. – *Prosopis cineraria* – *Salvadora* spp. based. The density decreased with decrease in rainfall. The density of *Prosopis cineraria* (found across all rainfall zones) tends to decrease with decreasing rainfall from east to west.

Crop Production

In upper transect of Arid Western Rajasthan rainfall seems to play determinant role in crop production. *Prosopis cineraria – Acacia nilotica* based agroforestry system was found to be highly productive and *Ziziphus spp. – Prosopis cineraria – Salvadora spp.* system was least productive (Table 4.4). It was very interesting that yield of pearl millet, main cereal crop of the region, below the canopy of woody components in any of system was not affected, rather in *Ziziphus spp. – Prosopis cineraria* and *Ziziphus spp. – Prosopis cineraria – Salvadora spp.* systems; it had better production.

However, legumes such as moth bean, cluster bean and mung bean exhibited yield reduction below the tree canopies, 5.0 per cent (*Ziziphus spp. – Prosopis cineraria* system) to 19.5 per cent (*Prosopis cineraria* system); 12.5 per cent (*Ziziphus spp. – Prosopis cineraria – Salvadora spp.* system) to 18.2 per cent (*Ziziphus spp. – Prosopis cineraria* system); and 10.0 per cent (*Prosopis cineraria* system) to 33.7 per cent (*Prosopis cineraria – Acacia nilotica* system), respectively. Yield reduction under tree canopies for sesame ranged from 26.3 per cent (*Prosopis cineraria – Acacia nilotica* system) to 46.1 per cent (*Prosopis cineraria* system) (Table 3.4) (Shankarnarayana *et al.*, 1987; Tewari, 2007).

Table 3.4 Crop production (kg/ha) in traditional agroforestry system in Arid region of Western Rajasthan

Tree Systems Crops Systems	*Prosopis cineraria - Acacia nilotica*	*Prosopis cineraria*	*Zizyphus spp. - Prosopis cineraria*	*Zizyphus spp. –* other spp.
Pearl millet				
Below the canopy	1005	709	200	200
Away from canopy	1008	709	108	102
Moth bean				
Below the canopy	208	201	109	104
Away from canopy	300	206	200	106
Cluster bean				
Below the canopy	205	108	90	80
Away from canopy	209	201	101	100
Sesame				
Below the canopy	104	201	109	-
Away from canopy	109	309	206	-
Mung bean				
Below the canopy	104	90	-	-
Away from canopy	201	100	-	-

Fuel Wood and Leaf Fodder Production

Foliage of trees constitutes nutritious components of animal feed in arid parts of Rajasthan. The leaf fodder of some tree species is as nutritious as leguminous fodder and is comparable with grass production from the pastures. Fuel wood and leaf fodder production potential of *Prosopis cineraria – Acacia nilotica* system was maximum (fuel wood=1.23 t/ha/yr**;** leaf fodder = 0.90 t/ha/yr) while it was less (fuel wood = 0.18 t/ha/yr; leaf fodder = 0.14 t/ha/yr) in *Ziziphus* spp. - *Prosopis cineraria – Salvadora* spp. System (Shankarnarayana *et al.*, 1987).

Improved Agroforestry Models

Tree growing in hot arid region is basically concerned with the management of trees for conservation and for limited production objectives like wood for fuel, poles and fencing material; leaves for livestock fodder; and pod / seeds for many types of use in human diet. The role of trees to conserve the fragile ecosystems of hot arid regions has been well recognized. The trees also provide so many services to mankind, which make them an intricate part of man-livestock-agriculture continuum, the lifeline of hot arid regions. In the light of increasing pressure on land resources, CAZRI, Jodhpur initiated systematic studies on intensive agroforestry models in early 1980s. Some of the most successful models are discussed below.

Agri-Horticulture

Leguminous crop (mung bean) sown under ber (*Ziziphus mauritiana* cv. Seb) plantation produced 0.2 t/ha of grain and 0.8 t/ha quality *ber f*ruits from same land unit even when seasonal rainfall was as low as 200 mm (Table 3.5), thus rendering a drought proofing mechanism to the system. The economics of this improved system indicated that in case of sole leguminous crop (mung bean) farming, the net profit per hectare was Rs. 4800/-, however, in case of *ber* intercropping, the profit was to a tune of Rs. 8000/- /ha (Tewari 2007; Tewari *et al.,* 2013).

Table 3.5 Production potential of *Ber* and mung bean agri-horticulture model

Treatment	Annual rainfall (mm)	*Ber* Fruit yield (kg/ha)	*Mung* bean Grain yield (kg/ha)	Net profit (Rs/ha)
Sole crop	200	-	520	4800
Intercropped with *Ber*	200	800	200	8000

Horti-Pasture

Ber based horti-pasture have proved highly remunerative in *Thar* desert on farmers' field. *Ber* trees were planted at spacement of 6 x 6 m and grass *Cenchrus ciliaris* was introduced between tree rows. On an average, the dry grass production was 1.55 t/ha/yr. The fruit, leaf fodder and fuel wood production from *ber* was 2.77, 1.87 and 2.64 t/ha/yr, respectively (Table 3.6).

Table 3.6 Improved horti-pasture *(Ber + Cenchrus ciliaris)* on farmers' field

Year	Dry grass (t/ha)	Tree products		
		Fuel wood (t/ha)	Leaf fodder (t/ha)	Fruit yield (t/ha)
1	1.50	3.10	2.13	3.10
2	1.67	2.74	1.80	2.74
3	1.42	2.46	1.71	2.49
4	1.66	2.49	1.63	2.85
5	1.48	2.43	2.01	2.80
6	1.57	2.63	1.94	2.67
Average	**1.55**	**2.64**	**1.87**	**2.77**

Silvi-Agri-Pasture

Diversified production systems appear to be sustainable for hot arid regions. A recent study conducted on *Ailanthus excelsa* based silvi-agri-pastoral model revealed its potential to provide multitude of products in inhospitable environmental conditions of the region. On an average the system productivity of herbaceous component for food grain (Table 3.7) and fodder (in the form of crop straw and grasses) (Table 3.8) was found to be the best under wider spacing (10 x 10 m) of *Ailanthus excelsa*. However, under closer (6 x 6 m) and as well as moderate (8 x 8 m) spacing of the species, the productivity of herbaceous component was satisfactory. This indicated that with proper management, diversified agroforestry systems have the potential to produce multitude of products in fairly good quantity (Tewari *et al.*, 2013).

Table 3.7 Grain productivity (kg/ha) under different spacing of *Ailanthus excelsa* based Silvi-Agri-Pastoral system

Year	Pearl millet			Moth bean		
	6 x 6 m	8 x 8 m	10 x 10 m	6 x 6 m	8 x 8 m	10 x 10 m
2007-08	425	429	504	202	195	205
2008-09	528	565	650	24	22	29
2009-10*	-	-	-	-	-	-
2010-11	1312	1408	1552	233	250	256
Average	**755**	**800.7**	**902**	**153**	**155.7**	**163.3**

(NOTE: *Complete drought year)

Table 3.8 Crop straw/grass productivity (kg/ha) under different spacing of *Ailanthus excelsa* based Silvi-Agri-Pastoral System

Year	Pearl millet			Moth bean			*Cenchrus ciliaris*		
	6 x 6 m	8 x 8 m	10 x 10 m	6 x 6 m	8 x 8 m	10 x 10 m	6 x 6 m	8 x 8 m	10 x 10 m
2007-08	978	1008	1256	300	285	310	552	581	680
2008-09	1368	1292	1665	260	231	267	562	708	890
2009-10*	456	508	677	212	227	296	411	507	666
2010-11	3818	4154	4627	639	789	683	1750	1821	2174
Average	**1655**	**1740.5**	**2056.3**	**352.8**	**383**	**389**	**818.8**	**904.3**	**1102.5**

(NOTE: *Complete drought year)

As the system is still in growing phase, the amount of leaf fodder production during subsequent years will increase. In the fifth year by way of 60 per cent vertical lopping, availability of leaf fodder was in order of 69.8, 155.4 and 184.0 in 6 x 6, 8 x 8 and 10 x 10 m spacing, respectively.

Livelihood Improvement

The most spectacular evidence in context of livelihood improvement potential of agroforestry in arid region came through *Acacia senegal* based localized traditional agroforestry system in parts of Barmer and Jodhpur districts (15 villages) of Rajasthan. *Acacia senegal* is source of gum Arabic which has very high commercial value. In addition to harvesting crop grain for food and crop straw for fodder, the farmers harvested substantial quantity of gum Arabic through small intervention using gum inducer provided by CAZRI (Roy *et al.,* 2011).

During the year 2008-09, 12,000 trees were treated through CAZRI gum inducer which resulted in exudation of 5.4 t of gum Arabic and farmers earned Rs. 27 Lakhs from the sale of gum. Subsequently in the years 2009-10 and 2010-11; 21,000 and 22,600 trees were treated, resulting in production of 10.5 t and 7.6 t gum, respectively. In the process farmers earned 52 lakhs in the years 2009-10 and Rs. 38 lakhs in the year 2010-11. In this way, the farmers of 15 villages earned Rs. 117 lakhs from the sale of gum arabic with the average modest sale price Rs. 500/kg in local market. This technology has been so successful that farmers have made their own cooperatives for purchasing of gum inducer and sale of produce in the market (Tewari *et al.,* 2013).

Summing Up

The ecosystems in hot arid region of the country are highly fragile and large liabilities cause severe impediments in development programs. Agroforestry systems combining tree/shrub, crop, grass and livestock have great scope and role in optimizing land productivity and environmental protection, more so from the angle of climate change.

The Indian hot arid zone is better placed in terms of tree and agricultural bio-diversity when compared to other similar regions of the world. Majority of trees / shrubs in this region are multipurpose and have the ability to satisfy the expectations and aspirations of rural folk for meeting basic needs *viz.,* fuel, fodder, timber, food (fruits / pods / seeds) and other products like exuded gum, products of medicinal value etc. for the inhabitants. Agroforestry with suitable tree species in different arid land forms thus assumes much significance for desertification control and ecosystem services as well.

More adoption of agroforestry in the region is recommended for maintenance of productivity and sustainability in this region. The characteristics of trees which are generally considered to be environmentally beneficial are on account of their ability to utilize incoming solar radiation throughout the year; to enrich micro sites by depositing litter in the topsoil for its subsequent utilization by crops/ grasses; to modify the microclimate, which can bring about favorable effect on the soil and associated plant species. The appropriate combination and management of tree/shrub (both forest and fruit), crops, grasses and livestock units (in mixed herds) will make agriculture a profitable and risk free proposal in light of emerging climate change challenges in the region.

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Chapter 4

Traditional Agroforestry Systems in India and their Relevance in Combating Climate Change

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Introduction

Traditional Agroforestry systems provide a particular example of a set of innovative practices that are designed to strengthen the system's ability to adapt to aberrant rainfall and adverse impacts of changing climate. This in a way often contributes to climate change mitigation through enhanced carbon sequestration, and at the global level, maintenance of biological diversity, green house gas regulation and climate moderation are the best known functions of such traditional agroforestry systems.

Traditional Agroforestry in India

India has a long tradition of agroforestry (AF) systems and several indigenous agroforestry systems, based on people's needs and site-specific characteristics have been developed over the years. The traditional agroforestry systems in India include trees on farms, community forestry and a variety of local forest management and ethno forestry practices. In India, the practice of growing scattered trees on farmlands is quite old and has not changed much over centuries; these trees are multipurpose, used for shade, fodder, fuel wood, fruit, vegetables and medicinal uses. Most often, this perennial integration are specific to topographic and edaphic factors (Table 4.1). Traditional agroforestry practices benefit biodiversity through *in-situ* conservation of tree species on farms, reduction of pressure on remaining forests, and the provision of suitable habitat for plant and animal species on farmland. Different traditional agroforestry systems practiced by farmers are:

- Scattered trees on farm lands / Parkland systems
- Trees on farm boundaries / boundary plantations
- Farm wood lots / block plantations
- Trees on range lands
- Vegetative live hedges / living fences

Table 4.1 List of woody species integrated in traditional agroforestry systems of Maharashtra

Traditional AF system in dry land areas of Maharashtra	Multipurpose woody species
Traditional farm forestry	*Tectona grandis*, *Gmelina arborea*, *Terminalia arjuna*, *Albizia odoratissima*, *Acacia nilotica*, *Azadirachta indica*, *Butea monosperma*, *Mangifera indica*, *Ziziphus mauritiana*, *Terminalia bellerica*, *Syzigium cuminii* and *Annona squamosa.*
Farm boundary plantations	*Pongamia pinnata, Acacia nilotica, Dalbergia sissoo, Azadirachta indica, Leucaena leucocephala, Eucalyptus* spp, *Gliricidia maculata, Acacia catechu, Albizia lebbeck, Albizia procera, Tectona grandis, Gmelina arborea, Dendrocalamus strictus, Bambusa arundinacea* and *Bambusa vulgaris.*

Block plantations / Farm wood lots	*Tectona grandis, Dalbergia sissoo, Eucalyptus* spp, *Acacia mangium, Casuarina equisetifolia, Leucaena leucocephala* and *Dendrocalamus strictus.*
Natural silvi-pasture	*Hardiwickia binata, Albizia lebbeck, Ziziphus mauritiana, Acacia nilotica, Mangifera indica, Erythrina indica, Emblica officinalis* and *Annona squamosa.*
Live hedges	*Prosopis juliflora, Ziziphus aenoplia, Caesalpinia sepiaria, Dodonaea viscosa, Lawsonia inermis, Lantana camara, Acacia senegal, Vitex negundo, Ipomoea carnata, Jatropha gossypifolia, Jatropha curcas* and *Bambusa* spp

Source: Ilorkar *et al.* (2011)

Scattered Trees on Farm Lands / Parkland Systems

Trees often planted deliberately or allowed to persist as scattered from natural regeneration in crop fields. Mature trees on farm lands frequently follow a random or irregular sequence pattern, such species do not receive or require much canopy management during the cropping seasons. They are often location specific, *viz.,* growing of *Acacia nilotica* in Indo-Gangetic plains and scattered trees of Borassus *flabellifer* in peninsular and coastal regions (Pathak *et al.,* 2000). Jambulingam and Fernandes (1986) have documented the cultivation of *Acacia nilotica* trees on rice bunds in Tanjavur and Thiruchirapalli districts of Tamil Nadu. Farmers in Koppal and Bijapur district of Northern Karnataka practiced scattered planting of woody perennials in their crop lands as most prominent traditional practice next to boundary planting (Table 4.2).

Table 4.2 Percentage of dry land farmers following traditional agroforestry practices in northern Karnataka

Agroforestry practices (plantation)	Dry land regions of northern Karnataka					
	Bijapur	Bagalkot	Gulbarga	Koppal	Raichur	Average
Bund	92.5	95.4	90.2	81.2	82.7	88.4
Boundary	52.4	45.6	76.8	18.7	72.5	53.2
Scattered	25.2	21.2	12.8	37.4	18.4	23
Block	5.8	6.4	4.2	12.6	4.2	6.6
Avenue	2.6	3.5	3.8	14.2	5.4	5.9

Source: Devaranavadgi *et al.* (2010)

Trees on Farm Bunds / Boundary Plantations

Trees in dry land tracts of agricultural crop fields are often planted on field risers (bunds) and / or borders or farm boundaries, to demarcate the field boundaries and also to serve as windbreaks / shelter belts / living fences. In this system, the space of the bund is gainfully utilized. In Bihar, *Dalbergia sissoo* and *Wendlendia exserta* are most common boundary plantations. *Casuarina equisetifolia* is extensively planted on field bunds in coastal areas of Orissa (Pathak *et al.,* 2000). Paddy field risers are usually planted with tree species such as *Borassus flabellifer, Casuarina equisetifolia, Eucalyptus tereticornis, Gliricidia sepium*, etc. in many parts of the country (Kumar, 1997). Traditional agroforestry systems *viz.*, agrisilviculture, agrihorticulture are prevalent in the Cold desert Region of Himachal Pradesh, India, that combines agriculture crops like *Hordeum vulgare* (Barley), *Triticum aestivum* (Wheat), *Fagopyrum tataricum* (Buck wheat), *Panicum miliaceum* (Millets), *Avena sativa* (Oat), *Brassic*a spp. (Mustard) etc. with boundary plantations of multipurpose trees like *Morus alba* (Mulberry), *Salix* spp. (Willow) and *Populus* spp. (Popular) which are the main source of fodder and fuel wood (Kaler *et al.,* 2017). Nearly 60.1 per cent of farmers in the villages of lower plateau of Melghat region district Amravati, Maharashtra State, India practicing boundary plantation to meet the diverse need *i.e.* food, fodder, fuel wood and timber in the changing climate, a prominent agroforestry practices in rainfed agro-ecosystem (Bhoyar *et al.*, 2016).

Wood Lots as Block Plantations

Recently the development of wood lots has been on the rise due to shortage of fuel wood, timber and demand for poles or pulpwood in industry. In semi-arid regions of India, the block plantations of *Leucaena leucocephala*, *Casuarina equisetifolia* and species of *Eucalyptus* are very common due to multiple uses and demand for pulp wood and poles from paper mills, and other industries in the surrounding vicinity.

Trees on Range Lands (Silvipastoral System)

Silvi-pasture denotes land use system in which grasses and legumes are integrated with woody perennials on the same unit of land management to improve the productivity per unit area, apart from increasing the period of fodder availability. These systems are more common in drier areas, and contribute a substantial amount of leaf fodder as top feeds for the animals during lean periods of fodder availability, through lopping/pruning of trees. In the semi-arid regions, silvipastoral systems involving native tree species (*e.g., Albizia procera, Albizia lebbeck, Acacia spp, Azadirachta indica*, *Dalbergia sissoo*, *Morus alba* and *Pongamia pinnata*) have been practiced for many years in India (Singh and Roy, 1993). Trees such as *Borassus flabellifer, Casuarina equisetifolia, Eucalyptus tereticornis, Albizia lebbeck, Senna siamea, Tamarindus indica, Acacia nilotica, Acacia leucophloea* and many others co-exist in the complex systems prevailing in the semi arid regions of peninsular India (Pathak *et al.*, 2000). Kangayam region in Tamil Nadu has a sustainable traditional grassland production system. *Acacia leucophloea* is the predominant tree species with occasional presence of *Acacia nilotica, Acacia planiformis, Albizia amara, Azadirachta indica* and *Borassus flabellifer* (Kumar *et al.*, 2011).

Vegetative Live Hedges / Fences

Vegetative live hedge / fence are an age old and traditional agroforestry practice in semi-arid tropics to protect the crops and garden lands. Besides their primary purpose of controlling human and animal movement, living fences may provide fuel wood, fodder and food, act as wind-break or enrich the soil, depending on the species used. Common hedge species are *Gliricidia sepium*, *Agave sisalana*, *Jatropha curcas*, *Jatropha gossypifolia*, *Lantana camara*, *Cactus* spp, *Optunia* spp, *Prosopis juliflora*, *Balanites aegyptica*, *Pithecellobium dulce*, *Lawsonia inermis*, *Carissa carandas* and *Parkinsonia aculeata*.

Geographical Spread of Traditional Agroforestry Systems

Shifting cultivation, home gardens and plantation-based cropping systems are mostly practiced in humid tropical regions. In India, home gardens are found in Kerala and Andaman and Nicobar Islands. Taungya, boundary plantations, live hedges, range land trees are agro-ecologically adapted to all regions. Boundary plantations are found in Uttar Pradesh, Gujarat, in parts of south India, particularly the Nilgiri hills, Haryana, Himachal Pradesh, Bihar and Orissa. Woodlots are found in hilly areas whereas shelter belts are found in wind-prone regions like coastal areas. In India, woodlots are found in Andhra Pradesh, Tamil Nadu, Karnataka, Orissa, Punjab, Haryana, Gujarat and Assam. Scattered trees on farmlands are found in all regions specially arid and semi-arid. Agro-silvo-pastoral practices are common in semiarid regions of India. Below we describe the major agroforestry practices in four important regions of India.

North East India: The major form of traditional agroforestry practiced in the region is shifting cultivation (jhum). The entire socio-economic structure is woven around this system and farmers maintain high species diversity. However with reduced shifting cultivation cycle, the system has become ecologically unsound and has resulted in forest degradation.

North West India: The states of Gujarat and Rajasthan receive scanty and erratic rainfall and failure of crop is a regular phenomenon. Traditional agroforestry practices have the potential to minimize the impact of extreme climate condition and can provide alternate income to the people. One of the major practices involves combining *Prosopis cineraria* with other agricultural crops in this region (Table 4.3).

Table 4.3 Traditional agroforestry systems in Arid region of Western Rajasthan

Rainfall zone (mm)	Agroforestry system
>400	*Prosopis cineraria – Acacia nilotica* based
300-400	*Prosopis cineraria* based
200-300	*Ziziphus spp. - Prosopis cineraria* based
<200	*Ziziphus spp. - Prosopis cineraria – Salvadora spp.* based

Source: Sharma and Tewari (2005)

The Western Ghats: Managed ecosystems of Western Ghats present a complex pattern with a great diversity of trees and field crops. Traditional agroforestry systems where trees are grown with crops, and/or sometimes animals, in interacting combinations in space or time dimensions are abound in the Western Ghats region. In particular, plantation agriculture involving coffee, tea and spices in association with a wide spectrum of trees and para rubber (*Hevea brasiliensis*), rice-based cropping systems, coconut based cropping systems, and homestead farming systems dominate the region (Kumar and Takeuchi, 2009).

Southern India: In the southern states of Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh, numerous forms of traditional agroforestry are popular. Home gardens and multistory combinations involving plantation crops are prevalent in Kerala; tree-spice gardens, and crop combinations involving them are common in coastal Karnataka; energy plantations, especially of *Casuarina* spp., are popular in coastal districts of Tamil Nadu and Andhra Pradesh and various forms of intercropping with fruit trees and silk cotton tree (*Ceiba pentandra*) are widespread in Tamil Nadu (Paramatma *et al.*, 2007).

Importance of Agroforestry in Combating Climate Change Hazards

Traditional agroforestry options may provide a means for diversifying production systems and increasing the sustainability of smallholder farming systems. The most worrisome component of climate change is poor distribution, increased inter-annual variability of rainfall and temperature. Traditional agroforestry systems have some advantages for maintaining production during wetter and drier years.

- First, their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during dry season.
- Second, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years.
- Third, traditional agroforestry systems have higher evapo-transpiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems (Dhillon *et al.*, 2010).

Benefits of Traditional Agroforestry Systems in Context of Climate Change

i) **Improved Soil Fertility:** Climate-related hazards can either improve the nutrient status or increase the degradation of the soil fertility. Enhancing and maintaining soil fertility is vital for food security, reducing poverty, preserving environment and for sustainability. Traditional agroforestry land use systems are efficient ways of restoring soil organic matter and carbon sequestration. Tree components of any agroforestry species perform one major function in controlling erosion; the trees may act as barriers or as cover.

ii) **Increased Income:** The diverse component of agroforestry provides multiple harvests at different times of the year. It increases food production, improves supply of fodder for fish and livestock, increases supply of fuel wood, improves soil fertility and water supply, habitats, etc. Thus it reduces the risk of crop failure and ensures alternate income to farmers (Pandey, 2007)

iii) **Increased Carbon Stock:** Traditional agroforestry has a huge potential as mitigation strategy to the changing climate because of its potential to sequester carbon in its plant species and soil. In tropics, for small traditional agroforestry systems, it has been found to be ranging from 1.5 to 3.5 MgC/ha/yr and can be a viable strategy for carbon storage (Montagnini and Nair, 2004).

iv) **Reduced Vulnerability:** Traditional agroforestry increases the resilience of farming systems by buffering against various risks, both biophysically (hydraulic lift, soil fertility) and financially (diversification, income risk). Other advantages include reducing seasonal labor peaks, earn income throughout the year and ensure benefits of short, medium and long term income to households (FAO, 2005).

v) **Increased Productivity**: Taungya cultivators got higher yields than from pure agriculture in Tarai region of Uttar Pradesh. IGFRI, Jhansi conducted experiments that indicated increased yield of fodder when fodder grasses were intercropped with fodder trees as compared to mono cropping of fodder grass (Prasad, 2003).

Carbon Sequestration Potential of Traditional Agroforestry Systems

Carbon stock potential in traditional agroforestry system of Garhwal Himalaya is given in Table 4.4. The Cardamom based traditional agroforestry system shows a net storage of carbon in the soil and the biomass. The carbon storage in Cardamom based traditional agroforestry is higher than the rain fed agriculture systems. However, it is comparatively higher in Alnus-Cardamom based agroforestry than the other farm based agroforestry systems (Table 4.5).

Table 4.4 Total carbon stocks (t/ha) of traditional agroforestry system

Villages	AGC	BGC	TC
Budali	27.64	7.40	35.0
Manjakot	15.69	4.20	20.0
Manao	16.55	4.42	21.0
Dungripanth	24.86	6.62	32.0
Chamdaar	45.39	12.10	58.0
Keshu	24.20	6.44	31.0

Source: Munesh kumar *et al.*, (2012)

Table 4.5 Carbon stocks (t/ha) in rain fed agriculture and Cardamom based traditional agroforestry systems in Sikkim

Agroforestry components	Rainfed agriculture	*Albizia*+ Cardamom	*Alnus*+ Cardamom	Forest+ Cardamom
Crops	4.24	4.51	6.46	1.68
Tree	5.04	9.19	37.25	7.89
Litter	-	1.84	12.06	2.27
Soil	37.11	65.27	106.00	121.00
System (total)	46.39	80.81	161.77	132.84

Source: Rita Sharma *et al.* (2007)

Enhancing Adaptive Capacity through Traditional Agroforestry

Impacts of climate change will be felt on several levels in the agricultural sector. Impacts will be felt most by rural poor in developing countries, who are the most vulnerable because of their low adaptive capacity. The adaptive capacity of farmers in developing countries is severely restricted by heavy reliance on natural factors and lack of complementary inputs and institutional support systems. The effects of different traditional agroforestry techniques in enhancing the resilience of agricultural systems against adverse impacts of rainfall variability, shifting weather patterns, reduced water availability, soil erosion as well as pests, diseases and weeds has been well tested. In reality, vulnerability in ecosystems is often the result of a degenerative process due a combination of factors (deforestation, continuous cropping and changing in land use system), which, when associated with extreme climate, represents a major setback for agricultural and economic development and that is where traditional agroforestry can be a relevant.

Conclusion

The concepts of resilience and sustainability are well established in agriculture and can be linked directly to the discussions within the climate change arena about adaptation and mitigation. Agroforestry management systems offer important opportunities for creating synergies between mitigation and adaptation activities. Traditional agroforestry can very likely contribute to increasing the resilience of tropical farming systems. However, our understanding of the potential of traditional agroforestry to contribute to adaptation to climate change is rudimentary at best. Better information is required on the role of traditional agroforestry in buffering against the biophysical and financial (diversification, income risk) points of view. Traditional agroforestry offers the potential to develop synergies between efforts to mitigate climate change and efforts to help vulnerable populations adapt to the negative consequences of climate change.

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Chapter 5

Tree Borne Oilseeds for Agroforestry

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Introduction

Tree borne oilseeds (TBO's) are gaining importance as a supplementary source of oil for food, fodder, fuel and industrial applications. All products of forests excluding timber have been traditionally classified as Non Timber Forest Produce (NTFP) or Minor Forest Produce (MFP). In addition to sources of oils and fats, the products fall into various categories *viz.*, medicinal plants, essential oils, spices, gums, resins, fibers, dyes etc. which may be used locally by the tribal's / forest dwellers. Tree borne oilseeds which form an important NTFP are region specific depending on the species supported in the particular agro-climatic zone. In order to prevent over exploitation and ensure sustainable supply, the alternative is to additionally raise them as plantations or in various agroforestry systems.

Agroforestry refers to the integration of farming with forestry practices, preferably on the same unit of land on sustainable basis. It is also a viable option for re-vegetation of degraded lands (Dasthagir *et al.*, 1996). This system not only results in profitable farming with fewer risks from environmental instability but also plays a role in improving environment by greening marginal lands in rural areas. Agroforestry systems can be in the form of scattered trees, rows or strips of trees and trees in border rows or boundaries. Farm boundary plantations, natural regeneration and scattered trees in farmlands are the main agroforestry components with well known traditional species of tree borne oilseeds like neem, mahua and karanj. Neem based agroforestry systems are prevalent in many states but the benefit is derived primarily from the timber, firewood and fodder whereas the seed which is the source of an important bio-pesticide is left unutilized as it is not collected. Many awareness creation programmes have been sponsored by the National Oilseeds and Vegetable Oils Development (NOVOD) Board, Gurgaon for quality collection and utilization of tree borne oilseeds like neem, *Jatropha* and mango kernel to harness the untapped potential of these useful species.

The establishment of a successful agroforestry system with tree borne oilseeds as a component begins with the selection of the tree species. Around 300 tree species bearing oleaginous seeds have been reported in literature (Tyagi and Kakkar, 1991; Bringi, 1987). Popular species grown in agroforestry are economically important for timber and related products primarily to meet various farm requirements or supplement income in case of surplus production. In contrast to species raised for firewood, fodder etc where coppicing and lopping of trees is practiced, tree borne oilseeds need to be allowed to grow undisturbed to allow for timely flowering and fruiting. In recent years, the focus of research has been on evaluating and propagating tree borne oilseeds for biofuels with emphasis on species like *Jatropha*, *Pongamia*, neem, mahua, *Callophyllum*, *Simarouba* with suitability for agroforestry primarily as border or sole plantations (Sudhakara Babu *et al.,* 2008).

Potential Species for Edible Oil Sources

Many tree species have been in use by ethnic communities since time immemorial, as they provide edible grade oil. Tree species used in the manufacture of margarine, confectionery and bakery products, other species like *Bombax* and *Capparis* the seed oil can form an additional product besides the fiber and the fruit which are the main products respectively are presented (Table 5.1).

Table 5.1 Trees yielding edible grade oils

Botanical name and Family	Common Name	Distribution	Oil content (%)	Uses
Bombax ceiba Bombacaceae	Silk cotton	Throughout India	20	Illuminant, soaps, edible
Capparis decidua	Caper berry	Rajasthan	20	Illuminant, edible
Diploknema butyracea Sapotaceae	Phulwara	Sub himalayan tract and outer Himalayas from Kumaon to Sikkim	42-47	Cocoa butter substitute,soap, candles, illuminant, ointments
Garcinia indica Guttiferae	Kokum	Forests of Western Ghats in Southern Maharasthra and slopes of Nilgiri hills	33-44*	Cocoa butter substitute, soap, candles, Vaseline
Juglans regia Juglandaceae	Wild walnut	Kashmir, Hills of Himachal Pradesh, Uttar Pradesh and Assam	60-70*	Edible, soaps, printing inks, oil colors, varnishes
Madhuca indica Sapotaceae	Mahua	Central India, plains of North India	35	Cocoa butter substitute, soap, illuminant vanaspati
Madhuca longifolia Sapotaceae	S. Indian Mahua	Monsoon forests of Western Ghats, Deccan and other parts of South India	35	Soap, illuminant, edible
Mangifera indica Anacardiaceae	Mango	Throughout India (tropical regions)	11*	Cocoa butter substitute, vanaspati
Manilkara hexandra Sapotaceae	Khirni		25	Edible
Mimusops elengi Sapotaceae	Maulsari	Central and South India	16-25*	Edible, illuminant
Schleichera oleosa Sapindaceae	Kusum	Eastern India and Forests of Sub-himalayan tracts in the north	36	Illuminant, soap, medicinal
Shorea robusta Dipterocarpaceae	Sal	Central India and Himalayan foothills in sub temperate regions	20*	Illuminant, edible(sal butter)
Simarouba glauca Simaroubaceae	Aceitino	Orissa, Karnataka, Maharasthra, Andhra Pradesh	55*	Cocoa butter substitute, soap
Theobroma cacao Sterculiaceae	Cocoa	Kerala, Tamil Nadu, Orissa, Eastern India	50-57	Confectionery, cosmetics, medicinal preparations
Vateria indica Dipterocarpaceae	Dhupa	Forests of Western Ghats from Maharasthra to Kerala	20-22	Confectionery, soap, candles, medicinal
Ximenia americana Olacaceae	False sandalwood	Dry forests of Deccan peninsula and rocky coastal regions of Andamans	49-60*	Lubricants, soap, candles, pomade for hair, ghee

* kernel oil

Source : Tyagi and Kakkar (1991); Wealth of India, Raw Materials series (PID) CSIR, New Delhi

Besides availability of seed material in required quantities for economically viable extraction, policies also play an important role in tapping of the full potential of tree borne oilseeds. Out of the 23 oils permitted for use in vanaspati, mahua, mango kernel fat and sal are included basically to encourage their collection by tribal’s. Cocoa butter equivalents are allowed for blending in vanaspati but not in cocoa butter. Newer sources will also need to be part of the policy framework for their utilization.

Potential Species for Industrial Oil Sources

Oils find use in a wide range of industrial applications; potential species for industrial uses and their natural distribution is presented in Table 5.2 to enable selection of suitable species for agroforestry systems in various agroclimatic regions.

Table 5.2 Trees yielding industrial oils

Botanical name and Family	Common name	Distribution	Oil content (%)	Uses
Actinodaphne hookeri Lauraceae	Pisa	Evergreen forests of Eastern and Western Ghats, Karnataka, Orissa, Sikkim and North East India upto 1500m	40	Textiles, soap, cosmetics, pharmaceuticals and perfumery
Aleurites fordii Euphorbiaceae	Tung oil	Assam, Bengal, Bihar, Karnataka	50-60*	Paints, varnish
Aphanamixis polystachya Meliaceae	Amoora	Eastern Uttar Pradesh, Western Ghats, Andamans, Bengal, Assam	35*	Soap, medicinal, illuminant
Azadirachta indica Meliaceae	Neem	Throughout India, more in the dry forests of Andhra Pradesh, Tamil Nadu and Karnataka	35-40*	Biopesticide, medicinal
Balanites roxburghii Zygophyllaceae	Desert date	West Rajasthan, Punjab to West Bengal and Sikkim	36-50*	Medicinal, soaps
Bauhinia purpurea Caesalpiniaceae	Khairwal	Throughout India in Sub Himalayan tract upto 1300m	15	Paints, varnishes
Bischofia javanica Euphorbiaceae	Bhillar	Karnataka, Kerala, Tamil Nadu, West Bengal, Sikkim, Arunachal Pradesh, Manipur	21.4	Surface coating, industrial
Butea frondosa Papilionaceae	Palash	Throughout India except arid regions	28	Soaps, solvent for drugs, ointment base
Callophyllum inophyllum Guttiferae	Undi	Along sea coasts	50-73*	Biodiesel feed stock, Illuminant, soap
Givotia rottleriformis Euphorbiaceae	White catamaran	Deciduous forests of South India	20	Lubricant
Gynocardia odorata Flacourtiaceae	Kadu	Eeastern Himalayas, Assam	27*	Paints, varnish
Hevea brasiliensis Euphorbiaceae	Rubber	Kerala	39	Paints, alkyl resins
Joannesia principes Euphorbiaceae	-	In gardens in tropical regions of India	48-56*	Veterinary medicines, paints, soaps varnishes, fuel
Litsea cubeba Lauraceae	Siltimur	Eastern Himalayas, Assam, Manipur	22	Illuminant
Litsea glutinosa Lauraceae	Garbijaur	Punjab, Himachal Pradesh, Assam, Bengal, South India	35-48	Candles, soaps
Litsea monopetala Lauraceae	Meda	East, North and central India	21	Candles, medicinal
Mallotus philippinensis Euphorbiaceae	Kamala	Himalayan foothills, Bengal, Orissa, Madhya Pradesh and Maharashtra	35*	Paints, varnish, ointments

Botanical name and Family	Common name	Distribution	Oil content (%)	Uses
Manihot glaziovii Euphorbiaceae	Manicoba rubber	Nilgiri hills, Malabar, Orissa, Assam	35-42*	Paints and varnishes
Mesua ferrea Guttiferae	Nahor	Forests of North East India, Karnataka, Kerala, Andamans	45	Soap, lubricant illuminant, medicinal
Myrica nagi Myristicaceae	Kaiphal	Sub Tropical Himalayas upto 2100 m.	20-25	Candles, soap
Myristica malabarica Myristicaceae	False Nut-meg	Western Ghats (Konkan southwards)	40*	Illuminant, soap, medic-inal
Olea ferruginea Oleaceae	Indian olive	Uttar Pradesh (>2400m)	15	Soap, medicinal
Quassia indica Simaroubaceae	Karanjoti	Kerala	37*	Medicinal, resins, illu-minant
Robinia pseudoacacia Papilionaceae	Black Locust	Punjab, Jammu and Kashmir	10-15	Paints, varnishes
Salvadora oleoides Salvadoraceae	Pilu, khakan	Arid regions of Punjab and Western India	40	Medicinal, soap, candle making
Sapium sebiferum Euphorbiaceae	Chinese tallow	North West India	53-64*	Soap, candles, paints
Simmondsia chinensis Simmondsiaceae	Jojoba	Arid tracts of Rajasthan and Gujarat	50	Lubricants, Adhesives, Pharmaceuticals
Sterculia foetida Sterculiaceae	Jangli Badam	West coast from Konkan southwards	30	Illuminant, rubber substitute, surface coating, soaps
Terminalia bellerica Combretaceae	Bahera	Tropical forests	44	Soaps, hair oil, edible
Thespesia populnea Malvaceae	Paras pipal	Coastal regions of Konkan, Bengal and Andamans	20	Illuminant
Trewia nudiflora Euphorbiaceae	Gutel	Kumaon Hills, Bihar, Bengal, Assam	18-22	Polyurethaneand Epoxy compounds
Ximenia americana Olacaceae	False sandal wood	Dry forests of Deccan peninsula and rocky coastal regions of Andamans	49-60*	Lubricants, soap, candles, pomade for hair, ghee
Xylocarpus moluccen-sis Meliaceae	Carapa	Coastal regions of Andamans	11	Soaps, illuminant, biodies-el feedstock
Ziziphus mauritiana Rhamnaceae	Ber	Punjab, Haryana, Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, Madhya Pradesh	33	Biodiesel feed stock

Source : Tyagi and Kakkar (1991); Wealth of India, Raw Materials series (PID) CSIR, New Delhi

* kernel oil

The species listed above include many TBO’s which are collected from naturally occurring stands and utilized. Efforts for their systematic cultivation are limited and need attention. Value addition of minor oils and cakes may result in many potential uses as neutraceuticals and unusual fatty acids. Among the species listed above, silk cotton, Manihot and *Ziziphus* can be raised in dry climates on marginal soils. *Adenanthera*, *Quassia* and *Thespesia* are adapted to coastal and island regions. Though many popular avenue trees are also sources of oil, seed collection and oil extraction from most of the species is limited and needs to be organized. Besides *Jatropha* and *Pongamia* oil, research is in progress in many institutes for evaluation of other sources for biodiesel feed stocks.

Agroforestry Systems with Tree Borne Oilseeds Component

The selection of the tree component in different agroforestry systems needs to take into account the tolerance of the crop component for partial or dense shade under the tree oilseeds. These can meet the requirements for energy, fruit and all other environmental benefits of tress (Table 5.3).

Table 5.3 Agroforestry systems for dry and moist climatic regions

DRY	MOIST
Silvipastoral in place of natural savanna on degraded lands Oil seed crops: *Jatropha curcas* (jatropha)*; Simarouba glauca* (simarouba).	Energy farms for high economic output of bio-mass to meet fodder and fire wood needs, may be included Simarouba
Horti-silvipastoral systems on marginal agricultural lands including *Jatropha curcas*, *Madhuca latifolia* and *Madhuca indica* (mahua), *Calophyllum inophyllum* (undi), *Azadirachta indica* (neem) and *Simarouba glauca* (simarouba).	Silvipastoral with species diversity and intensive management (Mahua, *Simarouba*, Undi)
Agri-silvicultural use of rainfed farming areas (Castor, Sun-flower, safflower, sesamum, groundnut, linseed, *Jatropha*, *Pongamia*, mahua, neem and Simarouba)	Agri-silvicultural with perennial species (*Jatro-pha*, *Pongamia*, mahua, neem and *Simarouba*) and annual crops (mustard, castor, sunflower, safflower, sesamum, groundnut, linseed)
Farm boundary planting with crop lands to get improved micro-environment by planting *Jatropha*, *Pongamia*, neem and *Simarouba*	Fruit trees on farm boundary mixed with fast growing MPTS (multi-purpose tree species) like neem, mahua, perennial castor
MPTS mixtures around homesteads for shade, fruit, feed (*Sima-rouba*, castor, neem)	MPTS around homestead for fruit and energy (Mahua, *Simarouba*, castor, neem)

Studies conducted at the Indian Institute of Oilseeds Research, Hyderabad, with six and eight year Melia and Kapok plantations revealed that horse gram and cowpea were compatible as intercrops, which provide immediate return but need regular cultivation. Perennial fodder legumes such as *Stylosanthus hamata* provide leguminous green fodder in three to four cuttings per rainy season (9 to 12 t/ha) and also provide good soil cover to resist wind and rain erosion, weed control and enrich soil fertility (Sudhakara Babu *et al*, 2006). The productivity of tree-oilseed crops also improves with intercropping (Mukta *et al*, 2000). Ayyasamy (2004) reported that intercropping black gram, green gram, cowpea and red gram in Simarouba plantations recorded similar yields to sole cropping besides improving soil fertility in terms of pH, EC, and soil NPK content. Intercropping two rows of pigeon pea with Jatropha (3 x 3 m spacing) increased income in the early periods of establishing plantations (Rao *et al*, 2006).

Different agroforestry systems are suggested for suitability to varied growing situations

Situation 1: Deep Loamy, Clayey Mixed Red and Black Soils with Length of Growing Period (LGP): 120-150 days

Oil Seed based Cropping Systems: Castor + pigeon pea (2:1) / Sorghum / mung bean / Urad bean (6:1))/ cluster bean / Setaria and Cowpea

Parkland Systems: *Azadirachta indica, Acacia nilotica, Tamarindus indica*

Trees on Bunds: *Tectona grandis, Leucaena leucocephala, Borassus flabellifera, Cocos nucifera, Acacia nilotica var., cupressiformis, Pongamia pinnata*, Simarouba

Silvipastoral System: *Leucaena leucocephala* + *Stylosanthes hamata*, *Leucaena leucocephala* + *Cenchrus ciliaris*

Alley Cropping: *Leucaena leucocephala* + sorghum / Pearl millet, *Gliricidia sepium* + Sorghum / pearl millet

Agri-Horti System: Mango / Ber / Custard apple / guava / Pomegranate / Amla + short duration pulses.

Fodder/Green Biomass: *Leucaena leucocephala. Azadirachta indica, Albizia lebbeck, Albizia amara, Albizia procera, Bauhinia purpurea, Bauhinia monosperma, Dalbergia sissoo*

Medicinal and Aromatic Plants: *Catharanthus roseus, Cassia angustifolia, Aloe barbadensis, Withania somnifera, Cymbopogan martini, Cymbopogan flexuosus, Vetiveria zyzanoides, Psoralea, Palma rosa.*

Situation 2: Deep Loamy, Clayey Mixed Red and Black Soils with Length of Growing Period (LGP): 80-120 days

Oilseed based Cropping System: Groundnut + pigeon pea (7:1) / castor (7:1 or 11:1) / Pigeon pea (11:1) / pearl millet (6:2)

Agroforestry Systems: Crop + livestock (sheep / goat @ 10/ha) system is sustainable than crop system alone.

Trees on Bunds: *Tectona grandis, Leucaena leucocephala, Borassus flabellifera, Acacia nilotica, Pongamia pinnata*, Simarouba, *Jatropha curcas*

Fodder / Green Biomass: *Dalbergia sissoo*, *Gliricidia*, *Albizia lebbeck*, *Cassia siamea*, *Azadirachta indica* / stylo, Marvel grass

Fruits: Ber, custard apple, pomegranate, amla

Medicinal and Aromatic Plants: *Cassia angustifolia*, *Catharanthus roseus, Palma rosa, Vettiveria zyzanoides, Rose*, *Geranium*

Vegetables: Onion, brinjal, chillies, cowpea, cucumber, cluster bean, drumstick.

Situation 3: Deep Loamy, Clayey Mixed Red and Black Soils with Length of Growing Period (LGP): 60-90 days

Cropping Systems: Sunflower + Pigeon pea / Groundnut + pigeon pea (7:1) / castor (7:1 or 11:1) / Pigeon pea (11.1) / pearl millet (6:2)

Agroforestry Systems: Crop + livestock (sheep / goat @ 10/ha) system is more sustainable

Trees on bunds: *Tectona grandis, Leucaena leucocephala, Borassus flabellifera, Acacia nilotica, Pongamia pinnata*, Simarouba, *Jatropha curcas*

Fodder / Green Biomass: *Dalbergia sissoo*, *Gliricidia*, *Albizia lebbeck*, *Cassia siamea*, *Azadirachta indica* / stylo, Marvel grass

Fruits: Ber, custard apple, pomegranate, amla

Medicinal and Aromatic Plants: *Cassia angustifolia*, *Catharanthus roseus*, *Palma rosa*, *Vettiveria zyzanoides*, *Rose*, *Geranium*

Vegetables: Onion, brinjal, chillies, cowpea, cucumber, cluster bean, drumstick.

Information on annual oilseeds for assessing their suitability for diversification in different Agroforestry systems is presented.

Future thrust

Oils and fats are important as sources of food, fuel and oleo chemicals. Concerted efforts need to be made for value addition of oils/fats from tree borne oilseeds and their cake. Initiatives by Institutes like IICT are already in place to search for new sources of oil for industrial, edible use and oleo chemicals. Bio-lubricants are another useful class of chemicals which are under standardization to replace / supplement lubricants from petroleum sources. Factors limiting the utilization of tree borne oilseeds include technologies for quality collection, processing and value addition (Mukta, 2003).

In view of the awareness of the benefits of incorporating tree borne oilseeds in agroforestry systems, efforts are being made by ICAR and ICFRE as well as their affiliated Institutes in different states. The major focus includes collection of germplasm for the assessment of variability for oil content as well as the identification of plus trees for prioritized species as source of vegetable oils and biofuels (Paramathma *et al.*, 2009). Profitable systems incorporating better provenances and compatible intercrops are being identified. Besides developing systems for identified species, introduction of potential exotic including edible sources like Shea butter tree (*Vitellaria paradoxa*) from Africa, *Argania spinosa* from Morocco, *Canarium* species not native to India and *Bertholletia excelsa* from South America into suitable niches also needs to be focused on. Future initiatives should emphasize on development of technologies and mechanisms to ensure suitable returns and sustainability through incorporation of TBO's in various agroforestry systems.

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Chapter 6

Agroforestry in Watersheds for Natural Resource Management and Livelihood Security

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Introduction

Resource use in rainfed area is highly complex and risk-prone. Although the people in these areas are socio-economically backward and disorganized, yet they use the natural resources in an integrated manner. Un-controlled grazing and excessive felling of trees have compounded the vagaries of monsoon resulting in both drought and flood. Droughts of 1987, 2002 and 2009 have posed a challenge to researchers, farmers and policy planners alike. Droughts and floods are the key manifestation of monsoon rainfall but mitigation of impact and the extent of severity can be mellowed. It is the livestock that faces the brunt of droughts and floods. Alternate land use systems including agroforestry and pasture management can cope with the challenge to a large extent and reduce the pressure on meager natural resources. This campaign calls for "People's Movement" for their active participation, and continued co-operation in greening of common pool resources (CPRs) and private property resources (PPRs). Integrated Watershed Management Programme (IWMP) and Community Forest Management (CFM) programmes aim at protection and improvement of CPRs and PPRs.

Most common pool resources in semi-arid India are severely degraded with the breakdown of traditional management systems and exacerbated by encroachment. CPRs are often characterized by low excludability and high sub-tractability. Low excludability indicates everyone's interest in rights but not in sharing the responsibility while sub tractability denotes reduction in availability of resources with usage (Osman *et al*., 2001). Groundwater, grazing land and forest resources are the good examples of CPRs. Groundwater depletion will be the main challenge for India's agricultural and rural development in the coming decades (Honore, 2002). Majority of grazing lands have been already encroached and the rest are in highly degraded condition (Osman *et al.*, 2001). Groundwater resource has to be treated as 'National Resource' and its judicious use and rationalization is the need of hour. Forests with the launching of joint forest management (JFM) and community forest management (CFM) programs, mostly confined to degraded areas, are showing the signs of recovery. Panchayat Raj Institutions (PRIs) have to play a key role for sustained management and for improvement of CPRs. There is no dearth of technologies but there is a crisis of dedicated leadership at local level and flexibility in guidelines. CPRs are significant for the landless and poor people's livelihood and require pro-poor legal and policy support. Also, PRIs can help in framing of social regulations over management of CPRs through active involvement of line departments, financial institutions, NGOs, CBOs, UGs, SHGs, etc.

Resources like land, perennial vegetation and water bodies having ownership rights are termed as private property resources (PPRs) and are used at various levels of intensities. A necessity has arisen to make the best use of PPRs based on their carrying capacity in view of the short term and long-term goals of sustainability. The short-term focuses on market demand and profitability, where as the long term covers the soil health and amelioration of microclimate, besides protection and improvement of ecosystem at large to mitigate changing climatic scenario. Agroforestry systems essentially involve a perennial component to impart stability in production from farmlands. Perennials are known for drought tolerance or avoidance characteristics and can withstand late onset or early withdrawal of monsoon and prolonged dry spells that are recurrent in drylands.

Network research carried out in India revealed that alternative land use involving perennials (tree/crop, grass shrub or a combination of both) has advantages and can conserve natural resources and increase productivity (Osman, 2001). Some of the advantages of perennial are:

- They can thrive well in relatively resource-poor soils,
- Provides vegetative cover to the soil round the year, thus, substantially control erosion caused by both wind and water. The net result would be amelioration of microclimate.
- Provides good quality green fodder, which is in short supply to support livestock.
- Improves soil quality through nutrient cycling by mining of deeper layers, litter fall and root turnover.
- Reduce surface evaporation and weed growth when pruned material is applied as mulch at surface, thus, improve water use efficiency
- Provide fuel, timber and minor forest products (*e.g.* gum, honey) and thus will lessen the dependence of farmers on forest.
- Supplement the diet of poor farm families and ensure their nutritional security.
- Generate much needed cash when aromatic and industrial value plants are included.
- Supports development of flora and fauna particularly soil microbial and earthworm activity.
- Generates employment throughout the year, which substantially increases the cash flow and reduces migration.
- Central Research Institute for Dryland Agriculture (CRIDA) from the past experience identified some basic principles that govern the success of any agroforestry system (Osman *et al*., 1997).
- Selection of suitable land use system from various models like agri-horticulture, agrisilviculture, alley cropping, silvipasture, ley farming, tree farming, etc. This essentially involves sound farmer participatory planning, based on various components like soil, climate, native vegetation, and socio-economic aspects.
- Shrubs or trees that are not palatable to livestock can be successfully grown compared to palatable ones because of high stocking rate and uncontrolled open grazing system prevalent in dryland areas. Shrubs have been found to be more compatible with crops when compared to trees.
- The acceptability of farming community is more for fruit plants compared to fodder or fuel wood trees. Horticulture in drylands has wide scope, provided selection of right fruit plants and elite planting material having short gestation is made. Selection has to be based on flowering and fruiting stages coinciding with rainy and post-rainy season, respectively. Fruit trees like guava, custard apple, ber, tamarind that flower during rainy season are highly compatible and bear fruit during post-monsoon period. Agri-horticulture system is highly suitable for drylands, both for arable and non-arable lands.
- Improvement of planting spot (microsite) is a pre-requisite for success of any perennial plant in rainfed areas. This should be coupled with timely planting (with the onset of monsoon), so that the saplings establish well before cessation of rains and becomes hardy enough to pass through the first summer.
- *In situ* water harvesting: Water is always a critical factor in drylands. Plant survival can be greatly enhanced by shaping the land surface in the immediate vicinity of the trees so that runoff is concentrated in the root zone. Various methods can be used to shape the soil surface so that water

can concentrate in one area around the base of a newly planted sapling. The principle is to construct mini-watershed that collects sheet flow near the plant even if light rain occurs. On sloping lands, construction of half moon terraces may be appropriate.

- *Ex situ* Water harvesting: A provision of supplemental watering during establishment phase is a must for the success of plantation. There is a need to dedicate about 5 per cent of the area to harvest runoff in a pond. Packaging of farm pond technology involving digging of pond, lining of pond, lifting devices and efficient application method (drip / sprinkler) is the need of hour for the success of agri-horticulture systems.

Agroforestry Systems

Drylands being devoid of normal vegetation, agroforestry as an option for natural resource management is highlighted in Fig 6.1. Various agroforestry models suitable for drylands are discussed below and given in Table 6.1.

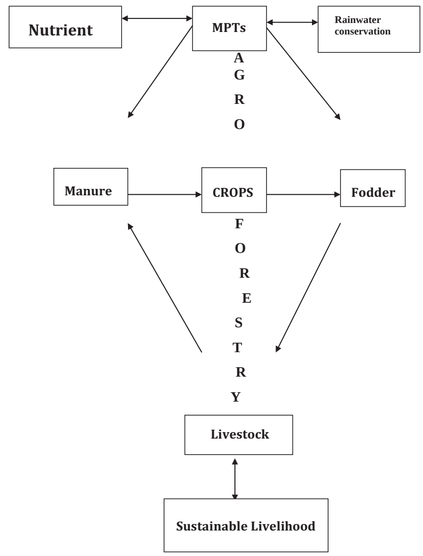

Fig 6.1 Agroforestry for natural resource conservation and livelihood generation on watershed mode

Agrisilviculture

Intercropping with Nitrogen Fixing Tree Species (NFT's)

Nitrogen continues to be one of the primary constraints for increased and sustained productivity of crops in drylands. Among various nitrogen fixing tree species (NFT's), *Prosopis cineraria* (Khejri) was found to be the most compatible with arable crops followed by *Acacia ferruginea, Albizia lebbeck* and *Leucaena leucocephala*. Pollarding of *Leucaena leucocephala* at 2.0 m height and frequent pruning during cropping period was found to reduce the competition between tree and crop and enabled a good harvest of sorghum and cowpea (Osman *et al*., 1998)

Bush Farming

Long term observations revealed that crops are compatible with short growing shrubs than with trees in drylands. Shrubs are the perennials with smaller canopy compared to trees. These are well suited to the rainfed regions and they offer least competition with the associated crops / vegetation. Plantation of economic shrubs and intercropping with arable crops would improve the production and income from rainfed areas apart from imparting the required stability.

Some of the shrubs that have shown the potential under rainfed conditions are henna (*Lawsonia inermis*), curry leaf (*Murraya koenigii*), annatto (*Bixa orellana*) and jatropha (*Jatropha curcas*). Henna has a potential of yielding 2500 kg dry leaf ha/yr from second year onwards. Curry leaf yields about 10,000 kg fresh leaf ha/yr from second year onwards. It can yield an additional yield by 2500 to 3000 kg ha/yr if the rainwater is harvested and recycled to irrigate the plants during the off-season. This system is profitable in places where there is demand for fresh curry leaf. *Jatropha* yields non-edible oil, though the survival of this plant is 100 per cent under rainfed conditions, but yield potential is low (600 to 700 kg/ha/yr). Annatto yields food grade dye and yields about 600-700 kg seed/ha from third year onwards. A stable market and price would make this plant popular. Further, short duration legumes such as black gram and green gram can be intercropped with curry leaf and annatto; they would yield 70 per cent of the sole crop. Cultivation of these species on a commercial scale will requires assured forward linkages with market for obtaining higher returns.

Alley Farming

In alley cropping food crops are grown in alleys formed by hedgerows of trees or shrubs. During the rainy season, the hedgerows are usually cut closer to the ground level with arable crops and kept pruned to reduce competition. Alleys when aligned along the contours act as vegetative barriers and conserve both soil and water. The suitable species are namely *Leucaena leucocephala*, *Gliricidia maculata* and *Cassia* sp.

Agri-Horticulture

Agri-horticulture system is one of the agroforestry systems that integrate the cultivation of arable crops and fruit trees. Because of high value, agri-horticulture occupies a prime position in the farming system research and development. Agri-horticulture systems are recommended for better land capability classes (LCC II and III) and in areas having water resources for supplemental irrigation. Integrated cultivation of guava (*Psidium guajava* cv Allahabad Safeda) and cereals/pulses yielded encouraging results (Das *et al.*, 1993). Higher monetary returns from agri-horticulture system were realized compared with monocrop or other tree based systems. Besides higher monetary returns, the runoff losses with agri-horticulture were 50 per cent of that with the monocropped system (Das *et al.*, 1993). The adoption rate of the "agri-horticulture" system is more when compared to other systems on account of risk distribution. The tree component is able to absorb weather related aberrations more efficiently. This approach lessens the financial imbalances during gestation period by regulating the income through intercropped annuals when the trees are too young to yield any beneficial produce.

Silvipastoral System

Marginal drylands, are usually poor in soil depth as well as nutrients. Yield of arable crops from these lands are low, uncertain and often not remunerative. The returns from these lands may improve if they are put to agroforestry system like silvipasture. Silvipasture system apart from yielding fuel wood and fodder, improves soil fertility. After one rotation with silvipasture system, say, 4-6 years, arable crops can be grown on the built up soil fertility, without fertilizer application, which is known as ley farming. This system need to be integrated with rearing of sheep and goat, which is a highly remunerative enterprise in drylands.

The silvipastoral system was found to be quite promising at CRIDA research farm. On an average, stylo yielded 4 t/ha/yr and *Cenchrus* 2.5 t/ha/yr of dry matter. The tree growth in stylo system was marginally better than that under the *Cenchrus* system. *Leucaena* dry matter accumulation was to the tune of 4 t/ha/yr and yielded 32 t/ha after 8 years, mainly through stem and branches. The soil organic carbon content increased from 0.15 to 0.57 per cent after eight years. The benefit to cost ratio was 2.45 as against 1.6 to 1.8 with sorghum and castor (Saharan *et al.*, 1989). In another study on canopy management of *Leucaena*, pasture production was more under pollarded trees than under non-pollarded ones. Biomass production of stylo and *Cenchrus* was 3.5 and 3.1 t/ha under pollarded trees compared to 2.0 and 1.7 t/ha under non-pollarded, respectively. The results revealed that efficient management of tree canopy is essential for the success of silvipasture system (CRIDA, 2002)

Farm Forestry / Block Plantations

Evaluation of Multipurpose Trees

Sixty tree species planted in 1989 are under test in a tree cafeteria at the research farm of CRIDA. One-third of the species had 100 per cent survival. Because of good survival and fast growth *Leucaena leucocephala* (var: K-636) and *Ailanthus excelsa* were found as promising trees for fodder and paper pulp production. Among oil yielding tree species, paradise tree *(Simarauba gluaca*) and hydro-carbon plant jatropha (*Jatropha carcus)* were found suitable for wasteland afforestation. The success of tree farming lies on developing a close linkage with the industry or value addition.

Block plantations of *Leucaena leucocephala*, *Casuarina equisetifolia*, *Eucalyptus sp*. are very common where the paper mills / industry are in near vicinity. In Prakasam and Nellore districts of Andhra Pradesh, *Leucaena* block plantations are popular and serving as an alternative to cultivation of tobacco, cotton, and chillies. In these areas farmers have realized that, *Leucaena* is superior to eucalyptus for improving soil health. Intercrops are grown in the first 1-2 years. Loppings from *Leucaena* are fed to livestock and it is the main constituent of the feed for buffaloes. Each farmer having a plantation of 2.0 ha is able to maintain three buffaloes and the income from the sale of milk (10 l/day) provides reasonable livelihood.

Protection of the perennial species, especially during the initial 2-3 years is important. This could be done through individual tree guards in case of high value widely spaced species or through social / live fences. A long-term approach would be to encourage stall- feeding of cattle, so that stray cattle menace is minimized. Stall feeding is already in place for cross-bred cattle. The live fences should be planned well in advance, as they require about 2-3 years to become effective. Some of the suitable species for live fences are *Gliricidia sepium*, *Agave sissalana*, *Jatropha curcas*, *Cactus sp.*, *Opuntia sp.*, *Prosopis juliflora*, *Balanites aegyptiaca*, *Pithecellobium dulce*, *Lawsonia inermis*, *Carissa carandas*, *Parkinsonia aculeata*, etc. These species, apart from protecting the crops, also yield by-products like green leaf manure, minor fruits, fodder, fiber, fuel wood, *etc.* Community mobilization for social fencing needs to be taken up as a campaign.

Conclusions

An agri-horticulture system distributes risk between perennial (sylvan) and annual arable (crop) components. Once firmly anchored, the impact of drought and abnormal rainfall distribution is minimal on perennial vegetation. Farm income stabilization, nutritional security and employment generation are possible by harmonizing fruit plants with arable crops. Poor returns in the event of large scale fruit production is a possible risk that we anticipate at this stage with agri-horticulture system. In order to sustain high profitability from agrihorticulture infrastructure facilities such as, cold storage, processing and marketing network need strengthening simultaneously.

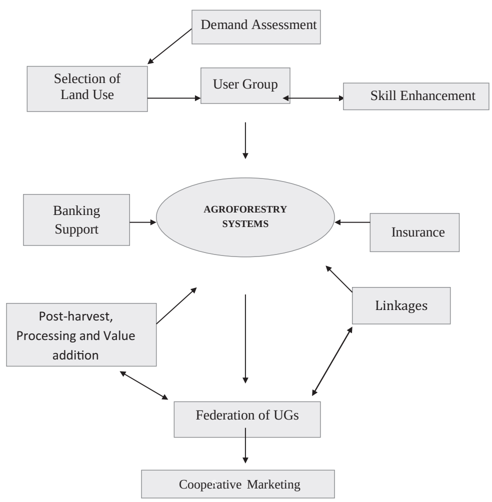

Fig 6.2 Strategy for popularizing agroforestry systems

The most important component of the strategy for popularizing agroforestry system is to assess the demand for the product in the market followed by formation of user groups (UGs), skills enhancement, banking support, insurance and linkages with other subsidiary enterprises and market (Fig 6.2). Exposure visit of the potential farmers to successful on-farm agroforestry models and hands-on training on different aspects is desirable to convince them to adopt the new models. Since farmers of dryland areas are used to single cropping season, the protection of perennials from stray (and their own) cattle during the non-cropping season is crucial. Capacity building should be undertaken for development of human resource, infrastructure, and institutional mechanism. For human resources, greater focus should be at grass root level. Adequate infrastructure for technology flow to grass root level, and related facilities needs to be created and nurtured for successful implementation of agroforestry systems on watershed mode.

Table 6.1 Agroforestry models for watersheds in selected rainfed regions

ACZ / (AERs)	Centre/Domain Districts	Rain fall (mm)	Soil type	Agroforestry models for*			
				SandWC	Fruit based systems	Biomass production	TBOs / MPTs for wastelands
Central / Eastern Vidarbha (6.3)	Part of Amaravati, Wardha, Buldana, east and west Khandesh districts of Maharashtra and parts of Adilabad and Nizamabad districts of Telangana State	813	Medium deep to deep black soils	Livebed of *Leucaena* / *Gliricidia* + grasses / *Stylosanthes hamata*	Aonla / ber / tamarind + crops	Dicanthium grass, *Cenchrus* grass	*Pongamia* / *Jatropha* / *Simarouba*
Southern Tamil Nadu (8.1)	Thoothukudi, Tirunelveli, Madurai, Virudhnagar and other southern districts of Tamil Nadu	743	Medium to deep black soils, red sandy loams	Hedge row intercropping of *Leucaena* + cotton	-	*Ailanthus* / *Ceiba pentandra* + curry leaf + senna	
Chittorgarh (4.2)	Districts of Udaipur, Chittorgarh, Bhilwara, Rajasamand and parts of Ajmer, Banswara and Dungarpur districts of Rajasthan	656	Medium, black loams	Shelter belts: *Acacia nilotica* var. *cupressiformis* / *Tecomella undulata* + Henna	*Aonla* / ber + fodders / short duration pulses	*Acacia nilotica* + Cenchrus	*Jatropha / Simarouba*
Kandi (14.2)	Ballowal Saunkhri, Kandi area along with north eastern border of Punjab	1000	Deep loamy to clayey alluvial	Maize + Bhabbar / *Saccharam munja*	Kinnow / Sapota / Peach / *Aonla* + crops	Bhabbar grass	*Jatropha / Simarouba*
Eastern Ghat (12.1)	Boudh, Rayagadh, Gajapathi of Orissa	1597	Well drained light textured sandy loams, highly leached acidic, lateritic soils	*Gmelina arborea* + Vegetative barriers	Unbunded uplands: Mango / Sapota / custard apple / Litchi / Jackfruit + crops/ turmeric / yam/ yam bean / Cassava + apiary	-	*Gmelina /* Sal, *Mahua / Simarouba*
Sub-Humid (12.3)	Jharkhand, Rohtas, Gay, Jamui in Monghyr dist., Banka sub-division of Bhagalpur dist in Bhir and Purulia and Bankura dist of West Bengal.	1200	Red, light textured, shallow sandy loams to sandy clay loams	*Gmelina arborea* + pine apple / *Gliricidia* / Vetiver / Bamboo	Litchi / mango / Jack fruit + ginger	Bamboo / Seri culture	Sal / Mahua
Semi – Arid (8.2)	Eastern dry zone	768	Red sandy to red loams	Dinanath grass / *Mucuna utilis* / *Pennisetum ohinekere* / Vetiver	Mango / Mulberry	Silver oak / Casuarina + guinea grass	*Simarouba*

ACZ / (AERs)	Centre/Domain Districts	Rain fall (mm)	Soil type	Agroforestry models for*			
				SandWC	Fruit based systems	Biomass production	TBOs / MPTs for wastelands
Scarce rain-fall (6.1)	Ahmednagar, eastern parts of Nasik, Pune, Satara, Sangli, Dhule and Nandur-bar, western parts of Beed, Osmanabad, Aurangabad, some parts of Jalgaon and Buldana districts	723	Soils very shallow to shallow, medium and deep black soils	Live bunding + grasses	Pomegranate / custard apple / Ber / *Aonla* + pulses / millets	*Leucaena* + Marvel grass	Neem / Melia
Scarce rain-fall hot arid ecosystem (3.0)	Kurnool, Chittoor districts of Andhra Pradesh.	520	Mixed red and black soils	Agave + groundnut	Custard apple / ber / tamarind + groundnut	*Stylosanthes hamata*	Neem
Malwa pla-teau (5.2)	Mandsaur, Rajgarh, Ujjain, Indore, Dewas, Shajapur, Ratlam, part of Dhar, Jhabua, part of Sehore dis-trict of Madhya Pradesh.	800	Medium to deep black soils	Henna + grasses	*Aonla* / ber + drumstick + soybean	Guinea grass	Teak / aon-la/ Neem

Note: * All the tree based systems should have micro catchments on mild sloping lands and contour trenches on sloping lands / graded bunds.

ACZ: Agro-climatic zone; AERs: Agro-ecological regions

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Chapter 7

Soil and Water Conservation Measures for Tree Based Systems

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Introduction

Tree based systems promote the conservation of natural resources particularly water and soil in the land scapes and can change the hydrological balance within the system. Large scale developmental efforts such as MGNREGA, IWMP and Horticulture Missions are being made to convert the wastelands or fallow lands to be brought under different tree based systems such as horticulture, Agroforestry systems etc. In the process, soils with low water holding capacity and shallow depth soils in low to medium rainfall zones located in undulating terrains etc are converted to tree based systems. In order to derive the optimum benefits through tree based systems, it is necessary that land be treated first with soil conservation measures so that even in low rainfall regions these systems might able to survive , though it may take a longer time to derive economical benefits. In the absence of this, the systems may not be in a position to establish themselves leading wastage of funds.

There are many time-tested technologies of soil and water conservation that can be adopted for tree based systems whether it is Horticulture, Agro-horti systems, Agro-forestry, Silvi-pasture system etc. Much of the literature dealing with growing trees in low rainfall areas come from Middle East countries etc. In India, tree plantations have been promoted on a wide scale in watershed development programme along with soil and water conservation measures such as continuous contour trenches, water absorption trenches etc. These interventions were chosen initially as *shramdan* of watershed beneficiaries and are promoted extensively to bring in the much needed vegetation on denuded hills. The type of soil and water conservation measure will depend on the size and shape of the areas to be developed for cropping, its location within the watershed of which this area is a part, the kind of plantation being taken up etc. For small farm fields areas, in situ conservation practices such as formation of basins, or micro relief systems and agronomic conservation practices may suffice whereas for large plantations, watershed scale development work may have to be taken up. The following section deals with few soil conservation measures which could be implemented for tree based systems in rainfed areas.

Soil and Water Conservation Systems

Majority of soil and water conservation measures include some type water harvesting with in the field which is often known as micro catchment water harvesting in which surface runoff is collected from a small catchment area and storing it in the root zone of an adjacent infiltration basin. This infiltration basin may be planted with a single tree, bush or with annual crops (Boers and Ben-Asher, 1982).

The advantages of MC-WH systems are:

- Simple design and cheap to install, therefore easily replicable and adaptable.
- Higher runoff efficiency than medium or large scale water harvesting systems; no conveyance losses.
- Erosion control function

- Can be constructed on almost any slope, including almost level plains.

The typical examples of this type of system: Negariam micro-catchments, contour bunds and semi-circular bunds (Critchley and Seeger, 1991), continuous contour trenches, water absorption trenches, staggered trenches, platform and trench type etc.

The general design principle of Micro catchment rainwater harvesting systems involves a catchment area, which collects runoff coming from ground surfaces which receives and concentrates runoff from the catchment area for crop water supply. The relationship between the catchment area and the cultivated area, in terms of size, determines by what factor the rainfall will be multiplied. For a more efficient and effective system, it is necessary to calculate the ratio between the two if the data related to the area of concern in terms of rainfall, runoff and crop water requirements is available (Moges, 2004).

Micro catchment systems provide many advantages over other irrigation schemes. They are simple and inexpensive to construct and can be built rapidly using local materials and manpower. The runoff water has a low salt content and, because it does not have to be transported or pumped, is relatively inexpensive. The system enhances leaching and often reduce soil salinity (Matthew and Bainbridge, 2000) The major techniques include: Pitting (wor105), earth basins, Strip catchment tillage, Semicircular bunds (wor105), earthen bunds, Meskat-type system, Negarim micro catchments (water harvesting, Sudan), contour ridges (swim07) and stone lines (Critchley and Siegert, 1991).

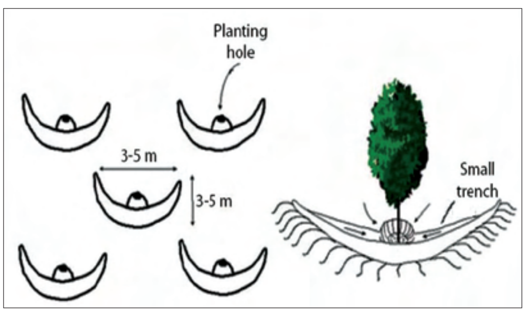
Pitting System

Pitting system consists of small circular pits, with about 30-50 cm in diameter and 20-50 cm deep, dug to break the crusted soil surface, to store water and to build up soil fertility. Organic manure and compost are usually added into the pit to improve fertility. It works by combination of water harvesting and conservation of both moisture and fertility in the pit. The catchment to command area ratio is about 3:1 and is suitable for rainfall of 300-600 mm/yr.

Earth Basins

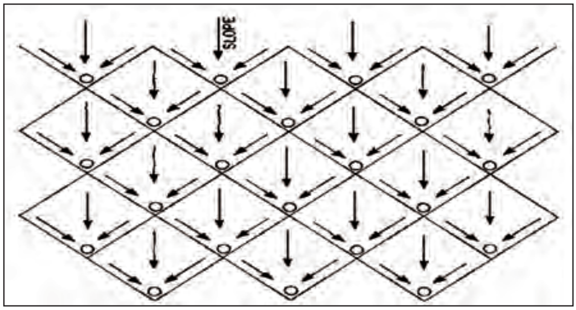
Earth basins are normally small, circular, square or diamond shaped micro catchments, intended to capture and hold all rainwater that falls on the field for plant use. They are constructed by making low earth ridges on all sides, to keep rainfall and runoff in the mini-basin. Runoff water is then channeled to the lowest point and stored in an infiltration pit. The technique is suitable in dry areas , where annual rainfall amounts are at least 150 mm, slops steepness ranges from flat to about 5 per cent, and soil that is at least 1.5 m deep to ensure enough water holding capacity. Earth basins are especially for growing fruit crops, and the seedling is usually planted in or on the side of the infiltration pit immediately after the beginning of the rains. The size of the basin may vary between 1 to 2 m in width and up to 30 m in length for large external catchments with a deep at about 0.5 m (Mati, 2005).

Earthen Bunds



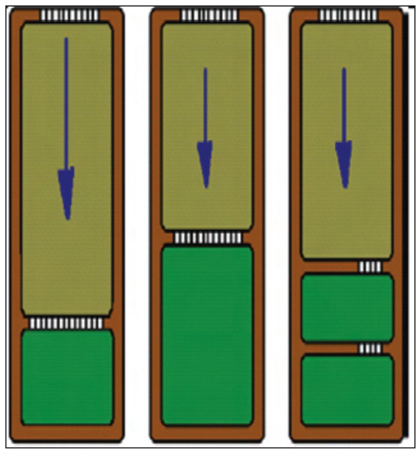
Earthen bunds various forms earth-shapings, which create run-on structures for ponding runoff water. The most common are within-field runoff harvesting systems, and can be easily done by manual labor and animal drought. The variations of the system include contour bunds, semi-circular bunds and negarims micro catchments. The normal designs for semi-circular bunds involve making earth bunds in the shape of a semi-circle with tip of the bunds in the contour.

The dimension of the holes and the spacing of the contours are dictated by the type of crop. For common fruits, the holes are made with a radius of at least 0.6 m and a depth of 0.6 m. the sub-soil excavated from the pit is used to construct a semicircular bund with a radius ranging from 3 m to 6 m on the lower side of the pit. The bund height is normally 0.25 m. the pits are mixed with mixture of organic manure and top soil to provide the required fertility and also to help retain the moisture.



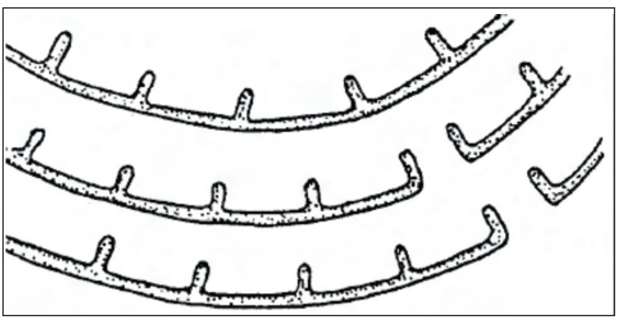
Negarims micro catchments are regular square earth bunds, which have been turned 45 degrees from the contour to concentrate surface runoff at the lowest corner of the square where there is an infiltration pit dug. The shape of the infiltration pit can be circular or square, with dimensions varying according to the catchment size. Manure or compost be applied to the pit to improve fertility and soil water holding capacity. The bund height changes with the catchment size and slope of the area. The catchment areas range from 10 to 100 m^2 depending on the specie of tree to be planted.

The catchment to command area ratio varies between 3:1 to 25:1 and suitable for rainfall regions of less than 600 mm/annum.



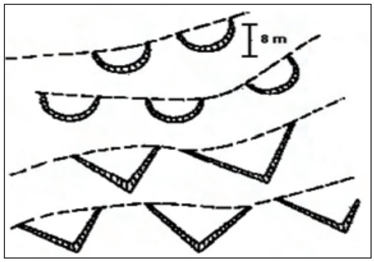
Meskat-type system is a type of micro catchment system in which the catchment area diverts runoff water directly onto a cultivated area at the bottom of the slope (Rose grant *et al.*, 2002). In this system instead of having catchment area and cultivated area alternating like the previous methods, here the field is divided into two different parts, the catchment area and cultivated area which is placed immediately bellow the catchment area. The catchment area must be compacted and free of weeds. The recommended ratio between the catchment area and cultivated area in Semi-arid areas is 2:1 (Hatibu and Mahoo, 1999). These types of systems are not normally practiced in India.

Contour Ridges is a micro catchment technique which consists on making ridges following the contour at a spacing of usually 1.5 to 2 meters, which means with a ratio between catchment and cultivated area from 2:1 to 5:1, respectively (Haile and Merga, 2002). Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. The systems can implemented in annual rainfall regions between 350 and 750 mm and on all soils which are suitable for agriculture, slopes from flat up to 5 per cent and smooth areas (Critchley and Siegert, 1991).



Semi-circular hoops (demilunes):

Triangular bunds: are also similar to contour ridges except that the bund are either formed in semi circular shape or triangle shapes and plating is done at place where runoff is collected within the bund. The catchment to cultivated area ratio is about 4:1 and can be taken up on lands with slopes of 2-20 per cent in annual rainfall regions of less than 600mm.

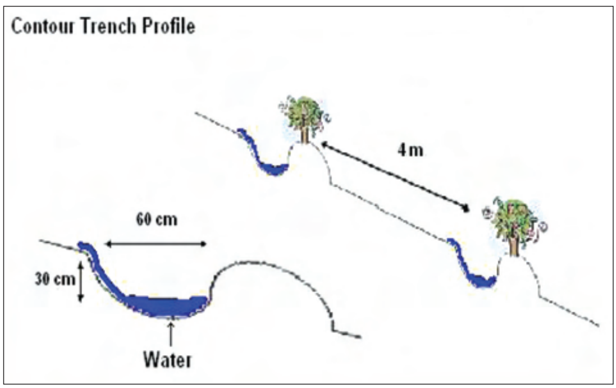


Inter row water harvesting: The catchment is divided in such way that part of area is considered as donor area and the land below is considered as receiver area. The donor area is kept vacant and sometimes measures are taken to induce runoff from this area so that it could be collected in the receiver area for meeting the water requirement.

Staggered Trenches / Water Absorption Trench / Continuous Contour Trench

At its simplest, contour trench construction is an extension of the practice of plowing fields at a right angle to the slope. Contour trenches are ditches dug along a hillside in such a way that they follow a contour and run perpendicular to the flow of water. The soil excavated from the ditch is used to form a berm on the downhill edge of the ditch. The berm is planted with permanent vegetation (native grasses, legumes) to stabilize the soil and for the roots and foliage in order to trap any sediment that would overflow from the trench in heavy rainfall events.

Water absorption trench (WAT) / CCT / ST treatment are proposed on hills and area where the catchment area and slope are more. Beside the soil and water conservation the main purpose of this treatment is to store and in filter the huge quantity of runoff. It is generally proposed on hills and at bottom of hills from where farms start. Therefore WAT treatment is very important as it increases soil moisture of down side fields.



This is low cost treatment and returns are in multiple compare to other drainage line treatments. It is also easy to plan, execute the work, maintenance and has life more than 10 years. It protects fields, which are at foothill side from damage and erosion of fertile soil. It also increases the moisture and simultaneously crop production in downside fields, which are mostly rainfed, and has low soil depth.

An average horizontal interval proposed between two consecutive contour lines is 20 m has been assumed depending upon the slope and given an average length of 100 m to 150 m/ha. The variation between CCT and WAT is the cross sectional area.

Trenches are not more than 15m length and are generally staggered with a cross of 0.3 *0.3 m or 0.5

*0.5 m with Side slopes of trenches are 1:1 or 0.5:1. The quantity of runoff expected to be collected is estimated by the following formula.

For continuous trenches

Q = w*d/(100*hi)

For staggered trenches

Q = w*d/(100*hi*(1+x/l))

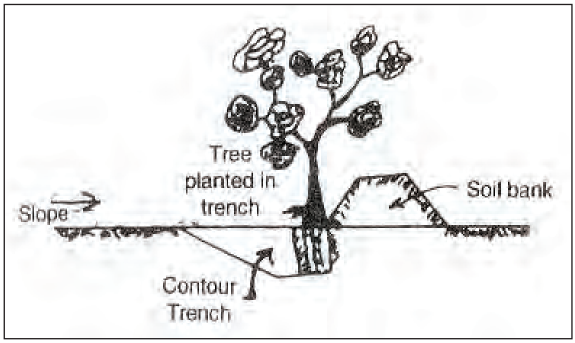
where

Q-depth of runoff from area, cm: w-width of trench, cm

d-depth of trench, cm:hi-horizontal interval, m

x-gap between trenches, m: l-length of trench, m

In medium rainfall areas with highly dissected topography, Staggered Contour Trenches (SCT) are



adopted. The length of the trenches is kept short around 2-3 m and the spacing between the rows may vary from 3-5 m. The chances of breaches of SCT are less as compared to Continuous Contour Trenches.

30 x 40 Model

The 30 x 40 model is a method of in-situ soil and water conservation. It involves dividing uplands into small plots of 30 x 40 ft (30 ft along the slope and 40 ft across the slope), digging pits at the lowest point in each plot and bunding the plot using the soil dug out of the pits.

Platform and Trench: In hilly areas, with slopes more than 15 per cent, a platform and trench is built around each tree. Platforms around trees are in the shape of a half moon, with a radius of 2 m, and have sloping sides. The platform is constructed with locally available stones or soil clods, or by filling murum. Height of platform varies according to the slope. A trench of 2 x 0.60 x 0.60 m is dug on the upstream side of tree.

Permeable Rock Dikes:

Permeable rock dikes are erosion control structures built along the natural contour of the land. They are built between 30 and

50 cm high and twice or three times as wide as they are high. They are made with different-sized stones and rocks, and the crest of the dike is horizontal. There are two main types of permeable rock dike: those without a filter layer, which are suitable for flat land with no gully erosion and those with a filter layer suited to land with heavy runoff. The permeable rock dike differs from the contour stone bund in that it is bigger in size, is constructed with various layers of stones and is designed to control stronger water flow. For this reason, such dikes are often constructed upstream of stone bunds to dissipate the force of the water flowing from the plateau and slopes. Permeable rock dikes are designed for use on cropland, but can also be used on forest / rangeland. They are recommended for ecological units with gravely and sandy-clayey soils and pediments. They can also be used to fill in small rills (Good Practices in Soil and Water Conservation and soil protection and restoration: An investment in Future Generations, (GIZ, 2012).

Prioritized rainfall based soil and water conservation measures for land capability classes of greater than 4 which are normally used for tree based systems is given below.

Land Capability Class	Rainfall <500 mm	Rainfall 500-750 mm	Rainfall 750-1000 mm
V	Outward Terraces	Outward Terraces	Outward Terraces
	Semi Circular basins	Semi Circular basins	Semi Circular Basins
	Small pits	Small pits	Small pits
	Hillside Ditches	Hillside Ditches	Contour Trenches
	Live Hedges	Live Hedges	Hillside Ditches
	Semi Circular Catchments	Semi Circular Catchments	Live Hedges
	Staggered Trenches	Staggered Trenches	Semi Circular Catchments
			Trapezoidal Catchments
VI	Outward Terraces	Outward Terraces	Contour Trenches
	Semi Circular basins	Semi Circular basins	Hillside Ditches
	Small pits	Small pits	Inward Terraces
	Hillside Ditches	Hillside Ditches	Semi Circular Catchments
	Live Hedges	Live Hedges	Trapezoidal Catchments
	Semi Circular Catchments	Semi Circular Catchments	Vegetative Buffer Strips
	Staggered Trenches	Staggered Trenches	
VII	Outward Terraces	Hillside Ditches	Contour Trenches
	Semi Circular basins	Inward Terraces	California type with Mechanical barrier
	Small pits	Semi Circular Catchments	Graded Terraces
	Hillside Ditches	Staggered Trenches	Trapezoidal Catchments
	Semi Circular Catchments	Trapezoidal Catchments	Vegetative Buffer Strips
	Staggered Trenches	Vegetative Buffer Strips	
	Vegetative buffer strips		

Land Capability Class	Rainfall <500 mm	Rainfall 500-750 mm	Rainfall 750-1000 mm
VIII	Hillside Ditches	Contour Trenches	Graded Trenches
	Inward Terraces	California type with Mechanical barrier	Graded Terraces
	Staggered Trenches	Hillside Ditches	California type with Mechanical barrier
	Trapezoidal Catchments	Inward Terraces	Trapezoidal Catchments
	Vegetative buffer strips	Trapezoidal Catchments	
		Vegetative Buffer Strips	

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Chapter 8

Inventory and Assessment of Trees Outside Forests using Remote Sensing and GIS

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Introduction

A foremost idea for a vegetation analyst, arising out of observing high resolution satellite images of a cultivated landscape, is to count tree crowns and assess the numbers, since their configuration in the contrasting background is appealing even to the uninitiated. However, due to pattern of trees either clustering in variety of habitats as well as due to terrain, ease of process is obscured soon. But due to the great strides in standardizing image processing algorithms and analyzing wide array of themes through GIS, can help to evolve a robust and reliable mechanism in doing this task.

Trees outside forests matter as a collective resource, since it reflects the way concerned citizens incorporate trees in to farming or urban avenues and in turn depend on them for range of needs (Arnold, 1996; Kumar *et al.*, 1994; Namwata, 2012), often casually. Indian scenario of major timber flowing from this sector, makes it a key element in planning timber resources for a developing nation. Above all, with at least three fifth (rest two fifths being forest or wasteland) of the country supporting one or the other form of tree outside forest, having a large anthropogenic dimension interwoven with its existence, makes it a dynamic case of woody and relatively permanent biomass, critical for understanding the carbon pools and fluxes. So we are dealing in this case a resource, which is discrete, highly dynamic, vastly spread, missing from earlier remote sensing applications yet critical for the upkeep of agro-ecosystem in future.

Here in an attempt is made to bring out the background of technologies suiting assessment of trees outside forests, based on experiences in applying principles of image processing as well as geographic information processing applied respectively to satellite derived high resolution images and spatial databases derived from various sources including satellite images. It is important to understand that geographic information system on its own can provide understanding about the overall status based on an earlier spatial study, but without a correspondence to current status of the resource as brought in by remote sensing imaging. Hence, any exercise needs to involve remote sensing imaging for a resource as dynamic as trees outside forests.

Inventory and Assessment

Inventory counts the entity or its attribute using sampling, while assessment defines the status and health of the resource to guide the plan intended. Finding out how many good trees prevail in the landscape is inventory, while what are the regional contours of tree health is assessment. Essentially a database should provide quantity and location of a natural resource for state-of-the-art management and hence spatial baseline is quite essential to provide spatially explicit assessment.

Inventory and assessment of any resource are two essential stages for managing it for a better productivity and sustenance. Inventory gets underway with a focus to report presence of the entity in time and space with a sampling frame supported by statistics generally. In case of natural resource study, statistical framework is critical while for any manufacturing process it can mostly be the census itself. Statistical design may be resulting from an a priori knowledge about overall spread of resource, supported by a spatial spread in addressing natural resources. Assessment is about deriving the inference about the status of the resource under question and drawing conclusion about condition, quality and amenability for utilization and conservation based on the specific traits considered while sampling (Kleinn, 2000). Use of various collection, measurement and analysis techniques and tools define the degree of complexity prevalent in the process. Comprehensive review of the issues related to TOF has been covered by Bellefontaine (2002).

Remote Sensing and Products

Application of remote sensing datasets for identification and mapping of trees outside forests satisfactorily assumes availability of high resolution remote sensing images. High resolution in spatial term means any spatial resolution lesser than 5 mts pixel, where as applications till now exploited 24 mts pixel. Remote sensing has evolved from stage of medium resolution to high and very high resolution in terms of spatial context, with concomitant increase in the information available in the images regarding discrete Earth bound entities of very small geographical extents. However, increase on spatial resolution meaning use of more pixels to define a given object, of vegetation origin or not, has rendered conventional image processing logic mostly to a limited scope especially for discrete objects like TOF. Conventional image processing algorithms focused on pixel based conceptualization of the image contents, meaning land cover extents were assumed to be homogenous and solution to categorize them was provided, with an accuracy tag with them.

Electromagnetic Spectrum and vegetation

Response of vegetation to different electromagnetic spectral regions especially red and near infrared regions is critical for identification of TOF elements from satellite images. However, response in green and shortwave infrared regions, which are other two spectral regions of any multispectral Indian Remote Sensing sensor, can also be valuable to further differentiate further categories of clustered trees outside forests, such as dense patches to open patches. Since trees being mostly evergreen while selected as intentional incorporation, they provide signals of vegetation mostly throughout the year.

Cartosat -1 Sensor and Imaging

Cartosat-1 is high resolution panchromatic sensor launched on 5th May of 2005 to observe Earth in a stereo mode using pair of camera tilted by 22 and 5 degrees in a fore and aft directions (towards ahead and towards back respectively). This sensor builds a black and white image using electromagnetic energy in the range of 0.4 to 0.75 micrometers with a stereo configuration. Cartosat PAN has 27 km swath and images same part of Earth only once in 48 days. Since satellite also has to image area away from nadir due to user requests, it may not cover the nadir area. Hence coverage of such high resolution images is limited and study has to accommodate this factor for setting the objective. Stereo images alone ensure best possible rectification of high resolution images to Earth terrain, where as non stereo high resolution images may not provide best geometry in hilly terrain due to parallax error. Parallax error is due to the fact that three dimensional objects result in different image geometry in different viewing directions and needs to be taken for high resolution images. Else two high resolution images may not match in terms of all the objects imaged.

LISS IV Sensor

In continuation with multispectral imaging protocol, IRS has built a high resolution image capable of imaging in four electromagnetic spectral regions at spatial resolution of 5.6 mts pixel. This sensor on Resourcesat -1 had only 23 km swath similar to Cartosat, however has been given a substantial improvement of increasing it to 70 km with a radiometry of 10 bit from an earlier radiometry of 7 bits. Improvement in radiometry as well as swath has improved the scope of this sensor for high resolution remote sensing considerably, hence for Trees outside forests (Singh, 2003).

Thematic Products

Land cover information for entire country is prepared as part of Natural Resource Census at 1:50 000 scale using IRS LISS III multispectral three season data for second cycle (2005-2006 period data) (NRSC, 2011). Study prepared database for more than 50 classes, which are generalized for 27 classes to be visualized on Bhuvan. Bhuvan is geo-visualization portal of ISRO supporting various display, query and data creation functionalities. Land use land cover information can help in setting up zones of interest for delineating TOF, since degree of presence of this resource with particular land cover is empirically known. In addition, land cover information can also help to prescribe a inventory scheme for field studies.

International efforts in assessing TOF as part of landscape dominated by agro-forestry or urban forestry seem to mostly have employed spatial resolutions of sub meter size using airborne sensors or space borne sensors. Airborne sensors such as CASI (Compact Airborne Spectrographic Imager) imaging in VNIR range with resolution less than half meter were employed to prepare a digital landscape of an agroforestry region in Kenya as well as to assess tree crop interaction in set ‘ digitally ’ planted situations. Classical study of Kenyan vegetation by Holmgren *et al.* (1994) used aerial images to report the sizeable quantity of trees prevailing outside forests. Expansion of Pinyon-Juniper woodlands in US also relied on bi-temporal aerial image based analysis.

Processing High Resolution Images

Current high resolution images, acquired using multispectral bands as well as panchromatic region result in to large number of pixels in a scene and similarly per entity. Entity can be any object situated in a scene ranging from a single tree crown to multitude of manmade objects as well as the small land cover sections having known contiguity of origin though with difference in spectral returns. For instance, a tree lit by sun at imaging time of the scene, may have shadowed crown as well as brightly lit portion, with varying grades of reflectance in between, which depending upon whether imaged in multispectral or panchromatic domain would result in to a complex set of pixels. These entities would have overlapping reflectance, in the sense, two trees would have similar set of reflectance due to imaging geometry and hence may belong to same category if we use conventional processing techniques. However, as per human cognition, it is clear that they are two distinct objects. Hence it was required to develop different image handling logic to arrive at categorization of entities in high resolution imaging domain.

Processing of satellite images can be achieved by following two major paradigms

a) Visual Interpretation as well as Combination with Rule based Extractions

Method may rely on setting up a clear interpretation key involving all image elements corresponding to trees outside forests. Image elements related to trees outside forests involve traits addressing configurations in terms of lines , patches or individual scattered tree crowns, like size of the entity, shape of tree crowns or clusters, tone of the patch, association with other image features etc. In case of high resolution image interpretation it is advisable to adopt grid based coverage of the area and advance from known sectors to complex sectors.

Apart from direct visual interpretation, combination with rule based GIS surfaces would also enable handling of complex situations quickly by avoiding poorly imaged or difficult to image areas by adopting a field based sampling. GIS rules can help to focus interpretation effort on optimal areas of the landscape followed by handling clustered areas by going for a statistically valid sample on ground to derive estimates.

b) Digital image processing involving direct delineation of tree crowns which in turn can consist of

i) Hybrid Approaches

Involve building aggregation of pixels and handling them as geographic entities through a series of hierarchical decision surfaces. This process is to eliminate per pixel approach and to capture the essence of entities to ingest them in to rule based approach. Rules may be for association or size or shape or properties of the group of pixels such as texture. Setting up of hierarchical rules can involve database sources from varied and unconnected theme also sometime.

ii) Object Based Image Analysis

This involves leaving the logic of pixels at the earliest stage and building aggregation of pixels with approved level of homogeneity (Baatz and Schaepe, 2000) as defined by the user intervention with respect to range of digital numbers as well as the size of entity intended. The aggregation is called objects and they follow across scale hierarchies (Joahansen *et al.*, 2010). It means a small object is embedded in a larger object above its scale. Smallest objects are defined by the users and other can be built in to coarser scales. Analogy of such a process can be trees inside stands, stands in turn inside the forest and forest in turn inside the watershed as seen in satellite image etc. The key concept of object oriented image processing was turned in to a very comprehensive software suite by Dr. Gerd Bennig, a German Nobel laureate for SEM. The software suite e-Cognition is based on object oriented image processing now formalized as GEOBIA to differentiate it from object based processing in the field of medicine or military applications of high resolution images. GEOBIA is Geographic Object Based Image Analysis corresponding to Earth observation applications.

E-Cognition enables most intuitive way of analyzing images for deriving image content (Fig 8.1). For an instance, a rule like if objects smaller than 100 m^2, showing high normalized difference vegetation index, with a shape near to roundness and sharing boundary with agricultural fallow, inside the agricultural landscape and away from major forest boundary by a distance of more than 200 mts can be a tree outside forest, may be implemented in this environment.

The ability to move seamlessly across scales can be observed as well as defining object traits can be possible. Range of object based traits itself is an unprecedented combination of spectral properties, property of association of digital numbers like image texture as well as associated with property of containing or contained objects. Probably it is one of the most comprehensive suite merging principles of image processing with rules of topology with an unprecedented sophistication and user friendliness. Demonstration suite of the software can be downloaded from the website of Trimble and familiarization may be built.

Geographic Information for Assessment

Enough expert knowledge exists in every thematic field regarding prevalence of trees in different formations. Thematic specialists dealing databases on water resources, urban systems, geological structures, regional planning, agricultural mapping, soil mapping, ocean and coastal processes, as well as microclimate modeling do have incorporated information of TOF in ways specific to the subject (Bellefontaine, 2002). Such a knowledge should get collated at a database so that rules of prevalence of

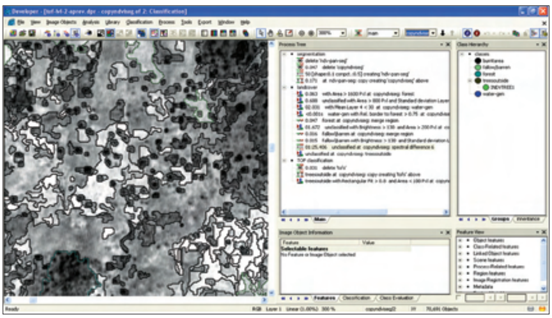

Fig 8.1 The object based image processing interface

trees outside forests are standardized and help in proper assessment of the resource. Bringing in such expert knowledge is possible using Geographic Information System since it enables spatial explicitness in handling spread of natural or man-made resources in optimal spatial and temporal detail. Comprehensive GIS algorithms available for collating, querying, reporting, analyzing as well as modeling the natural resource based structures and functions makes it a distinct domain of handling virtual landscapes efficiently.

Trees outside forests prevail as a result of natural processes or anthropogenic actions. Natural processes can be fragmentation of existing forest and preferential retention of selected species or natural regeneration of dispersed seeds due to agents such as birds, winds and animals. Such a prevalence is scattered across landscape. However, in general maximum proportion of TOF prevails as planted mass affected due to manmade plan. Such an addition of tree population is along with known infrastructure elements, such as roads, railways, farm bunds, pond rims, streams and canals. Degree of success of growth along with these elements can vary over wide range due to bio-climatic context. Apart from this, plantations grown as part of farm forestry initiative also adds up to the population, which of course do not follow very clear geographic rules as such. In addition, scattered trees established in discrete manner across agriculture landscape also may not follow any easily identifiable rules.

It is possible to collate information on aforementioned elements, referred as niche of trees outside forests or simply, “TOF niche”, in to a GIS covering vast swaths of TOF growth. Niche incorporates sense of space and time of interaction of biological being with its physical set up or habitat, hence relation of infrastructure elements with respect to TOF can be considered so. Currently most of this niche information is available from sources of topographic information or land use land cover map databases.

Geographic Information system has a great role in setting up the inventory design for sampling population of trees outside forests using multithematic information oriented around remote sensing derived content. Approximate image content derived with specified level accuracies can be integrated with digital terrain, proximity to various infrastructure parcels as well as land use land cover information to stratify the entire study area precisely and set up sampling framework to deploy inventory crew at a better precision pattern. Without a GIS iterative gap filling of remote parts of study landscape may be limited resulting in possible under sampling.

Assessment of National Level TOF

Current national level assessment by Forest Survey of India provides state level estimates of trees outside forests based on a stratified random sampling approach. Study adopts stratification of TOF formation over 60 blocks of the Country, based on IRS LISS IV or merged high resolution panchromatic data. Image processing approach relies on extraction of individual trees, linear formations and patch forests using per pixel approach as well as contextual correction to define the areas consisting of TOF. Following graphic illustrates the overall size of the covers to be considered as TOF and exclusions to be adopted for forests. Following definitions have been adopted for delineation of forest and trees outside forests based on IRS PAN and multispectral datasets.

Forest

Definition of forest is derived mainly based on three principles *viz.,* land use, crown cover and legal injunction either standalone or in combination. The FAO definition of forest or forest lands is based on tree formation structure, *i.e.,* percentage of crown cover, and height of tree species, plus the area covered.

Other woodlands include shrub cover and forest fallow.

Shrubs are “woody perennial plants, generally of more than 0.5 m and less than 5 m in height on maturity and without a definite crown. The height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 m approximately" (FAO). This definition thus embraces all low-growing woody formations.

TOF

Trees outside forests refers to trees on land not defined as forest and other wooded land (Fig 8.2). This may include agricultural land, including meadows and pasture, built-on land (including settlements and infrastructure), and barren land (including sand dunes and rocky outcroppings). It may also include trees on land that fulfils the requirements of forest and other wooded land except that:

1. the area is less than 0.5 ha ;
2. the trees are able to reach a height of at least 5 m at maturity in situ but where the stocking level is below 5 per cent;
3. trees not able to reach a height of 5 m at maturity in situ where the stocking level is below 10 per cent ;
4. iv) trees in shelterbelts and riparian buffers of less than 20 m width and 0.5 ha area.

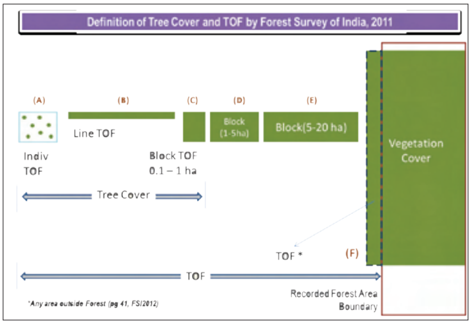

Fig. 8.2 Illustration of concepts of forest and TOF

* Tree: The expression « tree » in Trees outside forests includes both trees and shrubs.

Tree Cover

Tree Cover definitions have been adopted from Forest Survey of India methodology (SFR, 2011) which considers forest as the source of differentiation of tree entities and implies different categories of tree prevalence clustering various subcomponents.

Stratification arrived by image processing is employed for establishing sampling framework for each of the block with specified plot sizes for individual trees, line formations and block / patch formations. Data collected over each strata is extrapolated to each strata to estimate the TOF population. Rules of extrapolation need to satisfy basic rules of variability regarding the biomass or the diversity within the strata. Effort carried out is an operational one and addresses entire Country to build National estimates as well as provide biennial differential in overall average for the state as a non spatial product. It focuses more on arriving a biomass assessment so that efforts of greening up undertaken by various state department in increasing vegetation cover is represented properly in national tree biomass estimates. The method has its own strengths and has built a substantial baseline data regarding the diversity and distribution of the phytomass in TOF sector entire country for two reporting periods.

In line with similar effort, Andhra Pradesh has also taken up assessment of trees outside forests using Cartosat-1/LISS IV data for preparing a state wide database. Current pilot has been accomplished for Adilabad district. Methodology relied on interpretation of TOF elements from high resolution datasets and setting up a field based sampling to arrive at estimates.

Efforts at NRSC are done to develop a national approach using a grid based framework. Geospatial framework will be built to stratify grids based on niche factors (as earlier mentioned, the infrastructure elements holding the TOF) and select high resolution grids for content delineation using hybrid approach or object based methods. National framework of grids is primarily based on agro-ecological zoning, physiography and basin information to develop micro zones (about 200) across country. These would be selectively interpreted for high resolution image content and relations between the quantum of niche against TOF quantity estimated would be established for characteristic micro zone or group of micro zones. Such relation would help to quantify the TOF for entire Country to produce a spatially explicit TOF assessment (Pujar *et al.*, 2016).

As part of efforts to develop pilot understanding, two divisions of Haryana states were addressed using high resolution Cartosat -1 ortho-rectified panchromatic data as well as LISS IV data to develop TOF quantity as well as estimates on timber volume based on known volume equations following earlier efforts (FSI, 2000). Methodology involved designing a detailed classification scheme for addressing various configurations of TOF *viz.,* individuals, lines and tree patches and setting up clear rules of interpreting them from Cartosat images. Image elements of tones, texture and association as well as other critical field knowledge was considered for database preparation. High resolution images can help to segregate weakly manifested tree configuration in terms of growth also, as in case of degraded avenues, blocks and canal plantations. Database created was stratified for field inventory and data collected for different formations. Estimates of the spread of the resource generated, matched the average for the state as per published report of FSI. Yamuna Nagar had spread of about 111 km^2 and Panchkula at around 44 km^2, which matched the reported state-wise average of 75 km^2 (Pujar *et al.*, 2014).

Such efforts of assessing TOF are strengthening the resource understanding and can enable management of goods and services in a desirable manner. Increasing consideration of TOF as key element in debates related to implementation of REDD Plus or REDDES mechanism under UNFCCC is also noteworthy, since it provides a sound way of establishing an avoidance of degradation and ensuring carbon stocks for the 60 year or 20 year period to be earmarked for conservation of forest resources. Amenability of spatial framework to establish baseline, as well as scenario creation for field planting processes can handle most of the non-linear components of long term modeling of mitigation. Since GIS essentially incorporates principles of MARV, integration of such a discrete yet significant resource TOF may help to lend credence to the process.

Conclusion

Remote sensing coupled with GIS has a significant potential is assessing trees outside forests which is a discrete resource showing spatially diffuse spread not amenable to medium resolution remote sensing. Advent of high to very high resolution sensors have opened up scope for taking up assessment of this resource in a precise manner. Current experience of dealing with their image based delineation is still at initial stage, especially with regard to Indian context. However, incorporation of principles of GIS and associated statistical techniques can help to arrive at reliable solution and baseline database.

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Chapter 9

Managing Component Interaction in Agroforestry for Higher Yield

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Introduction

Multi tier systems make maximum use of the land. Every part of the land is considered suitable for useful plants. Emphasis is placed on perennial, multiple purpose crops that are planted once and yield benefits over a long period of time. Such benefits include construction materials, food for humans and animals, fuels, fibers, and shade. Trees in agroforestry systems also have important uses such as holding the soil against erosion and improving soil fertility (by fixing nitrogen or bringing minerals from deep in the soil and depositing them by leaf-fall). Furthermore, well-designed systems of agroforestry maximize beneficial interactions of the crop plants while minimizing unfavorable interactions. Most agroforestry practices produce multiple products including food, fiber and fuel, as well as income, shade and other ecosystem services, all of which need to be simulated for a comprehensive understanding of the overall system to emerge (Luedeling *et al.*, 2016)

The most common interaction is competition, which may be for light, water, or soil nutrients. Competition invariably reduces the growth and yield of any crop. Yet competition occurs in monoculture as well, and this need not be more deleterious in agroforestry than monoculture systems. Interactions between components of an agroforestry system are often complementary. In a system with trees and pasture, with foraging animals, the trees provide shade and/or forage while the animals provide manure. Thus, agroforestry systems limit the risks and increase sustainability of both small- and large-scale agriculture. Agroforestry systems may be thought of as principle parts of the farm system itself, which contains many other sub-systems that together define a way of life.

A microclimate is the climate of a small area that is different from the area around it. It may be warmer or colder, wetter or drier, or more or less prone to frosts. Microclimates may be quite small – a protected courtyard next to a building, for example, that is warmer than an exposed field nearby. Or a microclimate may be extensive - a band extending several miles inland from a large body of water that moderates temperatures. Interactions in agroforestry can be positive, neutral or negative. A positive interaction is the complementarity between woody and herbaceous components in resource acquisition. Competition between components for water, nutrients and light is one example of negative interactions. Allelopathy, damage caused by animals or pests, and disease transmission are other negative interactions. Neutral interactions occur in agroforestry systems when the different components of the system exploit the same pool of resources, and increases in capture by one species result in a proportional decrease in capture by the associated species (Atangana *et al.*, 2014)

Summary of benefits Multi Tier cropping systems

Agro ecological intensification (AEI) integrates ecological principles and biodiversity management into farming systems with the aims of increasing farm productivity, reducing dependency on external inputs, and sustaining or enhancing ecosystem services (Garbach *et al.*, 2017).

- Improved year-round production of food and of useful and salable products.
- Improved year-round use of labor and resources.
- Protection and improvement of soil (especially when legumes are included) and water sources.
- Increased efficiency in use of land.
- Short-term food production offsetting cost of establishment of trees.
- Furnishing of shade for vegetable or other crops that require or tolerate it.
- Medium and long-term production of fruits.
- Long-term production of fuel and timber.
- Increase of total production

Exploitation of interactions between woody and non woody (herbaceous or annual crop) components is the key to the success of all agroforestry (AF) systems. Therefore, a better understanding of the interactions provides an impetus strong for improvement of traditional, as well as evolving, systems

Radiation Use in Multi Tier Cropping Systems

In agroforestry, tree and agricultural crops are combined together and they compete with each other for growth resources such as light, water and nutrients. The resource sharing by the components may result in complementary or competitive effects depending upon the nature of the species involved in the system, the manner in which they are grown and depending on the climatic factors, plants and trees may influence its neighboring species, not only adding or removing of some factor, but also by affecting conditions such as temperature, light or wind movement or by altering the balance between beneficial and harmful organism. Opportunities for substantial temporal complementarity exist for storable resources like water and nutrient in a system if major resources demand is at different times. On the other hand for unstorable resources like light spatial complementarity is the only phenomenon available. The amount and spectral distribution of sunlight reaching the ground beneath a tree canopy depends not only on the crown closure, but also on the way that the canopy is structured. Young provides an illustrative example of this, showing how a 25 per cent tree cover can be arranged in different ways. Thus a plot of land can have the trees in a block, encircling the plot along its boundaries.

A great number of studies report that the tree shade, by reducing the photo synthetically active radiation (PAR) intercepted by crops, leads to a decrease in yield. The reduction of PAR increases with the time (22 per cent lower during wheat flowering, 56 per cent at maturity) (Li *et al.*, 2008) and the yield of cereal can decreased by more than 50 per cent (Dufour *et al.*, 2013). The varieties proposed to farmers are all bred under full sun and therefore they are not the best adapted to shade conditions. The first step to assess breeding criteria for shade tolerance is to determine if it exists a genetic variability in the target crop for the following traits: (i) plant and leaf shape that are able to capture more light, (ii) photoperiodic need, (iii) radiation use efficiency (RUE), (vi) phenology. Theoretically, wheat yield potential could increase by genetically improving RUE (Molero *et al.*, 2015) and phenology of crop should also be studied to better match the period of unshaded (Desclaux *et al.*, 2016)

Single-Layered Canopy vs. Deep Canopy

A deep canopy with more-or-less uniform distribution of vegetation elements has often been characterized (with respect to the attenuation of direct-beam radiation) as a uniformly scattering medium. In this case, the solar beam is attenuated according to the negative exponential equation:

I (below) /1 (above) = exp (-kx)

Where, x is the path length through the medium and k is an attenuation coefficient, a constant for a particular medium. If the canopy consists of a single layer of horizontal leaves, the solar beam is not attenuated, and the same proportion of direct-beam sunlight is transmitted at all solar angles:

I (below) /1 (above) = constant

The important factor to be considered here is the Maximum light-use efficiency. The biomass yield limit is set by the available amount of light, its efficiency of interception and the efficiency with which intercepted light is converted into biomass. Eco-physiological models calculate quantitative phenotypic traits (e.g. transpiration rate, expansion rate of organs or biomass accumulation) from environmental inputs such as organ temperature, light irradiance or soil water potential.

The capture of radiation and its use in dry matter production depends on the fraction of the incident photo synthetically active radiation (PAR) that is intercepted and the efficiency with which it is used for dry matter production. Intercepted radiation (Si) is often estimated as the difference between the quantity of incident radiation (S) and that transmitted through the canopy to the soil (St). However, this approach has inherent technical and theoretical difficulties since is does not account for the reflection of incident radiation from the canopy surface (typically 5–20 per cent depending on surface characteristics and moisture content), or for radiation intercepted by non-photosynthetic canopy elements. As a result, interception by photo synthetically competent tissues may be greatly overestimated, particularly for canopies which are senescing or contain numerous woody structural elements. Corrections for these errors have often been ignored when estimating Si and photosynthetic efficiency.

The quantity of radiation intercepted depends on the amount received by the canopy, its size and duration and fractional interception (f). The seasonal time course of f, defined here as Si/S, varies greatly depending on canopy architecture and the phenology of the vegetation involved; thus, f increases more rapidly in cereals such as sorghum (*Sorghum bicolor*) than in legumes such as groundnut (*Arachis hypgea*), reflecting their differing rates of leaf initiation and expansion. The variation in f between crops is generally smaller than that in green leaf area index, partly because the extinction coefficient for radiation (k) is often larger in species whose canopy expands slowly; maximum f values may therefore differ little between crops grown under non-limiting conditions. Mean f values calculated over the duration of the crop (fN) are generally lower in short-duration cereals (ca. 0.5) and legumes (ca. 0.15) than in perennial species (ca. 0.9), largely because of the differing duration of ground-cover

The conditions and methodologies used in radiation studies in monocropping and annual crops are clearly not met in intercrops or agroforestry systems because of the extensive horizontal and vertical variation in canopy structure introduced by the intimate mixture of species with differing planting dates and arrangement, heights and maturity dates. Canopy architecture is also constantly changing in mixed cropping systems because of the differing growth rates and canopy durations of the component species. For example, compact l legumes growing adjacent to taller cereals initially experience greater competition than in the equivalent monocrop because of the faster growth of the cereal, but subsequently experience less competition for much of the reproductive phase due to the earlier harvest of the cereal component. The methodological problems involved in characterizing the spatial and temporal variation in radiation interception are much greater in mixed communities than in monocultures, and the partitioning of radiation interception (and also water uptake) between the components of such systems has provided a major challenge. When growth is not limited by water or nutrient supplies, the quantity of biomass produced by monocrops is limited primarily by the quantity of radiation captured.

Transmitted radiation under trees shows variability in space and time that may have implications for the under storey. Light measurements are made in a young agroforestry system to assess the radiation distribution below the tree canopy. Measurements show that the variability of the transmitted radiation is mostly due to the size of the tree shadow and to the irradiance distribution in the shaded area. The light measurements are used to test the predictive capacity of a three-dimensional radiative transfer model based on the turbid medium analogy. The model correctly simulates the fraction of sunlit area and the irradiance distribution in the shaded area. However, it underestimates low radiation values and fails in describing the fine spatial pattern of transmitted radiation because of the stochastic nature of the radiation field. To obtain a mean error less than 15 per cent of the incident radiation, the distribution of transmitted radiation has to be described by elementary soil surface areas over 0.08 m^2. By manipulating time and number of hedgerow pruning's and pruning height, it was possible to reduce competition for light and water and to decrease water stress in the crop, thereby increasing crop yield. The use of the acquired resources was therefore assumed to depend on the conversion coefficient of the species involved and environmental influences such as drought. A major advantage of expressing productivity in these terms is to emphasize the apparent conservativeness of e under many conditions. This approach has subsequently been widely adopted in studies of resource partitioning in intercropping and agroforestry.

Shade Tolerance

Currently, there is no acceptable definition of shade tolerance but it may best be defined, agronomically, as the relative growth performance of plants in shade compared to that in full sunlight as influenced by regular defoliation. It embodies the attributes of both dry matter (DM) productivity and persistence. Morphological acclimatization of forages to light attenuation is an adaptive strategy to compensate, at least partially, for the lower photosynthetic rate per unit leaf area. In addition, chemical changes may also occur under low light to enhance photosynthetic efficiency. For both grasses and legumes, species differences were greater under moderate to high light transmission than under low light. The low yield potential of all species in low light remains a major constraint to forage productivity in plantations which close their canopies with age. However, in plantations with open canopies such as coconut, species with medium shade tolerance can be exploited to obtain higher yields.

Challenges Ahead

Progress in tropical agroforestry is more advanced, and perhaps more urgent at present, than in temperate agroforestry. However, many challenges still lie ahead in tropical agricultural research. So far, most studies have considered only two species growing simultaneously in intercropping or agroforestry systems, but the question remains of how to deal with the multi-species ecosystems which typify the vast majority of tropical agriculture. It is not an exaggeration to say that scientists and development experts are somewhat frustrated about the results and progress of agroforestry research. Scientists are unhappy that the science of agroforestry has not progressed to the extent desired and are, perhaps, also concerned that progress during the immediate future will be no brighter. Another major challenge facing tropical biologists is how to look beyond the plot and farm in order to deal with the 'interactions' between the mosaic of land uses at the landscape, regional and global scale. For example, agroforestry practices such as boundary planting and the use of widely scattered trees may create extensive interactions both above-ground in terms of microclimatic modifications and below-ground in terms of resource capture since tree roots may extend 20–60m from the trunks. Hence more progress may be made by defining relevant concepts and establishing general principles, than by collecting yet more empirical information. In the semi-arid tropics the prime consideration in the planning and management of agroforestry systems should be appropriate and efficient use of available water, with particular emphasis being placed on optimizing its partitioning between tree and crop components. Whenever we seek to improve the aerial environment within specific systems we should always be aware of the possible implications and consequences of below-ground interactions.

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Chapter 10

Capture of Light and Water and their Utilization in Agroforestry Systems

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Introduction

Agroforestry systems are expected to spread over millions of hectares during the twenty first century in both temperate and tropical countries (Nair, 2007). In India the current area under agroforestry is estimated at 25.32 Mha, or 8.2 per cent of total geographical area of the country (Dhyani *et al.*, 2013). This includes 20.0 Mha in cultivated lands (7.0 Mha in irrigated and 13.0 Mha in rainfed areas) and 5.32 Mha in other areas such as shifting cultivation (2.28 Mha), home gardens and rehabilitation of problem soils (2.93 Mha).

Agroforestry is also promoted as a strategy to overcome issues of climate change through both reducing the source and enhancing the sinks of greenhouse gases and through adapting to a production that fits in the changed climate (Smith *et al.*, 2014). Moreover, the important elements of agroforestry systems that can play a significant role in the adaptation to climate change include changes in the microclimate, protection through provision of permanent cover, opportunities for diversification of the agricultural systems, improving efficiency of use of soil, water and climatic resources, contribution to soil fertility improvement, reducing carbon emissions and increasing sequestration, and promoting gender equity (Rao *et al.*, 2007).

The productivity of both trees and the understory is highly dependent on resource availability and competition processes. Competition for light, soil water and nutrients is a major concern in Agroforestry systems (Sanchez, 1995). Water as a resource is essential for survival and growth of plants. Light provides energy for the photosynthetic processes and sets the potential for crop production (Loomis and Williams, 1963). Lal (1989) observed light to be limiting in the presence of adequate soil water while Ong *et al*. (1991) considered soil moisture alone, not light to be critical in the tropics limiting production in alley cropping studies. Competition for light and soil water is intimately related to one another (Cannell, 1993). A decrease in crop yield in agroforestry systems may be a response to water deficits or low availability of light or a combination of both. In this article, attempt was made to discuss in detail about light interception and water use, their measurements with some case studies for increasing the productivity of agroforestry systems through suitable interventions.

Solar Energy Interception

The yields of crops, whether tree crops or ground crops, are dependent on the radiant energy which they intercept. In order to estimate the potential productivity of crops, whether growing alone or mixtures, it is first necessary to know how much PAR is intercepted. In considering the potential productivity of multiple cropping systems, especially intercropping systems involving trees, shrubs and ground-cover crops, it is essential to be able to estimate the PAR intercepted by each of the component crops at any given time and to integrate this over the time they occupy space.

Two techniques can be used to calculate energy interception and distribution in discontinuous canopies of any form.

The first is the Monte-Carlo method used by Oikawa and Saeki (1977) and Oikawa (1977). In this the position of each leaf is defined in three-dimensional space in a computer simulation and penetration of beams of light of similar angular distributions to those occurring in nature is calculated. Such a technique requires access to a powerful computer and would, even then, be very laborious if applied to canopies of complex and irregular geometries with varying leaf characteristics.

The second (Jackson and Palmer, 1979; 1981) defines the basic functional relationships at the varying hierarchical levels rather than taking the individual leaf as the unit. It, therefore, treats a row of trees or a single tree as a unit with respect to some of its properties. Such an approach involves some simplifications and approximations and is easy to use, does not require expensive facilities.

Energy Interception by Discontinuous and Multi-Storey Canopies

With continuous-canopy crops such as wheat the calculation of light interception and distribution is governed by the equation

$I_L/I_O = e^{-KL}$ ..... (1)

where I_O is the light intensity above the canopy, I_L the light intensity below the canopy with a leaf area index of L. Leaf area index is expressed as m^2 leaf area/m^2 ground area, and K is an extinction coefficient.

This equation cannot be applied directly to a horizontally discontinuous two-layered canopy of trees and a ground-cover crop, but it can be applied, in a slightly modified form, after we have taken separate account of the light which reaches the ground-cover crop without passing through the canopy of any individual tree. Total transmission (penetration) to the ground-cover crop (T) is the sum of T_f (light which misses the trees completely and would reach the ground crop) and T_c, light which has passed through the canopy of the trees, that is

$T = T_f + T_c$ ..... (2)

T_c is related to the depth of the tree canopy and the density with which leaves are arranged within it and will be governed by an equation similar to (1). It would, however, be inappropriate to use L (leaf area per unit of total ground area) as the measure of depth of tree canopy penetrated. A more realistic measure is the tree leaf area per unit of ground surface which it potentially shades, that is the unit area enclosed by the outline of the projected cast shadows of the trees in direct light. This, defined as L’, can be calculated with respect to both direct and diffuse light by equation (3)

$L' = L/ (1- T_f)$ ..... (3)

in which T_f is defined as in equation (2) and expressed as a decimal fraction of the light which would reach the ground-cover crop if there were no trees, that is of the irradiance per unit horizontal surface above the canopy.

The total light reaching the upper surface of the ground-cover crop after transmission through the tree canopy (T_c) is

$T_c = (1- T_f)\, e^{-KL'}$ ..... (4)

and total transmission (T) to this 'under crop' is

$T = T_f + (1- T_f)\ e^{-KL'}$ ..... (5)

For the tree crop, maximum fraction of available energy, which it could intercept is $(1- T_f)$.If this is re-defined as F_{max} then

$T = T_f + F_{max}\ e^{-KL'}$ ..... (6)

and the fraction (F) of the available energy actually intercepted by the trees will be as in equation (7)

$F = F_{max} - F_{max}\ e^{-KL'}$ ..... (7)

T represents, for the ground-cover crop, the total radiant energy available above its canopy as a decimal fraction of that available above the trees. If this ground-cover crop forms a closed canopy over the surface of the ground then the energy intercepted by this crop can be calculated from equation (1) with I_O given the numerical value of I_O x T. If the ground-cover crop is markedly discontinuous with large gaps of bare soil then its energy interception can be calculated from an equation analogous to equation (7), bearing in mind that the value of F obtained relates to available energy at the upper surface of this crop (I_O x T) not total available energy above the multiple-crop canopy.

Distribution of Radiant Energy within the Trees and the Ground-Cover Crop

Lower layers in the canopy frequently contribute little to photosynthesis (Allen *et al*., 1974) and may contribute nothing to the economic yield of trees so it is wasteful to grow canopies to more than a certain depth. For the continuous cover crop it can readily be shown from the Monsi and Saeki (1953) equation (1) that if we define L_I as the leaf area in that upper zone of the canopy within which irradiance as measured on a horizontal surface is I or more, then

$L_I = (1n\ I)/(-K)$ ..... (8)

in the discontinuous canopy

$L_I = F_{max}\ [(1n\ I)/(-K)]$ ..... (9)

Measurement of Necessary Parameters

In order to calculate energy interception by its components, we need to know the leaf area index (LAI), K and F_{max}. LAI is laborious to measure but special techniques can reduce the labor involved in its measurement on some tree crops because leaf area is usually related to trunk girth. K, the light extinction coefficient, can be calculated by using the Monsi and Saeki equation (1) following measurement of radiant energy by radiation sensors held horizontally above and below a sector of canopy of measured LAI. For the calculations to be valid the sector of canopy must be fairly continuous and large relative to the sensors so that the radiant energy falling on the lower sensor has actually passed through the measured canopy. Determination of K must be over a time period appropriate to that over which the equations are to be used. For example, it should be based on daily or even weekly integrals of radiation. F_{max} (that is $1-T_f$) can be calculated, as long as the shapes of the discontinuous canopy elements are simple, over any desired period of time by using simple computer or desk calculator routines based on known distributions of sun and sky irradiance.

Water Use of Crops under Agroforestry

The highest possible yield of a crop can only be assured under conditions leading to maximum photosynthesis per unit area of land. In the case of C_3 and C_4 plants the stomata remain open as long as possible during the day to ensure maximum CO_2 uptake. This can only occur when the leaves are not water stressed. Water-use of plants is determined by (i) available energy (radiation R) and the fraction of total R which is used for evaporation of water (latent heat λE), (ii) saturation deficit (SD) and aerodynamic resistance (r_a), which depends on relative humidity, temperature, wind-speed and height and structure of the plant-surface, (iii) leaf-area (index) and (iv) plant species characteristics which determine the hydraulic resistance of water through the soil-plant-atmosphere continuum. The latter two factors determine the canopy resistance (r_c).

Empirical Estimates of Evapo-Transpiration or Water Use

Using a Combination of Meteorological Data

Under non-limiting water conditions and assuming a complete crop cover, transpiration (evaporation) occurring at a potential rate (E_T) is determined largely by the evaporative conditions of the air. Essentially, three factors are responsible for evapo-transpiration.

1. The Vapor Pressure Deficit of the Air (VPD)

It is the difference between the vapor pressure of saturated air (e_s), at the prevailing air temperature and the existing vapor pressure (e). Thus,

$$ET \alpha (e_s - e)$$

2. Wind Speed

Increasing the wind speed leads to greater turbulent transport of water vapor from the leaves to the bulk air above. The taller the plant, and the rougher and larger the crown, the greater will be the rate of turbulent transport at a given wind speed. This is one of the reasons why, under the same conditions, tree crops transpire faster than shrubs and herbs, and that is why water intercepted on tree foliage evaporates more rapidly than an open water surface at ground level. For a given crop at a given wind speed ET can be expressed as a simple function of the wind speed (U).

3. Heat Energy

In order to convert liquid water to water vapor heat energy (latent heat) is required and normally this comes directly from solar radiation. The balance that is the rate at which energy is being absorbed by the foliage is known as the net radiation (R_N). Ignoring the small fraction used in photosynthesis, and allowing for a certain amount of heat stored in the foliage and ground (G), the remainder, R_N-G, is dissipated by heat loss to the air (H), and as latent heat in evaporation (λE where λ = latent heat of evaporation). Thus, Penman (1963) combined the aerodynamic factors (VPD, U) with the energy factor (R_N-G). His original equation related to the rate of evaporation from an open water surface (EO). Later, by taking into account the reflection coefficient of the crop, and its extra roughness, he produced a second equation which could be applied directly to the crops:

$$E_T = \frac{\left(\frac{\Delta}{\gamma}\right)(R_N - G) + 0.35\left(1 + \frac{U}{100}\right)(e_s - e)}{\Delta + \gamma}$$

Where Δ = the slope of the saturation vapor pressure/temperature curve at the mean air temperature and γ= the psychrometric constant

Although originally based on a complete short grass cover, this equation with minor modifications to the empirically derived coefficients has been found to apply with reasonable accuracy to other crops, including deciduous forest, over a wide range of climates.

Penman-Monteith Equation

The most straight forward and still the most comprehensive energy budget equation was developed by Penman and modified by Monteith. This equation is useful in predicting water-use of canopies. From the original Penman-Monteith equation and the equations of the aerodynamic and canopy resistance, the following FAO Penman-Monteith equation was developed.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where

ET_o reference evapo-transpiration [mm/day]

R_n net radiation at the crop surface [MJ/m^2/day]

G soil heat flux density [MJ/m^2/day]

T air temperature at 2 m height [°C]

u_2 wind speed at 2 m height [m/s]

e_s saturation vapor pressure [kPa]

e_a actual vapor pressure [kPa]

$e_s - e_a$ saturation vapor pressure deficit [kPa]

Δ slope vapor pressure curve [kPa /°C]

γ psychrometric constant [kPa /°C]

The FAO Penman-Monteith equation determines the evapo-transpiration from the hypothetical grass reference surface and provides a standard to which evapo-transpiration in different periods of the year or in other regions can be compared and to which the evapo-transpiration from other crops can be related.

Relationship between Transpiration and Solar Radiation / Vapor Pressure Deficit

Transpiration followed the solar radiation pattern more closely during the morning till noon period than in evening (Fig.10.1). Transpiration continued at a higher rate till 1500 hours, although there was a reduction of incoming radiation. Transpiration continued even after the sunset (1800 hours), but at a negligible rate and ceased around 2000 hours.

A comparison of daily sapflow in forenoon and afternoon showed that 47 per cent of the total sapflow occurred from 06 to 12 hours in the forenoon compared to 50 per cent in afternoon (12 to 18 hours). The balance of 3 per cent was observed after the sunset from 1800 hours to 2000 hours.

The simple relationships between daily transpiration and solar radiation, daily transpiration and vapor pressure deficit were nonlinear, R^2 values improved with nonlinear model compared to linear. Both the environmental variables, solar radiation and vapor pressure deficit had the strong relationship with tree transpiration ($R^2 = 0.92$, $P<0.01$, n=17) (Fig. 10.2)

$$y = 0.154 * (x^{1.702}) \qquad \text{………… (4)}$$

where y = transpiration (L/day)

x = solar radiation [MJ/m^2/day]

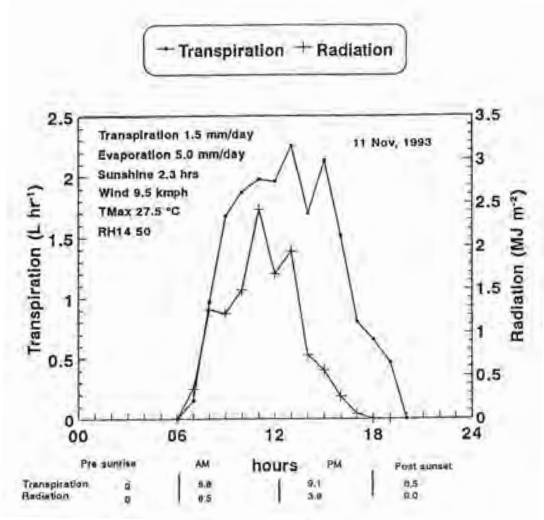

Fig 10.1 Hourly transpiration as influenced by solar radiation in a day

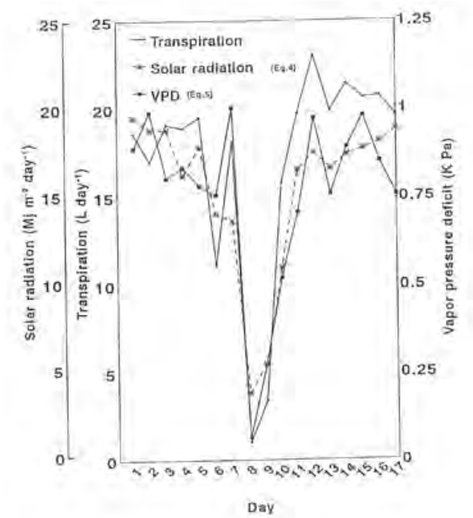

Fig 10.2 Relationship between transpiration and solar radiation/vapor pressure deficit

$$y = 22.874 * (x^{1.162}) \qquad \text{…………. (5)}$$

where y = transpiration (L/day)

x = vapor pressure deficit (KPa)

Management for Increasing Radiation Interception

Incidence of PAR under pruned and unpruned trees

Pruning of trees increased the availability of light essential for crop growth. Incident photo synthetically active radiation (PAR) on 60 and 90 days after pollarding was 72 and 60 per cent of "open" while they were 97 and 90 per cent in pruned treatments above the under storied crop cowpea in the year1993 (Fig 10.3). Four months after pollarding, near harvesting of the crop (3 months after sowing at end of September) incident PAR was 90 and 45 per cent for plots with pruned and unpruned trees. Six months after pollarding (November), incident PAR was 87 and 37 per cent for plots with pruned and unpruned trees. By April, the difference between plots having pruned and unpruned trees was negligible (12 per cent) because of leaf fall in unpruned trees as against leaf retention with pruned trees.

In 1991, the receipt of photo synthetically active radiation (PAR) at the ground level (beneath the sorghum canopy) on the 55th day after sowing of sorghum with pruned (20 days after pruning) and unpruned trees was 30 and 8 per cent of the "open" (Fig 10.4).

Effect of PAR on Yield of Crops

At the end of cropping season, intercropped plots with pruned and unpruned trees received about 90 and 45 per cent of PAR incident over pure crop (Table 10.1). Straw and grain yield of sorghum and cow pea were roughly proportional to the amount of light intercepted by the crop at harvest under pruned and unpruned tree plots.

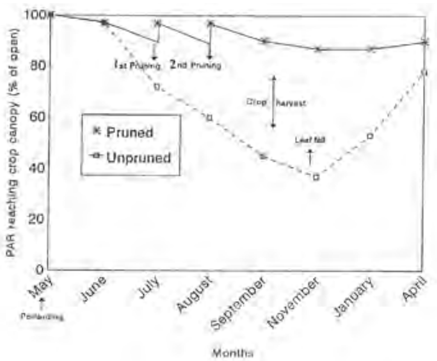

Fig 10.3 Effect of pruning on PAR availability above the crop with trees spaced at 4 x 4 m

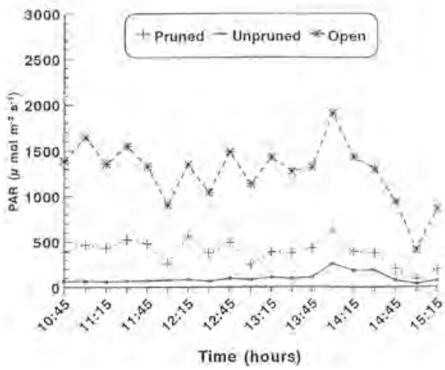

Fig 10.4 Incident PAR measured by line sensors placed close to tree, at ground level across the crop rows of sorghum at panicle initiation stage, 75 days after pollarding

Table 10.1 Relationship between incident photo synthetically active radiation at harvest and crop yield (% of pure crop)

Treat-ment	Incident PAR	% of pure crop							
		Sorghum yield				Cowpea yield			
		Straw		Grain		Dry matter		Seed	
		Barrier	No barrier	Barrier	No barrier	Barrier	No barrier	Barrier	No barrier
Pruned tree + crop	90	80±8.1	75±10.3	83±6.0	76±6.2	107±9.6	93±8.8	81±9.1	56±6.0
Unpruned tree + crop	45	45±9.2	36±5.0	49±6.0	37±6.5	53±2.4	45±9.2	33±3.4	29±6.0

Note: Average of two year data with standard error (n=6)

Conclusions

Formulas for estimation of radiation interception over the continuous and discontinuous crop canopy in agroforestry systems were discussed. Similarly, formulas for estimation of water use were elaborated. Relationship between transpiration and weather parameters was established. Pruning for increasing radiation interception and enhancing the yield of crops in agroforestry system using some case studies was presented.

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Chapter 11

Adaptation Strategies to Cope with Climate Variability: A Techno-Social Approach

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Introduction

Around 2200 BCE a shift in the Mediterranean westerly winds occurred. And it resulted in a reduction in the Indian monsoon leading to three centuries of lower rainfall and colder temperatures. This phenomenon hit agriculture from the Aegean Sea to the Indus River. This change in climate brought down Egypt's pyramid-building Old Kingdom and Sargon the Great's empire in Mesopotamia (Weiss and Bradley, 2001). After only a few decades of lower rainfall, cities lining the northern reaches of the Euphrates, the breadbasket for the Akkadians, were deserted. At the city of Tell Leilan on the northern Euphrates, a monument was halted half-built. (Ristvet and Weiss, 2000). With the city abandoned, a thick layer of wind-blown dirt covered the ruins for ensuring exciting job for the future archeologists! Even intensively irrigated southern Mesopotamia, which boasted of one of the most sophisticated bureaucracies of its time, could not react fast enough to the new conditions. Without the shipments of rainfed grain from the north, and faced with parched irrigation ditches and migrants from the devastated northern cities, the empire collapsed.

Societies have always depended on the climate but are only now coming to terms with the fact that the climate depends on their actions. The steep increase in greenhouse gases since the Industrial Revolution has transformed the relationship between people and the environment. The fact that climate affects development and development affects the climate has come to be known widely during recent times. Left unmanaged, climate change will reverse development progress and compromise the well-being of current and future generations. It is certain that the earth will get warmer on average, at unprecedented speed. Impacts will be felt everywhere, but much of the damage will be in developing countries. Millions of people from Bangladesh to Florida will suffer as the sea level rises, inundating settlements and contaminating freshwater. Greater rainfall variability and more severe droughts in semiarid Asia and Africa will hinder efforts to enhance food security and combat malnourishment. The hastening disappearance of the Himalayan and Andean glaciers-which regulate river flow, generate hydropower, and supply clean water for over a billion of people on farms and in cities-will threaten rural livelihoods and major food markets.

Increasing people's opportunities and material well-being without undermining the sustainability of development is still the main challenge for larger part of the world, as a severe financial and economic crisis wreaks havoc across the globe. Stabilizing the financial markets and protecting the real economy, labor markets, and vulnerable groups are the immediate priority. But can the civilization use this moment of crisis as an opportunity for better cooperation among societies and tackle the rest of development's problems. Among them, and a top priority, is climate change.

The fourth assessment report of IPCC observed that warming of climate system is now unequivocal, as is now evident from observations of increase in global air and ocean temperatures, wide spread melting of snow and ice, and rising global sea level (IPCC, 2007). Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of large population depending on agriculture, excessive pressure on natural resources and poor coping mechanisms. Several models predict that rising temperatures, increased climatic variability and extreme weather events could significantly impact food production in coming years. Climate change projections up to 2100 for India indicate an overall increase in temperature by 2- 4 ^{0}C with no substantial change in precipitation. However, different regions are expected to experience differential change in the amount of rainfall in the coming decades (Kavikumar, 2010). Besides, changed rainfall patterns, it is predicted that extreme events are likely to increase in the country resulting in more droughts and floods.

Impact of Climate Change on Indian Agriculture

Within agriculture, the rainfed agriculture which constitutes nearly 58 per cent of the net cultivated area will be most impacted for two reasons. First, rainfed agriculture is practiced on fragile, degraded lands which are thirsty as well as hungry. Second, the people dependent on rainfed agriculture are also less endowed in terms of financial, physical, human and social capitals limiting their capacity to adapt to the changing climate. Climate variability impacts food security at the household level particularly impacting small and marginal farmers and wage labourers. For example, heat wave during February-March in North India caused an estimated loss of 6 million tons of wheat in 2002-03. A sharp decline in production of rapeseed and in linseed was observed in Himachal Pradesh due to heat wave in March 2004. Pulse crops in large areas in Madhya Pradesh were damaged due to frost and cold in recent years (Venkateswarlu *et al.*, 2011). Similarly, delayed onsets of monsoon, mid-season and terminal droughts, particularly in rainfed areas are causing huge losses to agriculture and livestock production affecting livelihood of the poor. Within the same season, the country is experiencing severe droughts and floods in the many regions posing serious problems to the farmers, agricultural scientists and extension staff. Fall in yield of staples and consequent shortage of food grains lead to price rise and inflation affecting the poor most. Therefore, it is of utmost importance to enhance the resilience of Indian Agriculture to climate change.

Indian farmers have evolved many coping and adaptation mechanisms over time, but these are inadequate to cope with extreme weather events being witnessed in recent times. Changing rural social dynamics and institutional structures are also contributing to the failure in the traditional coping mechanisms. Hence, there is a strong need to use modern science along with indigenous wisdom of farmers to enhance climate resilience of Indian agriculture.

Considering these challenges, the Indian Council of Agricultural Research has developed district level contingency plans for all most all the rural districts of country with CRIDA, Hyderabad as the nodal agency. However, in the long term, it is important to make our agriculture more climate resilient through location specific adaptation and mitigation strategies by using available technologies and building capacity of the stakeholders.

Besides undertaking research to develop location specific climate resilient agricultural technologies, there needs to make immediate efforts to disseminate and demonstrate the already available technologies on the farmers' field in vulnerable regions. At the same time, there is also need to put in place innovative institutional mechanisms at the field level for successful technology adoption and up scaling. As part of National Innovations on Climate Resilient Agriculture (NICRA) extensive farmer participatory demonstrations of location specific climate resilient agricultural technologies are being promoted in 121 most vulnerable districts (Fig 11.1). The technology demonstration component of NICRA envisages identifying climatic vulnerabilities to agriculture in the selected village in each of the 121 districts based on a scientific analysis of climate related problems, farmers' experiences and perceptions, and preparing and implementing, adaptation and mitigation strategies following a bottom-up approach. The focus of the programme is not only to demonstrate the climate resilient agriculture technologies but also to institutionalize mechanisms at the village level for continued adoption. One village or a cluster of villages from each of the 121 selected districts was selected for this purpose by the respective Krishi Vigyan Kendra (KVK), in the district. To our knowledge, this is for the largest outreach involving farmers programme ever undertaken on climate change anywhere in the world (Table 11.1).

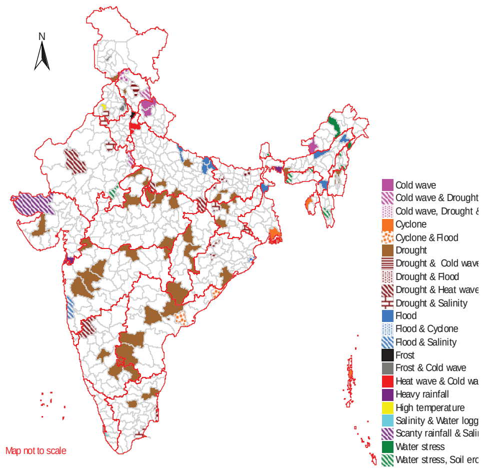

Fig 11.1 Districts selected for demonstration of climate resilient technologies

Rationale

Agriculture in India is practiced for over 5000 years and during this long history, the agrarian communities have faced various climate related challenges. During the past five decades, challenges in agriculture are being dealt with application of science and technology. Over the years, a range of technologies suiting to different situations have been developed by the NARS. Though these technologies cannot be termed as climate resilient they were applied in situations challenged by climate variability in different agro climatic environments. Therefore, the TDC component takes a fresh look at these technologies and aims to demonstrate the technologies with climate resilience perspective. Besides, current efforts underway for developing climate resilient technologies may take a while before getting ready for implementation. To sum up, the following points capture the rationale for implementing technology demonstration component under NICRA.

- Availability of technologies
- Availability of indigenous practices
- Long experience of NARS in evolving drought/flood resilient technologies
- Inherent resilience with the community for coping with disasters

The specific objectives of TDC are:

- To enhance the resilience of Indian agriculture (including crops, livestock and fisheries) to climatic variability and climate change through strategic research on adaptation and mitigation
- To demonstrate site specific technology packages on farmers' fields to cope with current climatic variability
- To enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and awareness of impacts

Process

The technology demonstration component of National Innovations on Climate Resilient Agriculture deals with demonstrating an integrated package of proven technologies for adaptation of the crop and livestock production systems to climate variability. This component is implemented in selected vulnerable districts of the country by implementing location specific interventions through Krishi Vigyan Kendras in a participatory mode. The project is implemented in one district (see map) involving over one lakh farm families across the country. Following is the breakup of the 143 project locations.

1. KVKs in eleven Zones -121
2. Co-operating centers of AICRP on Dryland Agriculture - 23

The selection of districts for implementing Technology Demonstration Component was done by following the criteria detailed below:

- Drought proneness based on 30 years rainfall data (Source: IMD)
- Cyclone proneness based on data on frequency as recorded by IMD and in consultation with State Disaster Management Departments.
- Flood proneness based on IMD data and National Disaster Management Authority (NDMA) maps.
- Vulnerability to heat wave and cold wave based on grid data (IMD) on temperatures.
- Actual incidence of floods and droughts as recorded by AICRPAM centers

Besides, areas affected with salinity and severe groundwater crisis were identified by superimposing salinity maps developed by CSSRI with water balance maps of NBSSandLUP. The criteria mentioned above were given a weightage of 75 per cent while the remaining 30 per cent was given to the ability/ potential of the KVK in terms of its past performance, staff strength and the rating of the ZPD. Care was taken to see that each state and important agroclimatic region is covered so that all the ZPDs and the Directors of Extension of each SAU gets firsthand experience on how to deal with climate variability with the help of available technologies.

The interventions covered under the component are broadly classified as four modules:

Module I: Natural Resources: This module consists of interventions related to in-situ moisture conservation, water harvesting and recycling for supplemental irrigation, improved drainage in flood prone areas, conservation tillage where appropriate, artificial ground water recharge and water saving irrigation methods.

Module II: Crop Production: This module consists of introducing drought / temperature tolerant varieties, advancement of planting dates of rabi crops in areas with terminal heat stress, water saving paddy cultivation methods (SRI, aerobic, direct seeding), frost management in horticulture through fumigation, community nurseries for delayed monsoon, custom hiring centers for timely planting, location specific intercropping systems with high sustainable yield index.

Module III: Livestock and Fisheries: Use of community lands for fodder production during droughts / floods, improved fodder / feed storage methods, preventive vaccination, improved shelters for reducing heat stress in livestock, management of fish ponds / tanks during water scarcity and excess water, etc.

Module IV: Institutional Interventions: This module consists of institutional interventions either by strengthening the existing ones or initiating new ones relating to seed bank, fodder bank, commodity groups, custom hiring centre, collective marketing, introduction of weather index based insurance and climate literacy through a village level weather station.

Table 11.1 Vulnerable districts covered for technology demonstration in different states

	State	Vulnerability	District
Zone -I Ludhiana	Uttarkhand	Cold wave, flood, hail storm	Uttarkashi
		Cold wave, hail storm, drought	Tehri Garhwal
	Himachal Pradesh	Drought	Hamirpur
		Cold wave / Drought / Frost	Chamba, Kullu, Kinnaur
	Jammu and Kashmir	Drought	Kathua
		Frost cold wave	Phulwama
	Punjab	Frost/cold wave	Ropar, Fatehgarh Shaib
		High temperature, depletion of ground water, heat wave	Faridkot , Bhatinda,
Zone-II Jodhpur	Haryana	Frost in winter, depletion of groundwater	Yamunanagar
		Cyclonic storm	South 24 Pargaras
	Rajasthan	Drought, flood,salinity	Bharathpur
		Drought, low and erratic rainfall, moving sand dunes, poor and impeded drainage and salinity and / or sodicity in soil	Jhunjhunu
		Flood prone area	Kota
Zone –III Kanpur	Uttar Pradesh	Flood	Bahraich, Gorakhpur, Maharajganj, Gonda, Kushinagar
		Drought and Heat wave	Jhansi, Chitrakoot, Sonbhadra, Hamirpur
		Groundwater depletion	Baghpat, Muzaffarnagar
Zone –IV Patna	Bihar	Flood / Drought	Saran, Supaul, Buxar
		Drought	Nawadah, Aurangabad, Jehanabadm, Koderma
	Jharkhand	Drought / Heat wave	Palamau, East Singhbhum, Gumla, Chatra
Zone –V Kolkata	Andaman and Nicobar Islands	Cyclone	Port Blair
	West Bengal	Heavy rainfall	Coochbehar
		Flood	Malda
		Cyclonic storm	South 24 Pargaras
	Orissa	Flood and Cyclone	Kendrapara
		Drought / Flood	Jharsugda, Sonepur
		Drought	Ganjam
	Sikkim	Soil erosion and Water Stress	East Sikkim
Zone-VI Guwahati	Assam	Floods	Dibrugarh, Cachar
		Drought	Dhubri, Senapati, Imphal East, Umaim, West Garo Hills, Phek, Dimapur, Mokokchung
	Arunachal Pradesh	Water stress	Tirap, West Siang
		Cold stress	West Kameng

	State	Vulnerability	District
Zone-VII Barapani	Tripura	Cyclones	West Tripura
Zone-VIII Pune	Maharashtra	Heat stress Drought	Nandurbar, Pune, Aurangabad, Ahmednagar, Amravati, Gondia
		Floods	Ratnagiri
	Gujarat	Drought	Kutchh
		Erratic rainfall, shallow soil	Rajkot
		Heavy rainfall	Valsad
Zone-IX Jabalpur	Chhattisgarh	Drought	Raipur, Bilaspur
		Soil erosion and Heavy rainfall	Dantewada
	Madhya Pradesh	Drought	Satna, Guna, Morena, Datia, Tikamgarh, Chhatarpur, Balaghat
Zone-X Hyderabad	Tamil Nadu	Drought	Villupuram, Namakkal, Ramanathapuram
		Drought, Floods, cyclones	Nagapattinam
	Andhra Pradesh	Cyclone	West Godavari
		Floods	Srikakulam
		Drought	Anantapur, Kurnool, Nalgonda, Khammam
Zone-XI Bengaluru	Karnataka	Drought, Heat wave	Tumkur, Kolar, Davanagere, Belgaum
	Kerala	Salinity, water logging	Alleppey

Overall Approach

Planning, and monitoring of the programme at national level is the responsibility of CRIDA while the eight Zonal Project Directorates (ZPDs) are involved in coordinating the project in their respective zones. At districts level, the selected KVK is responsible for implementing the project at village level through farmer's participatory approach. Under this programme, the interventions are focused only to address climate related constraints and not general agriculture development. Thus, the focus of the project is on minimizing losses due to variable climate rather than yield maximization as is seen in most agricultural development programmes.

Project Implementation Strategy

A multi-level participatory approach was followed for developing and implementing the TDC. The KVK team for each district carried out a detailed exercise on the needs of the village, the climatic vulnerability (drought / floods/ heat wave / frost / cyclone) and the available technology options from the concerned Zonal Agricultural Research Stations of the SAUs. After a careful study of the gaps, specific interventions under each of the module were selected and an integrated package from all modules was formulated. Majority farmers are covered with one or more of the interventions in order to demonstrate a discernable effect. The project was launched in each village with wide publicity and by involving all the line departments under the leadership of the district administration. The launch event was used to generate wide spread awareness within the community and across line departments so as to prepare a platform for exploiting synergy through convergence of other government projects.

Conclusion

The interventions for improving the adaptability of the community for coping with climate variability have shown promising outcomes. These interventions have imparted confidence in the implementing agency as well as the primary stakeholders. The lessons have shown that natural resource management interventions play key role in helping the communities to cope with climate variability. This reinforces the rationale with which the programme was designed and implemented at the field level. However, there is a long way to go especially in building responsible grassroots institutions so that the issues with climate variability are dealt with by the communities themselves. Besides, the learning's have also reconfirmed the fact that adaptation requires the support of good facilitation as well as technical backstopping. It also has brought out the fact that the effectiveness of the project improves if there is convergence with other on-going development programmes. This pilot initiative is being considered as the front runner for developing a nationwide programme to address climate variability in different regions. The success of this project has triggered interest among many vulnerable states like Maharashtra where investments are being made to build resilience among the farming communities against climate variability.

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Chapter 12

Carbon Sequestration Potential in Agroforestry Systems

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Introduction

Global climate change is a major issue in the world. Climate change is due to increasing concentration of green house gases (GHG) that includes carbon dioxide, methane, nitrous oxide, etc. The global average atmospheric carbon dioxide was 402.9 ± 0.1 parts per million in 2016 (Lindsey, 2017) as compared to 392 parts per million in 2012. Due to its increasing concentration, warming of atmosphere and oceans, diminishing snow and ice, rising sea levels is happening. Also, NASA and the National Oceanic and Atmospheric Administration (NOAA) reported that Earth's surface temperatures were the warmest in 2016 since 1880. In order to minimize the adverse impacts of climate change or occurrence of extreme weather events, it is absolutely essential to reduce the carbon dioxide content in the atmosphere. One way by which we can reduce the content in the atmosphere is to sequester or capture the carbon dioxide permanently. It is reported that agriculture in general and agro-forestry in particular can be a sink for atmospheric carbon dioxide. The World Agroforestry Centre (www.icraf.cgiar.org) defines it as "a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels." The Association for Temperate Agroforestry (AFTA) (http://www.aftaweb.org) defines it as "an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock." It is more practiced in developing countries compared to developed countries. Agroforestry has gained more importance as a land use system due to its positive impact on environment as they have a huge capacity to sequester carbon (C) since Kyoto protocol. Carbon sequestration is the removal of CO_2 from atmosphere and its storage in long-lived pools. Reports state that these systems have a capacity to store C that range from 0.29 to 15.21 Mg/ha/yr aboveground, and 30 to 300 MgC/ha up to 1 m depth in the soil (Nair *et al.*, 2010). They can store nearly 12 per cent of the world terrestrial C in them. The sink potential of agroforestry is high compared to field crops although its sequestration potential depends on number of factors such as age, soil type, tree species and their management. Recent studies showed that tree-based agricultural systems, stored more C in deeper soil layers compared to treeless systems; and C_3 plants (trees) contributed to more C in the silt- + clay-sized (< 53 μm diameter) fractions than C_4 plants that constitute more stable C in deeper soil profiles. Hence, agroforestry can be a GHG mitigating activity with technical mitigation potential of 1.1-2.2 PgC (IPCC, 2007). The area under agroforestry may further increase as option to mitigate climate change. The best way to sequester C by preventing deforestation is by adopting agroforestry systems on underutilized sites. This may be a best opportunity for small holder farmers by selling the produce from agroforestry systems. Also, for enhancement of local livelihoods of small holder farmers, the World Bank has initiated the Community Development Carbon Fund and the BioCarbon Fund due to its ability to enhance the resilience. In agroforestry systems, a large amount of biomass is added to soil in the form of leaf litter etc that helps in stabilizing soil organic matter. It is estimated that the total soil C pool in the form of soil organic C (SOC) and soil inorganic C (SIC) is 1462–1548 Pg and 659–748 Pg is (Batjes,1996) suggesting that agroforestry can increase soil carbon pool that would have a significant impact on reducing the adverse effects of climate change.

Measurement of Carbon Sequestered in Agroforestry Systems

In Agroforestry systems, biomass is the one of the element to assess the carbon flux, further, above and below the ground biomass is to be estimated for computing carbon sequestered by them.

Above Biomass Measurements

Earlier the above biomass was estimated by cutting down sample trees, separating various parts (stem, leaves, inflorescence, etc.), and determining their dry weights followed by C content. It is known destructive method. This method cannot be used to estimate in trees covering large area and for threatened tree species. Another method is non-destructive method where Allometric equations can be used to predict the above ground biomass in agroforestry systems (Tumwebaze *et al.*, 2013) as destructive method of determining tree biomass is extremely time- and labor-intensive. It is most commonly used to estimate above ground biomass in tree species. In these equations, the diameter at breast height and height of the tree species to be used as an independent variables and total dry weight as dependent variable. There are two different types of allometric equations-linear and non-linear that helps in calculating the above ground biomass in tree species. Such allometric equations are developed based on biophysical properties of trees. The drawbacks of allometric equations is its applicability to dicotyledonous trees because of their complex branching nature and applicable only for tree species with diameter at breast height between 60 and 105 cm. Hence, there is a need for developing tree based biomass equations for accuracy. There exist huge and excellent literatures regarding use of allometric equations in estimating above ground biomass. However there is a need to reduce the uncertainty in their use. Kettering *et al* 2001 reported that $B=aD^b$ is the common allometric equation where biomass is B, diameter is D and a and b are parameters which vary between sites and it is source of uncertainty. The site-specific relationship between height (H) and diameter, $H = kD^c$ as $b=2+c$ can be used to estimate parameter b *and* average wood density (ρ) at the site as $a=r\rho$, where r is expected to be relatively stable across sites to find out parameter a. There by an allometric equation $B=r\rho D^{2+c}$ was proposed.

Several biomass based models were also developed through several studies in different parts of the world for different tree species. These models also use diameter breast height as independent variable. The biomass based models also exist for tropical species (Cole and Ewel, 2006).In tropical areas, there exist several tree species in small areas and in such cases, and it is difficult to compute the biomass. For such situations, a pooled equation with logarithmic model was developed by Knut (1993). The equation is as follows:

$$\ln (\text{WSUM}) = \ln (\text{DBH}) + \ln (\text{CW}) + \ln (\text{HT}) + \varepsilon$$

Where,

WSUM = whole dry fresh biomass (kg)
DBH = diameter at breast height (cm)
CW = Crown width (cm)
HT- = Tree height in meters

By applying this pooled equation different tree species grown in an area can be found out.

a. Remote Sensing

Biomass estimation can also be done using remote sensed data as the primary source for biomass estimation. In remote sensing, for forest stand structure than the sites with complex biophysical environments, either optical sensor data or radar data are more suitable. And the same can be used for estimating biomass in agroforestry. A combination of spectral responses and image textures improves biomass estimation performance (Lu, 2006). Carbon sink estimation using remote sensing has a high degree of uncertainty due to regrowth of tree species. In such cases, approaches needed to be developed for estimating biomass changes. Earlier studies reported approaches by which biomass can be estimated. However, remote sensing techniques have recently gained importance in estimating above ground biomass (Zheng *et al.,* 2004; Lu 2005). Estimation of remote sensing was found easy in coniferous forests due to simple forest structure and tree species composition as compared to moist tropical forests (Zheng *et al.,* 2004; Lu *et al.,* 2005). Lu *et al.* (2014) reported that airborne LIDAR (Light Detection and Ranging) is one of the most accurate technologies to determine aboveground biomass. It can be used where optical sensor or radar fails to estimate the above ground biomass. Its use in several studies were found to find out the above ground biomass in various forests as it easily detects vertical structure and extracts ground elevation.

b. GIS methods

RS 1D LISS III is one of the geospatial technologies that can be used to estimate C stock in agroforestry systems. It was used to estimate the C stock in natural forests of Eastern Ghats in Tamil Nadu. GIS helps in developing thematic maps for agroforestry adopted in larger areas. This helps in capturing different imageries as phenology plays an important role in using satellite data for estimating qualitative and quantitative characters especially in vigorous growing vegetation. To have tree based stratification data, this technology plays an important role. GIS is gaining importance as traditional methods of estimation are tedious and time-consuming particularly where information is needed on the spatial dynamics of SOC stocks.

Belowground (Soils)

The determination of belowground organic C dynamics in AFS is crucial for understanding the impact of the system on C sequestration, but it is difficult – more difficult than that for aboveground C. Organic C occurs in soils in a number of different forms including living root and hyphal biomass, microbial biomass, and as soil organic matter (SOM) in labile and more recalcitrant forms. Difficulties of separating these different forms and their complex interactions make measurement, estimation and prediction of soil C sequestration a daunting task. The most common method of estimating the amount of C sequestered in soils is based on soil analysis, whereby the C content in a sample of soil is determined (mass per unit mass of soil, such as g C/100 g soil) and expressed usually in mega grams (Mg = 106 g or tons)/hectare.

Below ground Living Biomass

In addition to SOM, belowground biomass is a major C pool (Nadelhoffer and Raich, 1992). However, belowground biomass is difficult to measure. The root-to-shoot ratio is therefore commonly used to estimate below ground living biomass. The ratios differ considerably among species (*e.g.,* higher in palms than in dicot trees) and across ecological regions (*e.g.,* higher in cold than in warm climates). In the absence of measured values, many researchers assume that the belowground biomass constitutes a defined portion of the aboveground biomass and the values so assumed range from 25 to 40 per cent depending on such factors as nature of the plant and its root system and ecological conditions.

Modeling

In order to understand global carbon cycling, models that incorporate rates of terrestrial C cycling are used. Such models are based on a set of assumptions that are formed from our understanding of ecological processes including tree growth, and decomposition processes in the soil. The CENTURY and Roth C models are the most widely used soil C models. Mixed-effects models for biomass modeling and mapping can be used to estimate the stocks in agroforestry systems (Chen *et al.*, 2016).

Carbon Stocks in Agroforestry Systems in India

Carbon sequestration in different agroforestry systems occurs both belowground, in the form of enhancement of soil carbon plus root biomass and aboveground as carbon stored in standing biomass (Murthy *et al.*, 2013). Some of the earliest studies of potential carbon storage in agroforestry systems and alternative land use systems for India had estimated a sequestration potential of 68-228 MgC/ha (Dixion *et al.*, 1994). Studies done by Jha *et al.* (2001) showed that agroforestry could store nearly 83.6 tC/ha up to 30 cm soil depth, 26 per cent more carbon compared to cultivation in Haryana plains. In India, evidence is now emerging that agroforestry systems are promising land use to increase and conserve aboveground and soil carbon stocks to mitigate climate change (Table 12.1). However, the magnitude of carbon sequestration from forestry activities would depend on the scale of operation and the final use of wood.

Table 12.1 Carbon sequestration potential of different agroforestry systems on India

Location	Agroforesty system	CSP (MgC/ha/yr)
Uttarakhand	Agrisilviculture	15.91
Himachal Pradesh	Agrihorticulture	12.15
Khammam, Andhra Pradesh	Agrisilviculture	29.93
SBS Nagar, Punjab	Agrisilviculture	9.40
Dehradun, Uttarakand	Silviculture	10.30
Kurukshetra, Haryana	Silvipasture	14.68
Chandigarh	Agrisilviculture	10.48
Tripura	Silviculture	7.27
Tarai central division, Uttarakand	Silviculture	8.86
Jhansi. Uttar Pradesh	Agrisilviculture	3.70
Jhansi, Uttar Pradesh	Silviculture	9.96
Hyderabad, Andhra Pradesh	Silviculture	40.27
Hyderabad, Andhra Pradesh	Agrisilviculture	4.67
Raipur, Chhattisgarh	Agrisilviculture	3.23
Coimbatore, Tamil Nadu	Agrisilviculture	1.57
Kerala	Home garden	1.60

Source: Dhyani (2012)

Agrisilvicultural Systems

Carbon Sequestration in Tree Biomass

Maikhuri *et al.* (2000) estimated species wise annual carbon sequestration potential of planted tree species on abandoned agricultural land (3.9 t/ha/yr) and degraded forest land (1.79 t/ha/yr). The highest carbon sequestration was found for *Alnus nepaliensis* 0.256 tC/ha/yr and *Dalbergia sissoo* 0.141 tC/ha/yr intercropped with wheat and paddy. In a 6 year old *Gmelina arborea* based agri-silvicultural system 31.37 tC/ha was sequestered (Swami et al 2003). In another study the carbon sequestration in monocropping of trees and food crops were 40 per cent and 84 per cent less than agri-silviculture indicating that agroforestry systems have more potential to sequester carbon (Dhyani *et al.*, 2009). In an agri-silvicultural system, *Dalbergia sissoo* at age 11 years was able to accumulate 48-52 t/ha of biomass (Newaj and Dhyani, 2008). Carbon dynamics involving different pruning treatments were studied in an agri-silvicultural system where tree biomass was 23.61 to 34.49 tC/ha with black gram-mustard. In a study on poplar based agri-silvicultural system, total biomass in the system was 25.2 t/ha, 113.6 per cent higher than sole wheat cultivation, where net carbon storage was 34.61 tC/ha compared to 18.74 tC/ha in sole wheat cultivation (Chauan *et al.*, 2010). A study showed that by shifting agriculture to different agroforestry systems has resulted in an increase of 13 per cent of SOC stocks (De Stefano and Jacobson, 2017).

Moreover, agroforestry has high potential for simultaneously satisfying three important objectives *viz.*, protecting and conserving natural resources; producing a high level of output of economic goods; and improving income and raw materials for rural populations. The replacement of field crops and horticulture by silvipasture and agroforestry for, the productive and protective purposes has led to a reduction in runoff in watershed management of 48 to 99 per cent and reduction in soil loss 81 to 98 per cent (Utappa *et al.*, 2015). Table 12.2 exemplifies how different agroforestry tree species suitable for different problem soils can ameliorate the soil condition.

Table 12.2 Recommended tree species for problematic area

Problematic area	Recommended tree species
Sodic soils	*Accacia nilotica, Casurina equisetifolia, Prosopis juliflora, Prosopis cineraria, Tamarix articulata, Pithecellobium dulce, Salvadora persica, Terminalia arjuna, Pongamia pinnata, Sesbania sesban, Eucalyptus tereticornis, Butea monosperma, Acacia auriculiformis* and *Azadirachta indica*
Wetland	*Salix babylonica, Salix xuchonensis, Alnus cremastogyne, Alnus trabeculosa, Paulownia tomentosa, Morus alba, Taxodium distichum* and *Taxodium scandens*
Waterlogged area	*Eucalyptus spp, Casurina equisetifolia, Acacia nilotica, Prosopis juliflora, Azadirachta indica, Tecomella undulata, Capparis deciduas, Acacia Senegal, Ziziphus spp, Parkinsonia aculeta* and *Ailanthus excelsa*
Coastal area	*Anacardium occidentale, Ailanthus malabarica, Casuarina equisetifolia, Pongamia pinnata, Sesbania aculeate, Salicornia bigelovvi, Salvadora persica, Salvadora oleoides, Terminalia catappa, Callophyllum inophyllum, Pandanus, Nypa fruticans* and *Borassus flabellifer*
Mining area	*Anthocephalus cadamba, Gmelina arborea, Acacia auriculiformis, Acacia mangium, Albizia lebbeck, Bamboo* spp, *Grevillea robusta, Dalbergia sissoo, Anogeissus pendula, Leucaena leucocephala, Pongamia pinnata, Acacia catechu, Erythrina indica* and *Bombax ceiba*
Ravine area	*Acacia catechu, Dalbergia sissoo, Morus alba, Dendrocalamus strictus, Acacia nilotica, Azadirachta indica, Albizia* spp., *Holoptelia integerifolia*
Acid soils	*Pinus roxburghii, Pinus wallichiana, Celtis australis, Cassia, Acacia mearnsii, Acacia decurrens, Acacia dealbata, Acacia pycnantha, Manilkara hexandra, Phoenix* spp, *Acacia auriculiformis, Pterocarpus marsupium, Shorea robusta, Hardwickia binata, Terminalia* spp., *Tectona grandis, Gmelina arborea, Xylia xylocarpa, Bamboo spp.*, and *Alnus* spp

Silvipastoral Systems

Carbon Sequestration in Tree Biomass

Comparative studies conducted by NRCAF (2007) on biomass production from natural grassland and silvipastoral system comprising *Albizia amara, Dichrostachys cinerea* and *Leucaena leucocephala* as woody perennials with *Chrysopogan fulvus* as grass and *Stylosanthes hamata* and *Stylosanthes scabra* as legume revealed that in 8 years, rate of biomass carbon stored in silvipastoral system was 6.72 tC/ha/yr, two times more than 3.14 tC/ha/yr from natural grassland. Singh (2003) estimated the total carbon sequestered in farm forestry with species such as *Eucalyptus sp.*, *Populus deltoides*, *Tectona grandis*, *Anthocephalus chinensis* trees to be around 16,400 t/yr. Rai *et al.* (2009) studied the effect of introducing a silvipastoral system in a natural grassland in semi arid Uttar Pradesh, where introduced species of *Albizia procera*, *Eucalyptus tereticornis*, *Albizia lebbeck*, *Emblica officinalis* and *Dalbergia sissoo* accumulated 8.6, 6.92, 6.52, 6.25 and 5.41 t/ha/yr of biomass. Here, the carbon storage in the system was 1.89-3.45 tC/ha in silvipasture and 3.94 tC/ha in pure pasture.

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Chapter 13

Carbon Sequestration in Some of the Important Biofuel Systems

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Introduction

Alarming levels of depletion of world's fossil fuel reserves, their escalating cost and the global warming problems caused by the fossil fuel combustion have attracted the attention of researchers, policy makers, environmentalists and industrialists (Wani, 2006). Global warming may be result of the atmosphere greenhouse gases (Marland, 2001). The onset of industrial revolution has seen an increase of 110 ppmv CO_2 in our atmosphere resulting in the current atmospheric CO_2 concentration to be more than 3902 ppmv (NOAA, 2011).Using biofuels for carbon replacement in fossil fuels in the global level in general and in India in particulars considered as a strategy to address energy security and climate change related issues (Achten *et al.*, 2010b; Phalan, 2009). In the global carbon cycle biomass is an important building block, significantly carbon sequestration, and is used to help quantify pools and changes of Green House Gases from terrestrial biosphere to the atmosphere associated with land-use and land cover changes. Aboveground biomass, below-ground biomass, dead wood, litter, and soul organic matter are the major carbon pools in any ecosystem (IPCC, 2003). The increase in carbon emission is of major concerns for entire world as well addressed in Kyoto protocol (Ravindranarth *et al.*, 1997). Global interest in carbon sequestered by agroforestry systems increased after its recognition as a green house gas mitigation strategy under the Kyoto protocol. Comprehensive estimates of biomass and carbon stocks in plantations, including trees outside forests are important for the preparation of national communications as part of the international commitments of the UNFCCC. Besides there is growing enthusiasm in the market opportunities available for forest carbon credits (Hamilton *et al.*, 2007). In this context, *Jatropha curcas* and *Pongamia pinnata* emerged as most potential species for use in CDM projects. This type of crop not only helps mitigate climate change through sequestration and storage of carbon in the biomass, but it helps produce renewable energy, by replacing fossil fuels, as its seeds can be used for biofuel production. As plans are under implementation for expanding the *Jatropha* and *Pongamia* cultivation in large areas in several parts of the world, there is a need to assess the carbon sequestration capacity of the system, which has received less attention compared to its oil production. This underscores the need for methods to reliably assess the biomass production by *Jatropha* and *Pongamia* system as quantification of carbon in trees relies on biomass estimation. One of the precise way to measure and monitor above ground biomass estimate for a stand is through periodic destructive sampling (Van *et al.*, 2000; Norries *et al.*,2001; Brown *et al.*, 2004; Wadham-Gagnon and Sharpe, 2006; Saglan *et al.*,2008). Though destructive harvesting is tedious and labor intensive (Kale *et al.*, 2004; Delitti *et al.*, 2006; Telenius and Verwijs, 1995) but it gives correct estimation of biomass for a specific location.

As carbon sequestration studies in *Jatropha* and *Pongamia* plantations are lacking particularly for Indian conditions. Hence, field experiments were conducted with an objective to quantify carbon sequestration potential of *Jatropha curcas* and *Pongamia pinnata* by destructive sampling methods. To develop allometric equations between various biomass variables on Basal diameter of *Jatropha* and *Pongamia*.

Description of Experimental Site

The experiment was conducted during 2003-2011 at the Hayatnagar Research farm of ICAR-Central Research Institute for Dryland Agriculture (17°27′N latitude and 78°35′E longitude and about 515 m above sea level), Hyderabad in Southern part of India. The climate is semi-arid with hot summers and mild winters. The mean maximum air temperature during summer (March, April and May) ranges from 35.6 to 38.6°C, where as in winter (December, January and February) ranges from 13.5 to 16.8°C. Annual long-term rainfall for the site is about 746.2 mm received predominantly from June to October. The soils are medium-textured, red soil with shallow depth (Typic Haplustalf as per USDA soil classification).

Tree Establishment

In the year 2003, 4 weeks old nursery raised *Jatropha* plants and 4 months old *Pongamia* plants were planted in the pits of 45 cm^3 size during the month of August. The pit mixture contained good dugout soil + 2 kg compost + N, P and K at 10 g, 120 g and 16 g respectively. The *Jatropha* and *Pongamia* were planted with a spacing of 3 x 3m and 5 x 5m respectively.

Tree Growth and Biomass Production / Biomass Sampling

Data on tree growth such as height, DBH, crown diameter, number of branches and crown depth were measured at 6 monthly interval since planting. The entire field was divided in to 4 plots of equal size and within each plot, 25 per cent of trees were marked representing the population and the growth parameters of these trees were monitored at regular intervals. Trees were harvested at the end of 8^{th} year during July-August 2011. Entire plantation of *Jatropha* and *Pongamia* was divided into four diameter classes *viz.*, 5 -10 cm, 10 -15 cm, 15 -20 cm and 20 -25 cm. Four plants of *Jatropha* and three of *Pongamia* plants, representing the respective diameter class were selected for destructive sampling.

Destructive Sampling

Aboveground

Each randomly selected tree was cut at 10 cm above the soil surface, biomass partitioned in to three fractions- stem, branches, and leaves, manually. Total above ground fresh weight was measured by using a system of bi-pod frame, pulleys and scales. Components of subsamples of 100 gram were collected and weighed at the time of sampling and placed in bags for oven drying at 70^0C to a constant weight. Dry weight of subsamples was used to calculate to moisture ratios, which then applied to tree component fresh weights (Porte *et al.*, 2002; Ritson and Sochaki, 2003). Measurement was made to an accuracy of 0.01kg to determine the dry biomass/ha.

Belowground

Excavation of total root system was done manually and carried out within one week of the above ground sampling under dry soil conditions and subsequently washed with water to remove the adhering soil. During the digging, the horizontal spread of roots was measured and after excavation, the entire root system was rearranged to the extent possible into its original position. All categories of roots cut during excavation were carefully picked up from the soil and rearranged the root system. The total root biomass in different soil strata, *i.e.*, 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm, were estimated separately. Representative samples were taken from fresh roots and dried to at 70^0C to a constant weight to calculate moisture ratios, as was done in above ground biomass.

Results

Jatropha

In general there was an increasing trend in total dry biomass as the diameter of the trees increased from d1 to d4. Similar trend of increasing biomass with increasing diameter of the trees as observed in above ground biomass was noted in below ground biomass also. Stem and branch biomass in both the species contributed to more than 80 per cent of above ground biomass. In *Jatropha* the above and below ground biomass contributed 74.92 per cent and 25.08 per cent respectively to the total biomass (Table 13.1). The share of above and below ground parts to the total biomass in case of *Pongamia* was 52.85 per cent and 47.15 per cent respectively (Table 13.2). About 80 per cent of the root biomass in both the species confined to top 50 cm of layer of the soil. *Pongamia* plantation sequestered more than double Carbon (17.06 t/ha) compared to that of *Jatropha* plantation (7.36 t/ha).

Table 13.1 *Jatropha* dry biomass and carbon biomass.

Dia. Classes	Above ground dry biomass (t/ha) (A)	Below ground dry biomass (t/ha) (B)	Total dry biomass (t/ha) (A+B)	Total C biomass (t/ha)
D1 (5-10 cm)	3.10	2.23	5.33	2.56
D2 (10-15 cm)	14.28	4.28	18.56	7.84
D3 (15-20 cm)	16.19	5.32	21.51	9.12
D4 (20-25 cm)	18.44	5.56	24.00	10.08
Average	**13.00**	**4.35**	**17.35**	**7.36**

Table 13.2 *Pongamia* dry biomass and carbon biomass.

Dia. Classes	Above ground dry biomass (t/ha) (A)	Below ground dry biomass (t/ha) (B)	Total dry biomass (t/ha) (A+B)	Total C biomass (t/ha)
D1 (0-5 cm)	2.17	2.16	4.33	1.87
D2 (5-10 cm)	11.36	11.40	22.76	9.80
D3 (10-15 cm)	27.79	22.45	50.24	21.72
D4 (15-20 cm)	42.31	38.49	80.81	34.85
Average	**20.90**	**18.63**	**39.54**	**17.06**

Discussion

IPCC 2003, recommended to calculate below ground biomass by multiplying above ground biomass with the value of 0.26. However in the present study in *Pongamia*, the contribution of above ground and below ground biomass was 52.85 per cent and 47.15 per cent there by indicating that the blanket recommendation as suggested by IPCC would not accurately estimate below ground biomass in species like *Pongamia*. The increasing biomass with increasing diameter observed in the present study is because Wood constitutes the largest portion of the total biomass which is concentrated in the stem; biomass and basal diameter were closely related.

The carbon concentration of differ tree parts was rarely measured directly, but generally assumed to be 50 per cent of the dry weight on the basis of literature (Losi *et al.*, 2003; Jana *et al.*, 2009), as the content of carbon in woody biomass in any component of forest on average is around 50 per cent of dry matter (Paladinic *et al.*, 2009). The study conducted by (Firdaus *et al.*, 2010), revealed that carbon content in above ground and below ground biomass of *Jatropha* was 45.60 per cent and 44.68 per cent respectively. In the present study the corresponding values of carbon content in above and below ground biomass of *Jatropha* were 45.62 and 44.88 per cent respectively. The difference in biomass carbon content might be due to different lignin content in the biomass (Ragland *et al.*, 1991), as well as agronomic practices and site characteristics also.

Conclusions

Stem and branches biomass contributed to more than 80 per cent of the above ground biomass As diameter increases in general, the biomass also increases the contribution of above and below ground biomass to the total biomass was in the order of 74.92 and 25.08 per cent respectively in case of *Jatropha* where as in *Pongamia* the corresponding values were 52.85 and 47.15 per cent. *Pongamia* sequestered more than double the quantity of C compared to *Jatropha*.

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Chapter 14

Potential of Biomass Derived Biochar in Soil Carbon Sequestration and Adaptation to Climate Change

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Introduction

The role of forestry and agriculture in mitigating climate change through options such as by carbon sequestration via conversion of residues from forestry and agriculture (short-term biodegradable carbon) into a more recalcitrant form of C (biochar) appears to be one of the most promising strategies to sustainably sequester atmospheric CO_2. In India, the crop residues are becoming an issue of importance due to lack of bio residue management practices. The surplus residues, when left unattended, often disrupt land preparation, plant establishment and early plant growth, and are typically burnt on field causing environment and public health problems and substantial nutrient losses. Using pyrolysis technology, to turn the variety of agricultural plant, animal, and forestry wastes into a recalcitrant substance that is decomposed at a much slower rate, constitutes both a tool for carbon sequestration and avoided emission. Production of biochar, in combination with its storage in soils, has received increasing interest as a novel approach for creating a significant, long-term, nearly permanent locking of atmospheric carbon through a carbon negative process in terrestrial eco ecosystems compared with other terrestrial sequestration strategies, such as afforestation. Slow pyrolysis is a direct thermo-chemical decomposition (exothermic) process that can be used to transform low-density bio residue matrix into a biochar at a temperature ranging usually from 450-550°C under low-oxic or anoxic conditions (Roberts *et al.*, 2010). Biochar obtained by slow pyrolysis is a porous, high-carbon-density, fine-grained solid material rich in paramagnetic centers having both organic and inorganic nature, possessing oxygen functional groups and aromatic surfaces. The beneficial effects of biochar on soil properties have been reported by many and includes chemical (Yamato *et al.*, 2006), physical and biological changes in soil (Rondon *et al.*, 2007; Venkatesh *et al.*, 2012).

Need for Recycling of Crop Residue into Biochar for Use in Indian Agriculture

(adapted from Venkatesh *et al.*, 2015)

- To improve soil health through efficient use of crop residue as a source of soil amendment/nutrients
- To improve soil physical properties *viz.*, bulk density, porosity, water holding capacity, drainage etc, through incorporation of biochar
- Substantial amounts of carbon can be sequestered in soils in a very stable form
- Addition of biochar to soil enhances nutrient use efficiency and microbial activity
- To enhance soil and water conservation by using the biochar in rainfed areas
- Minimize reliance on external amendments for ensuring sustainable crop production
- Mitigation of greenhouse gas emissions by avoiding direct crop residue burning by farmers
- To enable destruction of all crop residue borne pathogens

Constraints in Recycling of Crop Residue

(adapted from Venkatesh *et al.*, 2015)

- Unavailability of farm labor, higher wage rates for collection and processing of crop residue
- Lack of appropriate farm machines for on-farm recycling of crop residue
- Inadequate policy support/incentives for crop residue recycling

Biochar

Biochar is the fine-grained, C-rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–600°C) in an environment with little or no O_2 (Amonette and Joseph, 2009). Biochar is not a pure carbon, but rather, mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions. The central quality of biochar and char that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased soil surface area.

Methodology of Preparation

Biochar can be produced from a number of methods. The ancient method for producing biochar was the "pit" or "trench" method (Odesola and Owoseni, 2010). The common processes include slow and fast pyrolysis, and the most successful approach for high-yield biochar production is via slow pyrolysis. Under slow pyrolysis, a biochar yield between 25 - 35 per cent can be produced (Hussein *et al.*, 2015); fast pyrolysis processes aim at production of bio-oil and the amount of biochar formed is nearly 12 per cent of the total biomass (Cheng *et al.*, 2012). The cook stove, earth mound kilns and drum kilns are the traditionally used for biochar production in India (Srinivasa Rao *et al.*, 2013). Number of biochar kiln has been designed, developed and used for making biochar from the crop residue and forest biomass (Reddy, 2012; Gangil and Wakudkar, 2013; Venkatesh *et al.*, 2013) in India. A summary of biomass conversion processes (Masek, 2009) is presented in Fig 14.1

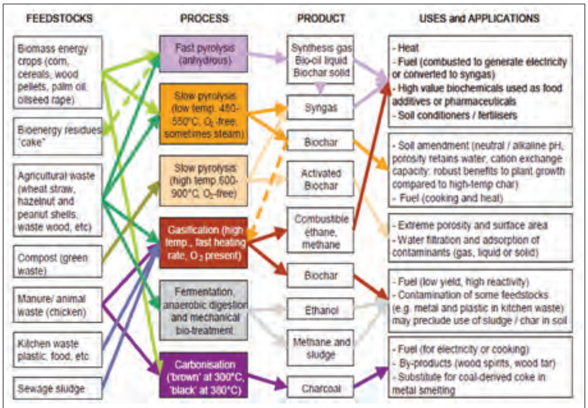

Fig 14.1 Biomass to biochar conversion processes

Biochar Application Method

Biochar application methods have a substantial impact on soil processes and functioning. Biochar application methods must be based on extensive field testing. Various methods of biochar application in soil were mixing the biochar with fertilizer and seed, applying through no till systems, uniform soil mixing, deep banding with plow, top-dressed, hoeing into the ground, applying compost and char on raised beds, broadcast and incorporation, mixing biochar with liquid manures and slurries (Hussein *et al.*, 2015).

Biochar Application Rates

Availability and type of crop residue, nature of biochar, application rate, soil type, crops to be applied, labor, time, climatic and topographic factors of the land, and the preference of the farmer may determine to employ one-time application of large quantity or frequent application of smaller quantity biochar (Venkatesh *et al.*, 2015). Past studies have found that rates between 5 to 50 t/ha have often been used successfully (Lehmann *et al.*, 2006).

Biomass Resources for Biochar Production

There are various types of biomass resources, namely agricultural crop residues, agricultural by-products, forestry residues, wood waste, organic portion of municipal solid waste (MSW), industrial wastewater and manures. The suitability of a particular biomass as a potential feedstock for biochar production depends upon various characteristics such as moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, volatiles, ash content, and cellulose/lignin ratio (Venkatesh, 2013).

Benefits of Biochar Incorporation in Soil

Transforming a low-value crop residue into a potentially high-value carbon source and its soil application has several important benefits (Venkatesh *et al.,* 2015)

Physical properties	Chemical properties	Biological properties
• Decreases bulk density, improves soil workability, reduces labor and tractor tillage and minimizing fuel emissions • High negative charge of biochar promotes soil aggregation and structure • Positive effect on crop productivity by retaining plant available soil moisture due to its high surface area and porosity	• Liming effect provides net carbon benefit compared to standard liming • Enhance the fertilizer use efficiency, reduce the need for more expensive fertilizers and improves the bioavailability of phosphorus and sulphur to crops • Reduce leaching of nutrients and prevents groundwater contamination • Carbon negative process, stable carbon, longer residence period and reduces GHG's emissions from soil	• Enhances the abundance, activity and diversity of beneficial soil bacteria, actinomycete and arbuscular mycorrhiza fungi • High surface area, porous structure and nutrient retentive capacity of biochar provides favorable microhabitats by protecting them from drought, competition and predation

Soil C Sequestration by Biochar

Carbon sequestration is the capture and subsequent storage of carbon to prevent it from being released to the atmosphere. The global carbon cycle is made up of flows and pools of carbon in the Earth's system. The important pools of carbon are terrestrial, atmospheric, ocean, and geological. The carbon within these pools has varying lifetimes, and flows take place between them all. Carbon in the active carbon pool moves rapidly between pools. In order to decrease carbon in the atmosphere, it is necessary to move it into a passive pool containing stable or inert carbon. Biochar provides a facile flow of carbon from the active pool to the passive pool. In comparison to burning, controlled carbonization, converts even larger quantities of biomass organic matter into stable C pools which are assumed to persist in the environment over centuries (Schmidt and Noack, 2000). The conversion of biomass carbon to bio-char leads to sequestration of about 50 per cent of the initial carbon compared to the low amounts retained after burning (3 per cent) and biological decomposition (less than 10–20 per cent after 5–10 yrs) (Lehmann *et al.,* 2002). Compared with other terrestrial sequestration strategies, such as afforestation or re-forestation, carbon sequestration in biochar increases its storage time. This can be done by using the income generated and the quantity of carbon that has been sequestered. Production and application of biochar to farm soils can tackle many global and domestic policy issues. Nevertheless, the application of biochar at the farm level is discouragingly slow, largely due to financial constraints.

Biochar and Greenhouse Gas Emissions Reduction to Tackle Climate Change

Apart from carbon sequestration, there are other environmental benefits that can be derived from the application of biochar in soils which include reduction in the emission of non-CO_2 GHGs by soils (Table 14.1). Reduction of N_2O and CH_4 emission as a result of biochar application is seen to attract considerable attention due to the much higher global warming potentials of these gases compared to CO_2 (Steiner, 2010). Biochar increased N retention when combined with ammonium sulphate (NH_4SO_4) fertilizer on highly weathered soils with extremely low cation exchange capacity (CEC) (Steiner *et al*., 2008), and increased plant uptake of fertilizer N on biochar plots (De Gryze *et al*., 2010). Such information emphasizes the need for further studies to aid the development of biochar as a tool for decreasing non-CO_2 GHG emissions from soil. More research is needed to understand the interactions between biochar, site specific soil, climatic conditions, and management practices that alter the sink capacity of soils. More research is needed to understand the interactions between biochar, site specific soil, climatic conditions, and management practices that alter the sink capacity of soils

Table 14.1 The effect of biochar additions on soil health and GHG emission under different soil types

Soil type	Biochar source	Rate of biochar addition (t/ha)	Impact of biochar addition on soil health and GHG emission	Reference
Anthrosol	Wheat straw	10 and 40	SOC increased by 57 per cent, total N content was enhanced by 28 per cent in the 40 t/ha without N fertilization; Total N_2O emissions decreased by 40-51 per cent and 21-28 per cent, respectively in biochar amended soils; Emission factor (EF) was reduced at 40 t/ha.	Afeng *et al.* (2010)
Sandy	Green cuttings	1, 10 and 40	Increased CEC, exchangeable K, total N, available P at biochar addition of 10 t/ha; 10 and 40 t/ha of biochar increased the water holding capacity of the sandy soil by 6 per cent and 25 per cent	Glaser *et al.* (2014)
Calcare-ous	Rice husk and shell of cotton seed	30, 60 and 90	Decreased soil bulk density, increased exchangeable K and water holding capacity at 90 t/ha	Liang *et al.* (2014)
Silty loam	Oak wood	7.5	Reduced soil bulk density by 13 per cent and increased soil-C by 7 per cent; Cumulative N_2O emission was decreased in the biochar-amended soil (by 92 per cent)	Mukherjee *et al.* (2014)
Sandy loam	Maize stover, Pearl millet stalk, Rice and Wheat straw	20	Maize biochar enhanced the soil available N and P; Wheat biochar increased the soil available K; Rice biochar being relatively labile in soil fuelled the proliferation of microbial biomass.	Purakayastha *et al.* (2015)

Influence of Biochar on Soil quality and Fertility Improvement

Several authors, also report that biochar has the potential to: (i) increase soil pH, (ii) decrease aluminum toxicity, (iii) decrease soil tensile strength, (iv) improve soil conditions for earthworm populations, and (v) improve fertilizer use efficiency. The combined application of biochar and inorganic fertilizer has the potential to increase crop productivity, thus providing additional incomes, and reducing the quantity of inorganic fertilizer use and importation.

Knowledge on the link between biochar function and its interaction with nutrient elements and crop roots may throw light on understanding fertilizer use efficiency. The enhanced nutrient retention capacity of biochar-amended soil not only reduces the total fertilizer requirements but also copes up the climate and environmental impact on crops. Biochar significantly increases the efficiency and reduces the need for traditional chemical fertilizers with sustainable crop yields. Addition of biochar to soil alters important soil chemical qualities; soil pH increased towards neutral values, typically increased soil cation exchange capacity. Glaser *et al.* (2002) observed increasing trend of bio-available P and base cations in biochar applied soils. Biochar application boosts up the soil fertility and improves soil quality by raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity and retaining nutrients in soil (Lehmann *et al.*, 2006). The immediate beneficial effects of bio-char additions on nutrient availability are largely due to higher potassium, phosphorus and zinc availability and to a lesser extent of calcium and copper (Lehmann *et al.*, 2003). Biological nitrogen fixation by common beans was increased from 50 to 72 per cent of total nitrogen uptake with increasing rates of biochar additions (0, 31, 62, and 93 tC/ha) to a low-fertility Oxisol (Rondon *et al.*, 2007). A beneficial impact of biochar on the plant-available phosphorus has been observed in soils enriched with biochar, which in contrast to ammonium, is not a characteristic generally associated with soil organic matter (Steiner *et al.*, 2007). Thus, biochar application could provide a new technology for both soil fertility and crop productivity improvement, with potential positive and quantifiable environmental benefits, such as carbon trading.

Impact of Biochar on Crop Productivity

Several workers have reported that biochar applications to soils have shown positive responses for net primary crop production, grain yield and dry matter (Table 14.2). The impact of biochar application is seen most in highly degraded acidic or nutrient depleted soils. Low charcoal additions (0.5 t/ha) have shown marked impact on various plant species, whereas higher rates seemed to inhibit plant growth (Ogawa *et al.*, 2006). Crop yields, particularly on tropical soils can be increased if biochar is applied in combination with inorganic or organic fertilizers (Glaser *et al.*, 2002).

Table 14.2 Summary of experiments assessing the impact of biochar addition on crop yield

Authors	Study outline	Results summary
Yamato *et al.* (2006)	Maize, cowpea and peanut trial in area of low soil fertility	*Acacia* bark charcoal plus fertilizer increased maize and peanut yields (but not cowpea)
Chan *et al.* (2007)	Pot trial on radish yield in heavy soil using commercial green waste biochar (three rates) with and without 'N'	100 t/ha increased yield; linear increase 10 to 50 t/ha - but no effect without added N
Rondon *et al.* (2007)	Enhanced biological N_2- fixation (BNF) by common beans through bio- char additions.	Bean yield increased by 46 per cent and biomass production by 39 per cent over the control at 90 and 60 g/kg biochar, respectively.
Kimetu *et al.* (2008)	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	doubling of crop yield in the highly degraded soils from about 3 to about 6 tons/ha maize grain yield

Biochar to Counter Climate Change

Biochar has the potential to counter climate change because the inherent fixed carbon in raw biomass that would otherwise degrade to greenhouse gases is sequestered in soil for years. In recent years the use of surplus organic matter to create biochar has yielded promising results in sequestration of carbon. Lehmann *et al.* (2006) estimated a potential global C-sequestration of 0.16 Gt/yr can be achieved from biochar production from forestry and agricultural wastes. In India, biochar from residues of maize, castor, cotton and pigeon pea can sequester about 4.6 Mt of total carbon annually in soil, making it a carbon sequestering process (Venkatesh *et al.*, 2015). A number of studies have reported on environmental benefits of biochar additions which will reduce emission of non-CO_2 greenhouse gases from soil that could be due to inhibition of either stage of nitrification and / or inhibition of denitrification, or promotion of the reduction of N_2O; increases CH_4 uptake from soil (Rondon *et al.*, 2006).

Constraints to adopt Biochar Systems

With limited studies in different soil type, climatic zone and land use situations, it is difficult to predict the agronomic effects. Due to the heterogeneous nature of biochar, cost of production of biochar for research and field application is likely to remain a constraint until commercial-scale pyrolysis facilities are established (Sparkes and Stoutjesdijk, 2011). Some of the practical constraints on use of biochar in agricultural systems were; once applied to soil, remains permanent, unavailability of enough biochar, dry biochar on soil surface is liable to wind erosion, response of local communities to adopt biochar systems (Adtiya *et al.,* 2014); unavailability of farm labor, higher wage rates for collection and processing of crop residue, lack of appropriate farm machines for on-farm recycling of crop residue and inadequate policy support / incentives for crop residue recycling (Venkatesh *et al.,* 2015) .

Conclusion

Efficient, sustainable disposal of organic waste remains a key issue in rural farm areas and in urban societies. Most wastes are either burnt or end up in landfill, which degrades the environment and also produces large amounts of GHGs. The production of biochar from farm wastes and their injection into farm soils offers multiple environmental and financial benefits Biochar production and application in soils has a very promising potential for the development of sustainable agricultural systems in India, and also for global climate change mitigation. There is significant availability of non-feed biomass resources in the country as potential feedstock for biochar production. However, to promote the application of biochar as a soil amendment, and also as a climate change abatement option, research, development and demonstration on biochar production and application mentioned below seem to be very vital. First, a baseline study comprising compilation of data on non-feed biomass resources in India needs be conducted. Second, a review of current non-feed biomass utilization and thermo chemical conversion technologies, particularly slow pyrolysis also has to be carried out. It is also relevant to create awareness among the various biochar stakeholders such as farmers, agricultural extension officers, research scientists and fertilizer wholesalers, and to build their capacities in biochar production and application technologies through the development and implementation of training programmes. Since there are both agronomic and environmental benefits that could be derived from the production and application of biochar in soil, implementation of agricultural schemes involving the application of biochar should first be critically evaluated in the form of a pilot or demonstration project. This could then be transformed into large-scale schemes throughout the country. Participatory approach could be adopted in conducting on-farm trials using the biochar that would be produced. Finally, a business plan for national scale-up biochar production and application project could be prepared based on available carbon finance opportunities in the country.

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Chapter 15

Improving Soil Health and Crop Productivity amidst Climate Change through Conservation Agriculture

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Introduction

Of the total geographical area of 329 Mha, 142 Mha is devoted to agriculture (FAI, 1990). There are recent estimates that out of the 142.2 Mha net cultivated area, only about 69 Mha is under irrigation, while about 83 Mha is unirrigated. The irrigated area produces about 56 per cent of total food requirement of India. The remaining 44 per cent of the total food production comes from rainfed agriculture. Essential commodities such as coarse cereals (90 per cent), pulses (87 per cent), and oil seeds (74 per cent) are produced from the rainfed agriculture. These statistics emphasize the importance of rainfed areas towards food contribution to the food bowl of India. Owing to diversity in rainfall pattern, temperature, parent material, vegetation and relief or topography, this country is bestowed with different soil types, predominantly alluvial soils, black soil, red soils, laterites, desert soils, mountainous soils etc. Taxonomically, soils in India fall under Entisols (80.1 Mha), Inceptisols (95.8 Mha), Vertisols (26.3 Mha), Aridisols (14.6 Mha), Mollisols (8.0 Mha), Ultisols (0.8 Mha), Alfisols (79.7 Mha), Oxisols (0.3 Mha) and non-classified soil (23.1 Mha). Rainfall wise, 15 Mha area falls in a rainfall zone of <500mm, 15 Mha under 500 to 750 mm, 42 Mha under 750 to 1150 mm and 25 Mha under > 1150 mm rainfall. Predominant soil orders which represent semi-arid tropical region are Alfisols, Entisols, Vertisols and associated soils. Other soil orders such as Oxisols, Inceptisols and Aridisols also form a considerable part of rainfed agriculture. Most of the soils in rainfed regions are at the verge of degradation with low cropping intensity, relatively low organic matter status, poor soil physical health, low fertility, etc.

Moisture stress accompanied by other soil related constraints results in low productivity of majority of the crops (Sharma *et al.*, 1999). Besides natural causes, agricultural use of land is causing serious soil losses in many places across the world including in Indian subcontinent. It is probable that human race will not be able to feed the growing population, if this loss of fertile soils continues at the existing rate. In many developing countries, hunger is compelling the community to cultivate land that is unsuitable for agriculture and which can only be converted to agricultural use through enormous efforts and costs, such as those involved in the construction of terraces and other surface treatments.

Indian sub-continent predominantly represents wide spectrum of climate ranging from arid to semi arid, sub humid and humid with wider variation in rainfall amount and pattern. Seasonal temperature fluctuations are also vast. Soils representing rainfed regions are marginally low in organic matter status. The first predominant cause of soil degradation in rainfed regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition and consequently loss of soil fertility. Above all, the several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc aggravate the process of soil degradation.

Predominant Causes of Land and Soil Degradation

The predominant causes which degrade land and deteriorate soil quality could be as follows : i) Loss of topsoil and organic matter associated with clay size fractions due to water erosion resulting in a 'big robbery in soil fertility', ii) intensive deep tillage and inversion tillage with moldboard and disc plough resulting in a) fast decomposition of remnants of crop residues which is further catalyzed by high temperature, b) breaking of stable soil aggregates and aggravating the process of oxidation of entrapped organic C and c) disturbance to the habitat of soil micro flora and fauna and loss in microbial diversity, iii) miserably low levels of fertilizer application and widening of removal-use gap in plant nutrients, iv) mining and other commercial activities such as use of top soil for other than agricultural purpose, v) mono cropping without following any suitable rotation, vi) nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients, vii) no or low use of organic manures such as FYM, compost, vermi-compost and poor recycling of farm based crop residues because of competing demand for animal fodder and domestic fuel, viii) no or low green manuring as it competes with the regular crops for date of sowing and other resources, ix) poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification, x) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, *etc.*, resulting in poor soil and water quality, xi) water logging, salinity and alkalinity and acid soils. As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (Sharma *et al.*, 2007). In order to restore the quality of degraded soils and to prevent them from further degradation, it is of paramount importance to focus on conservation agriculture practices on long-term basis.

There is no doubt that, agricultural management practices such as crop rotations, inclusion of legumes in cropping systems, addition of animal based manures, adoption of soil water conservation practices, various permutations and combinations of deep and shallow tillage, mulching of soils with in-situ grown and externally brought plant and leafy materials always remained the part and parcel of agriculture in India. Despite all these efforts, the concept of conservation farming could not be followed in an integrated manner to expect greater impact in terms of protecting the soil resource from degradative processes.

Likely Effect of Climate Change and its Variability on Soil Quality

Climate change and variability are likely to have a variety of impacts on soil quality. Soils vary depending on the climate and show a strong geographical correlation with climate.

The key components of climate in soil formation are moisture and temperature. Temperature and moisture amounts cause different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation. Soils and climate are intimately linked. Climate change scenarios indicate increased rainfall intensity in winter and hotter, drier summers. Changing climate with prolonged periods of dry weather followed by intense rainfall could be a severe threat to soil resource. Climate has a direct influence on soil formation and cool wet conditions and acidic parent material have resulted in the accumulation of organic matter. A changing climate could also impact the workability of mineral soils and susceptibility to poaching, erosion, compaction and water holding capacity. In areas, where winter rainfall is high, some soils may become more susceptible to erosion. Other changes include the washing away of organic matter and leaching of nutrients and in some areas, particularly those facing an increase in drought conditions, saltier soils, etc.

Effect of Rising Temperature

It has been estimated that in India, about two-third of the increase in atmospheric CO_2 during the past 20 years is due to fossil fuel burning. The remaining is due to land-use change, especially deforestation, and to a lesser extent, cement production. Global average surface temperature increased 0.6 (0.2) ^{o}C in the 20th century and will increase by 1.4 to 5.8^{o}C by 2100. Estimates indicate that India's climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33^{o}C to 4.78^{o}C with a doubling in CO_2 concentrations. Over the past 100 years, mean surface temperatures have increased by 0.3-0.8^{o}C across the region. The 1990s have been the hottest decade for a thousand years. The time taken for CO_2 to pass through the atmosphere varies widely, with a significant impact. It can take from 5 to 200 years to pass through the atmosphere, with an average of 100 years. This means that CO_2 emission produced 50 years ago still linger in atmosphere today. It also means that current emissions won't lose their deleterious effects until year 2014. Even though drastic measures to reduce climate emissions have been taken in recent years, climate change is impossible to prevent.

As a result of increasing pressure from climate change on current key areas of food production, there might be a rising need for increased food production. To meet food production and security objectives, there might be the need to afford prime agricultural land more protection. The rise in temperatures will influence crop yields by shifting optimal crop growing seasons, changing patterns of precipitation and potential evapo-transpiration, reducing winter storage of moisture in snow and glacier areas, shifting the habitat's of crops pests and diseases, affecting crop yields through the effects of carbon dioxide and temperature and reducing cropland through sea-level rise and vulnerability to flooding

Effects of Climate Change on Soil Fertility and Erosion

As of now, no comprehensive study has been made of the impact of climatic changes on soils.

Higher temperatures could increase the rate of microbial decomposition of organic matter, adversely affecting soil fertility in the long run. But increases in root biomass resulting from higher rates of photosynthesis could offset these effects.

Higher temperatures could accelerate the cycling of nutrients in the soil, and more rapid root formation could promote more nitrogen fixation. But these benefits could be minor compared to the deleterious effects of changes in rainfall.

Availability of Nitrogen in soil fertility and N cycling is altered by human activity. Increasing atmospheric CO_2 concentrations, global warming and changes in precipitation patterns are likely to affect N processes and N pools in forest ecosystems. Temperature, precipitation, and inherent soil properties such as parent material may have caused differences in N pool size through interaction with biota. Keller *et al.* (2004) reported that climate change will directly affect carbon and nitrogen mineralization through changes in temperature and soil moisture, but it may also indirectly affect mineralization rates through changes in soil quality.

Impact on Biodiversity

There are apprehensive that climate change will have significant impact on biodiversity and in turn biodiversity loss as the Land degradation such as soil erosion, deteriorating soil quality and desertification are driven by climate variability such as changes in rainfall, drought and floods. Degraded land releases more carbon and greenhouse gases back into the atmosphere and slowly kills off forests and other biodiversity that can sequester carbon, creating a feedback loop that intensifies climate change.

Conservation Agriculture – Concepts and Components

Conservation agriculture has been defined as a practice that reduces soil erosion, sustains soil fertility, improves water management and reduces production costs, making inputs and services affordable to small-scale farmers. Conservation agriculture is defined as a set of practices aimed at achieving the following three principles simultaneously: i) maintaining adequate soil cover, ii) disturbing the soil minimally, and iii) ensuring crop rotation and intercropping. Conservation agriculture as defined by Food and Agricultural Organizations (FAO) of the United Nations is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt the biological processes (Philip *et al.*, 2007). Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels. Tillage is one of the important pillars of conservation agriculture which disrupts inter dependent natural cycles of water, carbon and nitrogen. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage allows protective amount of residue mulch on the surface (Mannering and Fenster, 1983).

Conservation Agricultural in Rainfed Areas – Scope and Importance

Land degradation and Soil quality deterioration are more predominant in rainfed agro-ecoregions because of natural and human induced crop husbandry practices, which call for the adherence to the conservation agriculture management as top priority. Conservation agriculture has the main aim of protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status in the various production systems, hence more suited and required in rainfed agriculture. Predominantly, this goal can be achieved by minimizing the soil tillage, inclusion of crop rotation or cover crops (mostly legumes) and maintaining continuous residue cover on soil surface. The former is governed by the amount of draft, a farmer is using and the latter by the produce amount, harvesting index and fodder requirements including open grazing. The crop rotations are induced by crop diversification, which has wider scopes in the rainfed agriculture than in irrigated agriculture. Diversification will help not only in minimizing the risk occurred due to failure of crops, improving total farm income but also in carbon sequestration.

Tillage, which is one of the predominant pillars of conservation agriculture, disrupts the inter-dependent natural cycles of water carbon and nitrogen. Tillage unlocks the potential microbial activity by creating more reactive surface area for gas exchange on soil aggregates that are exposed to higher ambient oxygen concentration (21 per cent). Tillage also breaks the aggregate to expose fresh surfaces for enhanced gas exchange and perhaps, may lead to more carbon loss from the interior that may have higher carbon-dioxide concentration. Thus, an intensive tillage creates negative conditions for carbon sequestration and microbial activity. However, the main question is whether the intensity of tillage or length of cultivation of land which is an environment enemy in production agriculture in terms of loss of carbon-dioxide, soil moisture through evaporation and biota dwindling is a major production constraint to agriculture or not. The developed countries suffer from heavy-duty mechanization, while India is suffering from long use of plough without caring much about the maintenance of land cover. The major toll of organic C in slopping lands has been taken by water erosion due to faulty methods of up and down cultivation.

Role of Conservation Agriculture (Reduced Tillage and Residue Management) in Mitigating the Adverse Effect of Climate Change

Conservation tillage and residue management helps in the following ways in influencing some of the soil properties and mitigating the adverse effects of climate change.

a) **Soil Temperature:** Surface residues significantly affect soil temperature by balancing radiant energy and insulation action. Radiant energy is balanced by reflection, heating of soil and air and evaporation of soil water. Reflection is more from bright residue.

b) **Soil Aggregation:** It refers to binding together of soil particles into secondary units. Water stable aggregates help in maintaining good infiltration rate, good structure, protection from wind and water erosion. Aggregates binding substances are mineral substances and organic substances. Organic substances are derived from fungi, bacteria, actinomycetes, earthworms and other forms through their feeding and other actions. Plants themselves may directly affect aggregation through exudates from roots, leaves and stems, leachates from weathering and decaying plant materials, canopies and surface residues that protect aggregates against breakdown with raindrop impact, abrasion by wind borne soil and dispersion by flowing water and root action. Aggregates with. 0.84 mm in diameter is non-erodable by wind and water action. Well-aggregated soil has greater water entry at the surface, better aeration, and more water-holding capacity than poorly aggregated soil.

c) **Well-Aggregated Soil also Resists Surface Crusting:** The impact of raindrops causes crusting on poorly aggregated soil by disbursing clay particles on the soil surface, clogging the pores immediately beneath, sealing them as the soil dries. Subsequent rainfall is much more likely to run-off than to flow into the soil. In contrast, a well-aggregated soil resists crusting because the water-stable aggregates are less likely to break apart when a raindrop hits them. Any management practice that protects the soil from raindrop impact will decrease crusting and increase water flow into the soil. Mulches and cover crops serve this purpose well, as do no-till practices which allow the accumulation of surface residue.

d) **Soil Density and Porosity:** Soil bulk density and porosity are inversely related. Tillage layer density is lower in ploughed than unploughed (area in grass, low tillage area etc). When residues are involved, tilled soils will reflect lower density. Mechanization with heavy machinery results in soil compaction, which is undesirable and is associated with increased bulk density and decreased porosity. Natural compaction occurs in soils, which are low in organic matter and requires loosening. But, practicing conservation tillage to offset the compaction will be effective only when there is adequate residue, while intensive tillage may adversely influence the soil fauna, which indirectly influence the soil bulk density and porosity.

e) **Effects on other Physical Properties:** Tillage also influences crusting, hydraulic conductivity and water storage capacity. It has been understood that the textural influences and changes in proportion of sand, silt and clay occur due to inversion and mixing caused by different tillage instruments, tillage depth, mode of operation and effect of soil erosion. Soil crusting which severely affects germination and emergence of seedling is caused due to aggregate dispersion and soil particles resorting and rearrangement during rainstorm followed by drying. Conservation tillage and surface residue help in protecting the dispersion of soil aggregates and helps in increasing saturated hydraulic conductivity. Increased HC in conjunction with increased infiltration resulting from conservation tillage allows soil profile to be more readily filled with water. Further, less evaporation is also supported by conservation tillage, and profile can retain more water.

f) **Effect on Soil Organic Matter and Soil Fertility:** Conservation agricultural practices help in improving soil organic matter by way of i) regular addition of organic wastes and residues, use of green manures, legumes in the rotation, reduced tillage, use of fertilizers, and supplemental irrigation

ii) drilling the seed without disturbance to soil and adding fertilizer through drill following chemical weed control and iii) maintaining surface residue, practicing reduced tillage, recycling of residues, inclusion of legumes in crop rotation. These practices provide great opportunity in maintaining and restoring soil quality in terms of SOM and N in SAT regions. It is absolutely necessary to spare some residue for soil application, which will help in improving soil tilth, fertility and productivity.

Conservation Agriculture and Agroforestry System

Anitta Fanish and Sathya Priya (2012), reported that agroforestry is a land use option that increase livelihood security and reduce vulnerability to climate and environmental change. According to Planning Commission report "Greening India", that 33 per cent forest cover can only be achieved through agro-forestry. Inclusion of agro-forestry systems in agriculture has many benefits such as increase in the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, micro-climate improvement, carbon sequestration, bio-drainage, bio-energy and bio-fuel etc. Now-a-days, agro-forestry has gained popularity among farmers, researchers, policy makers and others for its ability to contribute significantly in meeting the deficit of tree products, socio-economic and environmental benefits. Thus, agroforestry systems conserve natural resources and give the advantage just like conservation agriculture.

Trees play an important role in controlling soil erosion. The effect of perennial vegetation in controlling erosion in forest ecosystems depends on a number of factors such as canopy cover, ground vegetation, litter effects, root effects and changes in the physical properties of the soil. Use of alley cropping (hedgerow intercropping) has often been emphasized for erosion control (Young, 1989; Lal, 1989). Gupta *et al.* (2010) reported that soils of forest lands had generally higher values of pore space (41.4 to 47.2 per cent) followed by cultivated well-managed lands (41.4 to 45.1 per cent), barren (40.1 to 43.4 per cent) and unmanaged cultivated lands (40.0 to 43.2 per cent). Further, he also stated that water holding capacity (per cent) ranged from 21.9 to 32.2, 30.5 to 40.5, 35.4 to 47.5 and 35.3 to 47.3 in soils of barren, cultivated unmanaged, cultivated well managed and forest lands, respectively which is attributed to the occurrence of high amount of organic carbon and clay in the surface than sub-surface soils, which help to form soil aggregates and thus retain water. In an another study, Rudramurthy *et al.* (2008) found higher values of soil moisture holding capacity, field capacity and permanent wilting point in arecanut and mixed forest land use system compared to fallow and sugarcane land use system in Karnataka. Lal (1989a) showed that erosion in plots tilled and alley cropped with gliricidia and *Leucaena* was reduced by 73 and 83 per cent respectively compared with a tilled control treatment. Young (1989) attributed the beneficial effects of alley cropping in controlling soil erosion partially to the barrier effect of the hedgerows, but mainly to the presence of prunings applied as mulch. Hosur and Dasog (1995) evaluated the influence of tree species on soil properties and observed higher aggregate stability, aggregates of 2.5 mm size and mean weight diameter of aggregates under forest plantations compared to control site.

Sims *et al.* (2009) opined that it is not just loss of soil fertility that results from the soil degradation as a consequence of unsuitable farming practices: water resources, biodiversity and ecosystems are also affected negatively. Soils protected by conservation agriculture (CA) and agroforestry systems (AF) have improved water holding capacities. The increased soil organic matter (SOM) levels improve the availability of water accessible to plants (1 per cent of OM in the soil profile can store 150 m^3 water/ha). Not tilling the soil will reduce soil moisture evaporation and, overall, crop water requirements can be reduced by up to 30 per cent with no till. Goulart *et al.* (2012) reported that agroforestry systems such as traditional shade-cocoa, shade-coffee, and agroforestry home-gardens helped in retaining part of the natural habitat structure and ecosystems properties, provided habitat for rich and diverse fauna and flora including threatened and endemic species. Whereas, intensive agricultural systems, such as pastures and extensive mono specific plantations, harbour low levels of biodiversity, hamper biological flux, and lead to soil leaching, and nutrient import/export. Intensive agriculture is one of the major drivers of change in some bio- chemical cycles.

Promotion of Conservation Farming- Steps

In order to promote conservation Agriculture, the following steps need to be considered:

a) There is a need to create awareness among the communities about the importance of soil resources, organic matter build up in soil. Traditional practices such as burning of residues, clean cultivation, intensive tillage and pulverization of soil upto finest tilth need to be discouraged.

b) Systems approach is essential for fitting conservation tillage in modern agriculture. In order to follow the principle of “grain is to man and a residue is to soil”, farming systems approach introducing alternative fodder crops is essential. Agroforestry systems with special emphasis on silvipastures systems need to be introduced. Unproductive livestock herds needs to be discouraged

c) For the adoption of conservation tillage, it is essential that complete package of practices may be identified based on intensive research for each agro ecological region.

d) The increased use of herbicides has become inevitable for adopting conservation tillage/conservation farming practices. The countries that use relatively higher amount of herbicides are already facing problem of non-point source pollution and environmental hazard. In order to reduce the herbicidal demand, there are scopes to study the allelopathic effects of cover crops and intercultural and biological method of weed control. In other words, due concentration is needed to do research on regenerative cropping systems to reduce dependence on inorganic chemicals.

e) Low tillage, crop rotation, cover crops, maintenance of residues on the surface, control of weeds through herbicides, are the key components of conservation farming. Therefore, it is essential that these themes must be studied in depth under diverse soil and climatic conditions across the country on long-term basis.

f) The other objective of conservation farming is to minimize the inputs originating from non-renewable energy sources. Eg. Fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in use of pesticides. This aspect can be strengthened by following integrated nutrient management and integrated pest management approach.

g) The past research experiences of conservation tillage reveal that the major toll of yield is taken by poor germination and poor crop stand because of poor microclimatic environment and hard setting tendencies of soil, excessive weed growth and less infiltration of water to the crop root zone. Therefore, the important aspects which need concentrated research focus include appropriate time of sowing, suitable seed rate, depth of seed placement and soil contact, row orientation, etc. Suitable cultivars having responsiveness to inputs also become important component of conservation farming.

h) The issues related to development of eco-friendly practices for tillage and residue recycling – appropriately for specific combination of soil-agro climatic cropping system – to alleviate physical constraints with higher water and nutrient use efficiency need to be addressed.

i) Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations. Conservation Agriculture becomes more complete when it is practiced by integrating different alternate land use systems. Afforestation in general and embedding of different alternate land use systems in agriculture fields needs more technical support and financial incentives.

Research focus is needed on modeling of tillage dynamics and root growth, incorporation of soil-physical properties in crop-growth simulation models and relating it to crop yields under major cropping sequences.

Conclusion

In the years to come, due to the expected climate change, the degree of land degradation is likely to increase owing to extreme climatic events like drought, flood, high intensity rains etc. This would in turn result in decrease in the productivity of soil. Not only does climate influences soil properties, but also regulates climate via the uptake and release of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Soil can act as a source and sink for carbon, depending on land use and climatic conditions. In order to protect the lands from further degradation and to improve the resilience of soil towards ill effects of climate change, conservation agriculture comprising of zero or reduce tillage, surface residue retention an effective crop rotation can play an important role. In this chapter, various aspects of conservation agriculture, in field crops and alternate land use systems have been discussed.

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Chapter 16

Techniques of Assessing Soil Health - Physical, Chemical and Biological

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Introduction

Intensive production of agricultural crops has contributed to decline in soil quality, leading to lower crop productivity and farm profitability. Major causes of this decline are soil compaction, surface crusting, low organic matter, and increased pressure and damage from diseases, weeds, insects, and other pests, as well as a lower density and diversity of beneficial soil organisms. These constraints have increased the interest of farmers in assessing the health status of their soils and in implementing sustainable soil management practices. Soil health is critically important to sustainable agricultural productivity and environmental wellbeing. Healthy soils provide a range of environmental services including water infiltration, habitat provision and profitable and sustainable agriculture.

Soil Quality and Health

Soil quality and health are terms describing similar concepts and are used synonymously, but a subtle difference may be made out that soil quality is related to soil function whereas soil health presents the soil as a finite non-renewable and dynamic living resource. Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen *et al.*, 1997). Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries (Doran and Zeiss, 2000). Soil quality includes two components, an inherent component and a dynamic component (Fig 16.1). The former is an expression of the soil forming factors, often documented by soil surveys. Dynamic soil quality, on the other hand, generally refers to the condition of soil that is changeable in a short period of time by human impact, including agricultural management practices (Karlen *et al.*, 2003). The dynamic component is of most interest to growers because good management allows the soil to come to its full potential. The inherent and dynamic soil quality components do interact and some soil types are much more susceptible to degradation and unforgiving of poor management than others. With farmer audiences, the term

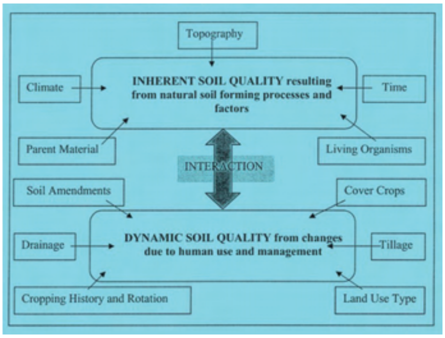

Fig 16.1 Inherent and dynamic soil quality and factors affecting them (Idowu *et al.*, 2006)

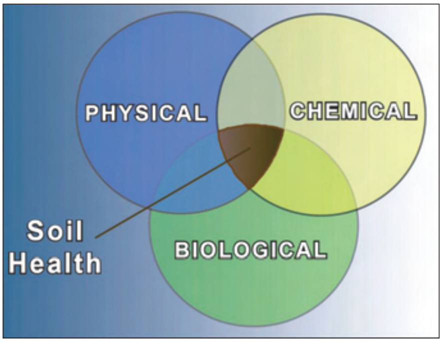

Fig 16.2 The integrated soil health paradigm (Gugino *et al.*, 2009)

"soil health" is often preferred over soil quality as it connotes a holistic approach to soil management, including the integration of physical, biological and chemical processes (Idowu *et al.*, 2007). In the past, an overemphasis on chemical soil management has resulted in a loss of the biological and physical fertility of the soil. A new emphasis on soil health through the linkages between the chemical, biological and physical processes (Fig 16.2) therefore provides a more useful framework for sustainable soil management for diverse cropping systems with tools such as organic and inorganic fertilizers, reduced tillage, cover cropping, new rotations, etc.

Soil Health Indicators

Soil health is best assessed through soil properties that are sensitive to changes in management. Thus, soil health assessment evaluates the soil's ability to accommodate most of the relevant processes relevant to crop production and soil hydrology. The Cornell soil health program of the Cornell University, New York, has done significant work on soil health assessment. The program evaluated 39 potential soil health indicators (Table 16.1) and selected 12 measurements for inclusion in the soil health assessment program. These measurements or properties can be considered as indicators of different soil processes (Table 16.2). The selection of these measurements is based on

- sensitivity to changes in soil management practices
- relevance to soil processes and functions
- consistency and reproducibility
- ease and cost of sampling
- cost of analysis

Table 16.1 Thirty nine potential indicators evaluated for use in the Cornell soil health assessment protocol (Gugino *et al.*, 2009)

Indicator
Physical Indicators
Bulk density
Macro-porosity
Meso-porosity
Micro-porosity
Available water capacity
Residual porosity
Penetration resistance at 10 kPa
Saturated hydraulic conductivity
Dry aggregate size (<0.25 mm)
Dry aggregate size (0.25 - 2 mm)
Dry aggregate size (2 - 8 mm)
Wet aggregate stability (0.25 -2 mm)
Wet aggregate stability (2 - 8 mm)
Surface hardness (penetrometer)
Subsurface hardness (penetrometer)
Field infiltrability
Biological Indicators
Root health assessment
Organic matter content
Beneficial nematode population
Parasitic nematode population
Potential mineralizable nitrogen
Decomposition rate
Particulate organic matter
Active carbon test
Weed seed bank
Microbial respiration rate
Glomalin content
Chemical Indicators
pH
Phosphorus
Nitrate Nitrogen
Potassium
Magnesium
Calcium
Iron
Aluminum
Manganese
Zinc
Copper
Exchangeable acidity

Table 16.2 Indicators of physical, biological and chemical health of soil and their respective soil processes (Idowu *et al.*, 2007)

Soil health assessment indicator	Soil functional processes
Physical Indicators	
Aggregate Stability	Aeration, infiltration, shallow rooting, crusting
Available Water Capacity	Water retention
Surface Hardness	Rooting, water transmission
Subsurface Hardness	Rooting at depth
Biological Indicators	
Organic Matter Content	Energy / C storage, water and nutrient retention
Active Carbon Content	Organic material to support biological functions
Potentially Mineralizable Nitrogen (PMN)	N supply capacity, N leaching potential
Root Health Rating	Soil-borne pest pressure
Chemical Indicators	
pH	Toxicity, nutrient availability
Extractable Phosphorus	P availability, environmental loss potential
Extractable Potassium	K availability
Minor Element Contents (4 elements)	Micronutrient availability, element imbalances

A brief description of the selected soil health assessment indicators is given in Table 16.3. Detailed protocols for measurement of each of the indicators are available in the Cornell soil health assessment training manual (Gugino *et al.*, 2009).

Table 16.3 Brief description of the selected soil health assessment indicators (Gugino *et al.*, 2009)

Indicator	Description
Physical	
Aggregate Stability	Measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a rain simulation sprinkler that steadily rains on a sieve containing a known weight of soil aggregates between 0.5 mm and 2.0 mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of soil that remains on the sieve determines the percent aggregate stability.
Available Water Capacity	Reflects the quantity of water that a disturbed sample of soil can store for plant use. It is the difference between water stored at field capacity and wilting point, and is measured using pressure chambers.
Surface Hardness	Measure of the maximum soil surface (0 to 6 inch depth) penetration resistance (psi) determined using a field penetrometer.
Subsurface Hardness	Measure of the maximum resistance (in psi) encountered in the soil at the 6 to 18 inch depth using a field penetrometer.
Biological	
Organic Matter	Material that is derived from living organisms, including plants and soil fauna. Total soil organic matter consists of both living and dead material, including well decomposed humus.
Active Carbon	Measure of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community (the fuel of the soil food web). Active carbon is a “leading indicator” of soil health response to changes in crop and soil management, usually responding much sooner than total organic matter content.

Indicator	Description
Potentially Mineralizable Nitrogen	Amount of nitrogen that is converted (mineralized) from an organic form to a plant-available inorganic form by the soil microbial community over seven days in an incubator. It is a measure of soil biological activity and an indicator of the amount of nitrogen that is rapidly available to the plant
Root Health Rating	Measure of the quality and function of the roots as indicated by size, color, texture and absence of symptoms and damage by root pathogens such as *Fusarium*, *Pythium*, *Rhizoctonia*, and *Thielaviopsis.*
Chemical	
Soil Chemical Composition	A standard soil test analysis package measures levels of pH, plant nutrients and toxic elements. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific.

To aid the interpretation of soil health measurements, scoring functions were developed for the individual indicators following the work of Andrews *et al.* (2004). The scoring functions enable a value for a specific indicator to be converted to a rating and assigned a color (red, yellow, green) on the soil health report. In the context of soil health assessment, a scoring function is a curve that assigns specific scores between 0 and 100 to the values measured for individual indicators. A score of 100 is the best (highest) while a score of 0 is the worst (poorest). For most of the indicators, scoring functions were developed separately for the major soil textural groups. Soil textural information is used to score most of the other soil health indicators because interpretations cannot be made without correcting for soil texture. In the soil health assessment scoring process, distinction is made between coarse-textured (sand, loamy sand, sandy loam), medium-textured (loam, silt loam, silt, sandy clay loam) and fine-textured (clay loam, silty clay loam, sandy clay, silty clay, clay) soils. For example, coarse textured soils like loamy sands generally have lower organic matter levels than fine-textured clay loams because they lack the ability to stabilize organic matter through organo-mineral bonds. The measured organic matter contents are therefore adjusted to better reflect the health status of a soil. Similarly, a clayey soil is expected to have higher aggregate stability than a sandy soil and the measured values of aggregate stability are scored accordingly. Texture group-wise scoring functions for soil organic matter and aggregate stability are shown in Fig 16.3 and 16.4 respectively.

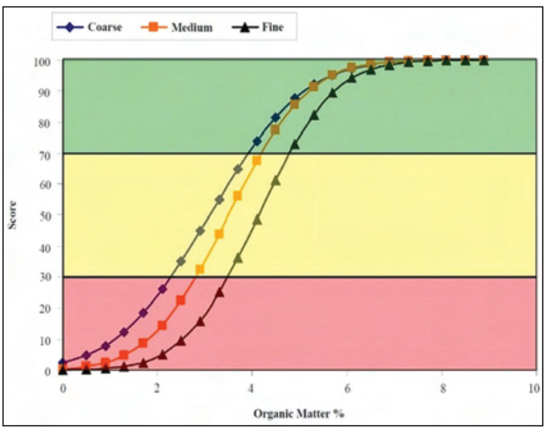

Fig 16.3 Soil texture-wise scoring functions for organic matter (Gugino *et al.*, 2009)

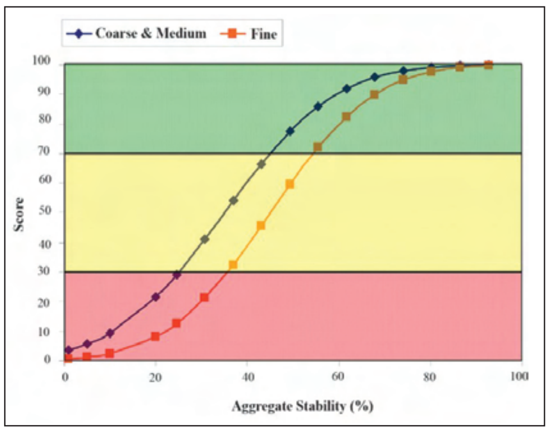

Fig 16.4 Soil texture-wise scoring functions for aggregate stability (Gugino *et al.*, 2009)

The scoring functions for many indicators consist of the cumulative normal distribution (CND) curves normalized to a scale of 0-100 for scoring soil health indicators. Fig 16.5 shows the distribution of active carbon in silt soils with the normal distribution curve drawn to fit the data. Generating a CND from these data and normalizing the Y axis on a scale of 0-100 yields the scoring curve (Fig 16.6).

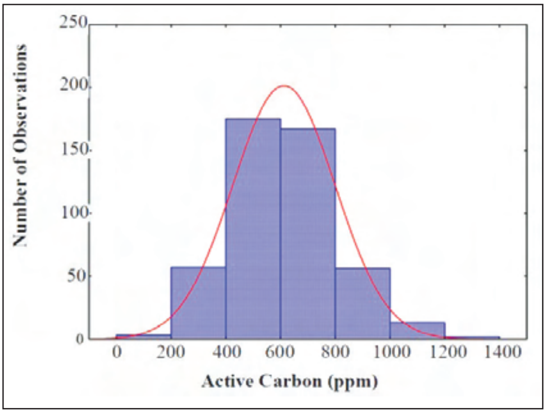

Fig 16.5 Distribution of active carbon in silt soils (Gugino *et al.*, 2009)

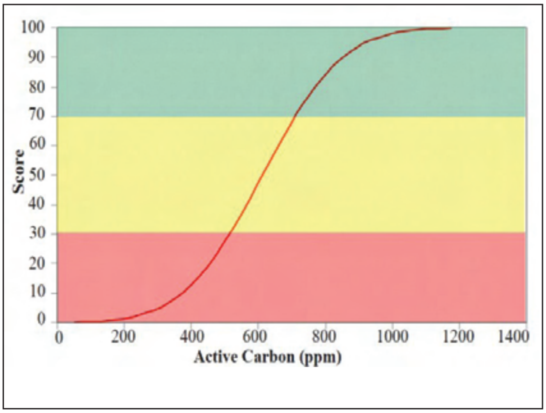

Fig 16.6 Cumulative normal distribution curve for scoring active carbon in silt soils (Gugino *et al.*, 2009)

The thresholds for rating soil health indicators are: i.) 0 - 30 corresponds to deficiency of an indicator implying that it will constrain soil use; ii) >30 - <70 corresponds to the intermediate region of the indicator and iii) 70 – 100 indicates that the indicator value is at an optimal level. The soil measurements scored in this manner include aggregate stability, available water capacity, surface hardness, subsurface hardness, organic matter, active carbon and potentially mineralizable nitrogen.

Scoring curves for soil health assessment generally follow three types of functions:

1. More is better: In this situation, the higher the value of the indicator, the higher the score until a maximum level is attained. Indicators falling in this class include aggregate stability, available water capacity, organic matter content, active carbon content, potentially mineralizable nitrogen, and extractable potassium. A more is better scoring curve is depicted in Fig 16.7.

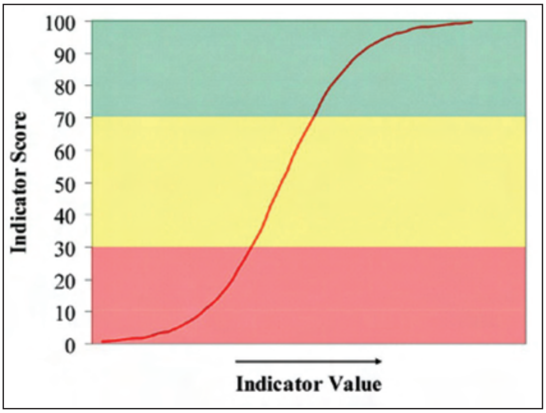

Fig 16.7 A more is better scoring curve
(Gugino *et al.*, 2009)

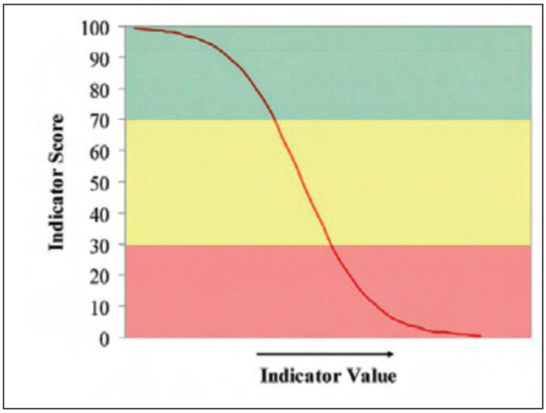

Fig 16.8 A less is better scoring curve
(Gugino *et al.*, 2009)

2. Less is better: The scoring curve in this case gives higher scores to lower values of the indicator (Fig 16.8). Soil measurements in this group include surface hardness, subsurface hardness and root health assessment.

3. Optimum curve: In this case, the curve rises to the highest level with increasing indicator values and remains stationary at the maximum score (Fig 16.9). As the indicator value increases, the scores start decreasing. Indicators that were scored this way are pH and extractable phosphorus.

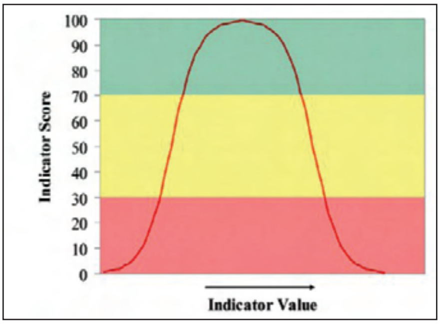

Fig 16.9 An optimum scoring curve (Gugino *et al.*, 2009)

Soil Sampling Protocol

The approach for collection and processing of soil samples for soil health assessment is identical to routine soil sampling for conventional soil testing. The number of samples to be collected depends on the degree of uniformity of the field. One sample is sufficient if the field is uniform (Fig 16.10), but if the field is non uniform, it has to be divided into homogenous sampling units and samples have to be collected from each unit (Fig 16.11). Fields should be divided into sampling units when there are differences in soil type, management practices and crop growth and yield. A 'W' shaped transect is recommended for taking subsamples (Fig 16.10). Irregular areas in the field such as the low spot in Fig 16.11 should be avoided. At each of five stops on the 'W' shaped transect, two soil subsamples are collected at least 15 feet apart and placed in a plastic bucket or container. Penetrometer readings at two depths are recorded at each subsample location (Fig 16.10). Each penetrometer reading is taken through 2 depths (0-15 and 15-45 cm). For each depth, the highest/maximum measured penetrometer reading is recorded. Subsamples are bulked into a single sample, dried under shade and stored in a refrigerator.

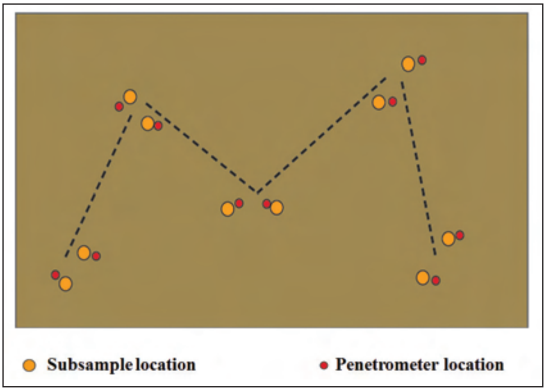

Fig 16.10 Soil sampling pattern in a uniform field (Gugino *et al.*, 2009)

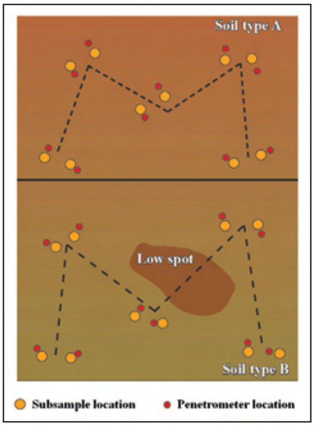

Fig 16.11 Soil sampling pattern in a non uniform field (Gugino *et al.*, 2009)

Chemical Analysis

The chemical analysis part of the Cornell soil health test is a traditional soil fertility test analysis package that measures levels of pH and plant macro and micronutrients. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific. The analysis results for pH, extractable phosphorus and potassium have been integrated into the soil health test report. The secondary nutrients and micronutrient analyses are combined into one rating for the soil health report. Plant nutrients included in the soil health assessment are extractable phosphorus, extractable potassium, magnesium, iron, manganese and zinc. The available nutrients are extracted with Morgan's solution, a sodium acetate-acetic acid solution, well buffered at pH 4.8. Activated carbon is added to the extraction to aid in the removal of organic matter and to help decolorize the extraction solution. After shaking, the extraction slurry is filtered and analyzed for PO_4-P, K, Ca, Mg, Fe, Al, Mn, and Zn. Soil pH is determined in a suspension of one part water to one part soil. The scoring functions for soil pH, extractable P and K are given in Fig 16.12, 16.13 and 16.14 respectively. Other soil nutrients are rated as shown in Table 16.4. If all nutrients are in the prescribed range, a score of 100 (good) is given. If one nutrient is deficient / excessive, a score of 56 (moderate) is given. If two or more nutrients are deficient / excessive, a score of 11 (poor) is given.

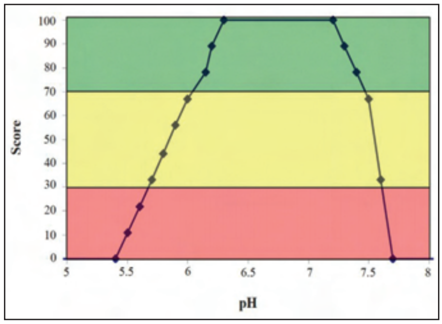

Fig 16.12 Scoring function for soil pH (Gugino *et al.*, 2009)

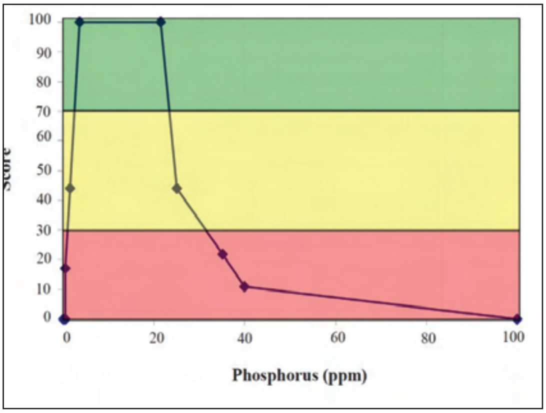

Fig 16.13 Scoring function for extractable P (Gugino *et al.*, 2009)

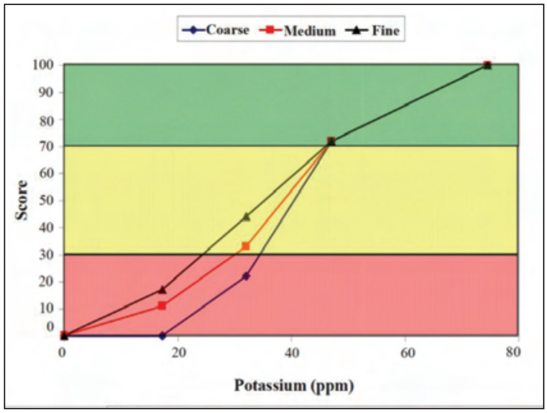

Fig 16.14 Scoring function for extractable K (Gugino *et al.*, 2009)

Table 16.4 Optimal ranges for secondary and micronutrients (Gugino *et al.*, 2009)

Nutrient	Optimum level (ppm)
Magnesium	> 33
Iron	< 25
Manganese	< 50
Zinc	> 0.25

Soil Health Report

The results of measurements are synthesized into a farmer friendly soil health report that can initially be used as a baseline assessment. Subsequent sampling and analysis of the same field can be employed to determine the impact of implemented soil management practices on soil health. The sections of the report include:

Background information: Information collected during sampling including the farmer's name and contact information, the sample number, the date of sampling, the local extension educator's name, current crop and tillage and their history over the past 2 years, drainage and slope conditions, soil type and soil texture.

Indicator list: This section gives a list of indicators that were measured for soil health assessment. They are color coded to separate the physical, biological and chemical indicators.

Indicator values: This presents the values of the indicators that were measured either in the laboratory or field.

Ratings: This section presents the scores and color coded ratings of the soil quality indicators. The indicators are scored on a scale of 1-100 based on scoring functions developed for individual indicators. In addition, the indicators are rated with color codes depending on their scores. Generally, a score of less than 30 is regarded as low and receives a red color code. A score from 30 to 70 is considered medium and is color coded yellow. A score value higher than 70 is regarded as high and color coded green.

Constraints: If the rating of a particular indicator is poor/ low (red color code), the respective soil health constraints will be highlighted in this section. This is a very useful tool for identifying areas to target their management efforts.

Overall quality score: An overall quality score is computed as the mean of the individual indicator scores. This score is further rated as follows: less than 40 per cent is regarded as very low, 40-55 per cent is low, 55-70 per cent is medium, 70-85 per cent is high and greater than 85 per cent is regarded as very high. The highest possible quality score is 100 and the least score is 0, thus it is a relative overall soil health status indicator.

The management practices for soil health are grouped into 5 major activities called the Soil health management tool box. They are

1. Reducing or modifying tillage
2. Crop rotation
3. Growing cover crops
4. Adding organic amendments
5. Adding chemical amendments

Alternative Methods for Soil Health Assessment

Tests such as the Cornell soil health test may be a little too sophisticated and require laboratory analysis which involves time and expenses. Sometimes more farmer friendly methods are required by which soil health can be assessed in the field itself. Such methods include soil health cards and soil health/quality kits. Visible-Near Infrared Reflectance Spectroscopy (VNIRRS) is another method for rapid and less expensive assessment of the soil quality indicators.

Soil Health Cards

Soil health or soil quality assessment card is a qualitative tool designed by and for farmers. The cards contain farmer-selected soil quality indicators and associated ranking descriptions typical of local farmers. Generally, indicators listed, such as soil tilth, abundance of earthworms, or water infiltration, can be assessed without the aid of technical or laboratory equipment. All cards have a scoring system, which usually includes either a range of poor to good or a numerical scale from 1 to 10 for each indicator.

Health cards integrate physical, biological, and chemical properties in ways that are familiar to farmers. For example, the cards use terms like tilth, which refers to the physical structure of soil and which also depends on biological properties. Soil health cards are farmer friendly, quick, and require only basic tools.

Results are obtained immediately, allowing evaluation of numerous fields quickly. Directions for use are found on each card. Further information on soil health cards and examples can be found at http://soils.usda.gov/sqi/assessment/state_sq_cards.html.

Soil Health / Quality Kits

The United States Department of Agriculture has developed a soil quality test kit (USDA, 1999). It is a quantitative assessment kit that can provide results to diagnose possible soil problems, such as compaction or salinity, compare management systems and monitor changes in soil quality over time. The kit uses a minimum dataset of indicators chosen primarily for agricultural soils quality assessments, which are integrated into quantitative tests for biological, chemical and physical properties of the soil ecosystem. A total of 11 tests can be performed, including soil respiration, infiltration, bulk density, electrical conductivity, soil pH, soil nitrate content, aggregate stability, soil slaking, earthworm counts, and various observations of soil physical attributes. The kit consists of a portable box, which includes most of the equipment needed to complete the tests. A guide is included in the kit. The kit is used as a screening tool to give a general direction or trend of soil quality; *e.g.,* whether current management systems are maintaining, enhancing, or degrading the soils. It can also be used to troubleshoot problem areas in the field. Several soil test kits, developed by research institutions and private industry are in use in India.

Visible- Near Infrared Reflectance Spectroscopy (VNIRRS)

In VNIRRS, soil reflectance characteristics are determined over the entire visible (350-700nm) and near infrared (700-2500 nm) region with the use of a spectroradiometer. In these wavelength regions, overtones of unique absorption features can be measured due to stretching and bending vibrations in molecular bonds such as C-C, C-H, N-H and O-H (Idowu *et al.,* 2008). Hyper spectral soil sensing yields large data sets that can be used to find correlations with measured soil properties. More than thirty soil variables were predicted simultaneously with variable level of success by Chang *et al.* (2001), and they reported successful predictions ($r^2 > 0.80$) for total organic carbon and nitrogen (g/kg), gravimetric soil moisture content, 1.5 Mpa soil water at wilting point (kg/kg), exchangeable calcium, CEC (cmol c/kg), silt and sand (per cent). Idowu *et al.* (2008) evaluated VNIRRS for some soil quality indicators and concluded that in the future some soil quality indicators may be assessed using VNIRRS, but it is unlikely that the methodology will completely replace laboratory and field measurements.

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Chapter 17

Root Studies on Crops / Trees in the context of Adaptation and Mitigation for Climate Change

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Introduction

In the soil- plant- atmosphere continuum, manifestation of the ill effects of both the soils and atmosphere result in reduced yields of crop both as grain and fodder. Agro forestry systems are one of the land use systems survive the effect of soil and climatic factors on both tree and associated crop which interact agronomically in a field. The major objective of such systems is utilization of space in a productive and profitable way. Till now most of our studies revolved around the above ground plant biomass in relating the cause and effect of extreme weather events especially in semi-arid and arid environments.

In order to deal with the risks due to climate variability and in turn climate change, farmers are advised to grow both annual and perennial components of the farming system. However, the annual crop interacts with the perennial tree for space, moisture and fertility besides the climatic factors since root is the interface between soil and above ground plant part. Climate variability in long term as a climate change may affect the temperatures of both ambience and soil due to increased green house gas emissions especially CO_2, N_2O and methane. Consequently the losses in organic matter, nutrient supply and soil moisture need to be assessed for addressing the same for future food security.

Why Study Roots?

Soil resource availability is dynamic in nature with varied zones of soil moisture retention, soil fertility *etc*. The spatial and temporal diversity in the soil system requires higher degree of variation in the root dynamics and its architecture. This variation may be both genetic and environmental while more inclination may be observed towards environmental variation especially after the seedling stage of the plant.

Most of our studies since based on the observations on above ground biomass, the outcome from these studies may not be always applicable as the adaptation to the agro-ecosystem, its resilience and recovery would be dependent upon the plasticity of the roots more. Further, Indian soils are diversified in their types, depths, textures, physical and chemical properties *etc*. History on these studies suggest that till now root dynamics was the only nature of understanding we could draw while intrigued by the behavior of root at various soil depths. Information on root architecture is critical for assessing root performance at different soil depths also is gaining importance. Therefore, in the context of climate change and agro-forestry systems, root dynamics *in toto* and the root architecture in particular of both crop plant and the tree needs to be assessed for understanding the agro-ecological interactions of both soil and climate on crop and tree. Eco-physical effects of various soil factors with the concomitant effect of climate on both soil and crop / tree are evident from root parameters. Root biomass production depends on shoot canopy, duration of the crop, soil moisture availability and land use pattern. In the context of climate change, resource quality in addition to the studies over resource availability feature crucial in future studies.

Most of the studies related to extremities of moisture either drought or excess moisture in the form of transient water logging to be assessed through the dynamics of above ground biomass. But below ground biomass by virtue of its location has major share of contribution towards plant's survival. Therefore, root studies gained distinction in the present context of agriculture.

Soil Factors

Soil Organic Matter, Soil Moisture and Soil Carbon Sequestration

Both above ground biomass as litter and below ground biomass as roots contribute to the soil organic pool. However, according to Cadisch *et al*. (2002) above ground biomass litter contributed 31 per cent nitrogen while roots contributed 39 per cent nitrogen through soil aggregates. Further 49 per cent of foliage litter was found in free organic matter fractions. Therefore, above ground biomass improved soil fertility through nitrogen mineralization while roots improved soil structure formation in the form of soil stable aggregates. Consequently improved soil structure due to water stable aggregates facilitates increased water holding capacity, infiltration and reduced erosion. Root dry matter when starts decomposing leave the macro pores for drainage. According Vanlauwe *et al*. (1996) the fine root (<2mm in diameter) composition of crop plants will be decomposed faster while the coarser roots of trees decompose much slowly due to lignifications and contribute to the soil C stocks substantially. Also most of the root studies indicate the contribution of roots for the maintenance of soil organic matter and improved soil structure (Watts *et al.*, 2006) than the plant nutrition as the roots are highly lignified and low in tissue nitrogen and polyphenol concentrations. Fine roots with a short span of 10 days to two weeks will contribute to the organic matter in the soil while tree fine roots survive up to one year. Root decay is a part of carbon sequestration process (carbon sequestration is capturing and storing carbon in soil for the benefit of mitigating the effects of climate change as CO_2 is one of the GHGs in climate change) which builds not only the soil organic matter leading to soil fertility but also acts as a long standing sink for carbon storage.

Soil Fertility, Soil Strength, Soil Spacing and Land Use Pattern

Vulnerability of soils depends on agricultural land use. In case of a single season dryland crop the land exposed to various vagaries of climate. Given the requirement of presence of vegetation to the longest possible periods, agroforestry systems might be a better solution. In case of agroforestry systems, it is the space and availability of soil moisture, nutrients and solar radiation matter when it comes to associated crops while the concomitant effect of extreme weather events influence the effect of above soil factors (Ball *et al*., 2005). As already mentioned most of our studies on crops while encountering the extreme events of the climate *viz.*, drought, excess moisture and low or high temperatures only are on dynamics of above ground biomass. However, below ground biomass studies though are very difficult and tedious are straight troubleshooters as the root is the prime component in direct contact with the situation.

Climatic Factors

Inadequate rainfall resulting in spells of dry conditions does affect the soil moisture depending upon the soil type, soil depth and soil physical, chemical properties. Basically drought is a complex phenomenon ensconcing the multiple effects of heat, temperature both in ambience and soils and water *etc*. Whitmore and Whalley (2009) reviewed that enhanced above ground biomass and mycorrhizol association is taxing on the part of root system as resource spenders while reduced root length and mass as resource savers piloting us to select the suitable crops/varieties for optimal moisture and nutrient management.

During sudden and extreme events of rainfall, possible water logging or exposure to high rainfall intensities occurs for a short time might result in hypoxia (inadequate oxygen in the tissue). According to Rogers and West (1993) hypoxia affects the root growth in certain species of *Trifolium,* while *Trifolium repens* showed increased root dry weight as new adventitious roots were added. Reason might be these roots had higher percentages of internal gas spaces within the root tissue even under flooded conditions. Electron micrographs of root sections illustrated the presence of gas spaces or aerenchyma. Therefore, this type of studies would help us in differentiating the suitable crop or suitable species or a variety for root zone hypoxia. Further Van Noordwijk (1993) have developed a methodology for assessing root–solid and root–air contact as the optimization of these two contacts could able the plant withstand hypoxia.

In terms of temperature, a 12-day period of high temperature stress close to anthesis reduced spring wheat root biomass from 141 to 63 g/sqm (Ferris *et al*., 1998) by the end of the elevated mean temperature period, whereas mean temperatures over the treatment period had no effect on either above-ground biomass or grain yield at maturity. Interestingly, it was increasing maximum temperatures over the mid-anthesis period which was related to a decline in the number of grains per year at maturity. Grain yield and harvest index also declined sharply with maximum temperature. This study suggested that high temperature extremes may reduce yields considerably.

Root Studying Methods

Root traits that lead us to the decisive understanding are total root length, Root length density, root surface area and depth wise distribution of roots of different diameters etc. Root studies lately have been infiltrated into the soil depths as the studies ensconced with soil moisture and nutrient availability especially in arid and semi arid tropical agro-ecosystems aiming at precision farming indirectly supporting reduced GHG emissions from agriculture without affecting the production.

The researchers to assess various root parameters researched upon different methods. Among them they can be classified as.

Root Proliferation Studies

Root Dynamics

Root studies have historically been conducted to evaluate the effects of soil moisture deficits on the plant performance especially in India. Therefore, the root system *in toto* is extracted (many on field methods and pot studies involved) and using Newman's line grid method measured total root length, root volume through water displacement method and root dry weights by drying till constant weights were achieved. According to Bohm (1979), mostly these are Excavation methods, monolith methods, Auger methods, Profile Wall methods, Glass Wall methods for field studies and Container methods for greenhouse studies while Radioactive tracer methods as indirect methods. Gradually these root studies led to the understanding of importance of different components of root system especially fine roots at different soil depths, activity of roots or the activity in the rhizosphere and the soil profile wise criticality of roots and their abilities to capture moisture and nutrients *etc*. Therefore, emphasis was on the root architecture studies and attempts were on to study them both on field and under greenhouse conditions.

Root growth though increased under elevated CO_2 emphasizing increase in the number of lateral branches and root length of soybean crop in the same volume of soil, there was no increase in the elongation of individual roots (Del Castillo *et al*., 1989). The impacts of CO_2 enrichment could be studied using growth chambers under elevated CO_2 or Free Air Carbon dioxide Enrichment (FACE) or Free Air Temperature Enrichment (FATE) facilities. In case of trees, core sampling method is followed and the sampling sites around the trunk of the tree and the technique was standardized by Weller (1971).

Root Architecture

Root architecture is the spatial configuration of roots in the soil profile. Studies on Root architecture give insights in understanding the spread of roots including various sizes of roots at different soil depths in the profile which may be related to the soil moisture extraction pattern. Generally once the root system is sampled, it is very difficult to retain the root positioning when soil is washed off. Since root architecture is positioning of varied sizes of roots and exploitation of resources largely at that particular soil depth, apparent retention of roots may provide design of roots and in turn the plasticity to exploit that particular soil depth for moisture and nutrients. Further, according to Eissenstat and Yanai (1997), while fine roots directly acquire water and nitrogen and coarse roots might be responsible in placing fine roots at deeper depths for economical supporting of water. Lately, the concept of understanding root architecture has been preferred in the context of soil moisture depletion, root proliferation depth wise and the effects of drought and transient water logging *etc (*Maruthi *et al., 2013)*. The methods (Böhm, 1979) include Cage method, Box method, Pin board (Maruthi *et al*., 2010) Needle board method, Minirhizotron (van Noordwijk *et al*., 1995) and indigenous CRIDA pin board method for root architecture sampling *etc*.

Root Decomposition and Carbon Sequestration

Root turnover is important in the context of carbon fixing, sequestration and decay into organic matter. According to van Noordwijk *et al.* (2004) through functional equilibrium (cycles of root mortality and new root growth) root systems access limited resources and maintain root length density and in turn response. Root biomass turnover and Root length turn over are two terms/parameters used as indicators. Dead roots contribute to soil aggregation. Of root turnover especially the dead roots are very important in mountainous areas where topsoil layer is very shallow and the root network holds the soil from landslides before they decay (may take long time). Prospects of tree growth will have implications in future disaster management. These studies on root decomposition include Root Litterbag Studies as well (van Noordwijk, 1993).

Soil carbon dynamics (part of carbon sequestration), a critical issue related to climate change as soil is considered as carbon sink reducing the emissions curbing atmosphere pollution. Roots being the interface between plant and soil contribute to soil carbon through their root biomass. Perennials with their predominant coarse roots, delay the decomposition process storing more carbon in soil away from soil disturbance though annuals add more fine roots (van Noordwijk and Brouwer, 1997) Water stable aggregates prevent loss of soil carbon thereby improving carbon stocks in turn increasing carbon sequestration reducing emissions. In addition to this, soil clay and silt fraction decide carbon sequestration capacity of soils. Further the greenhouse gases measurement includes carbon, N_2O and methane, which would be carried by CN analyzer, total organic carbon analyzer, and gas chromatography *etc.*, (Srinivas *et al.*, 2017). Root studies gained importance due to the role roots play in the survival of plant under any extremities of weather though the methodologies are yet to be refined. These studies are helpful for plant breeders in selecting the germplasm with better root traits; of course need to be topped up with the good yields even and agronomists/production scientists in refining the management strategies reducing the assumptions of their applicability status.

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Chapter 18

Agri-Horti and Horti-Pastoral Cropping Systems for Climate Resilience

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Introduction

Climate Change is an unpredictable condition or sequence of weather events for unspecified period or duration. Droughts or uneven rainfall situations are frequent in Semi Arid Tropical (SAT) regions of India. Suitable fruit and vegetable species and varieties for SAT regions, benefits of farm pond water harvesting system, nutrient management, intercropping of suitable annuals within the perennial fruit tree rows, suitable grass and legume species for horti-pastoral systems are discussed. Integrated horticultural management practices for climate resilience are discussed in the present paper.

Long-term indicators of available water include climate and weather conditions, soil moisture, water tables, water quality, stream flow, mountain snow pack, and watershed runoff. Indicators of such changes in the hydrologic cycle are termed first order impacts. Second order impacts would affect food production, transportation, and industries that are particularly dependent on water resources, and sensitive to supply disruption. A third order impact would be one that requires significant reductions in high water-use activities, requires serious adjustment in lifestyle, and impinges on the social welfare, behavior, economy, and health of the community. A supply insufficiency may have an immediate second or third order impact, but generally for a shorter period of time. From areas which have experienced drought, it is evident that drought is not a constant or totally predictable condition in occurrence or duration. Rather, there are levels of drought and levels of drought impact.

For semi-arid or arid or dryland climatic environments having negative moisture index, poor soil quality and traditional agricultural practices, the food security, nutritional security, sustainability and profitability of a horticultural production system especially to those below poverty line, is still a distant dream. The total precipitation received in these areas seems to be adequate for crop production; however, its erratic distribution often causes drought conditions and seriously affects the agri-horticultural production. Therefore, effective utilization of every drop of water through adoption of appropriate technology is imperative for improving productivity to augment agri-horticultural production and to achieve sustainable improvements in the living standards of resource poor small and marginal farmers. Efficient utilization of every drop of water in crop production also assumes significance because utilizable water resource for agriculture sector is becoming increasingly scarce owing to unpredictable monsoons, depleting groundwater reserves, rising alternative demands *viz.*, domestic and industrial uses. It is a matter of concern that it is happening at a time when there is an increased demand for various agricultural commodities due to phenomenal growth in the population. The need of the hour is, therefore, to maximize the agricultural production per unit of water used

Horticultural Crops for Higher Production and Productivity

Over the past 70 years, the world's agricultural systems have been changing in response to population pressures. Population growth and local economics are driving both the intensification of agriculture and its extensification in to the marginal lands, where risks of crop failure and environmental degradation are high.. Horticulture based production systems are now considered to be the most ideal strategy to provide food, nutrition and income security to the people. The importance of horticulture in improving the productivity of the land, generating employment, improving economic conditions of the farmers and entrepreneurs, enhancing exports and above all, providing nutritional security to the desert dwellers, can hardly be overemphasized. Horticulture has assumed significant importance in the crop diversification in recent years, which has become essential to arrest serious land degradation and enhancing the farm income. Diversification of agriculture from traditional land use with predominantly cereal / legume-based cropping systems to more productive and remunerative one has become a milestone to be achieved. Horticulture provides one of the few viable and most attractive alternative land use system. Apart from their contribution to the total agricultural production, their potential for providing much higher income to the farmers has been another major factor for favoring these crops in this campaign (Table 18.1, 18.2 and 18.3)

Table 18.1 Improved cultivars, propagation method, plant geometry and yield potential of different fruit crops

Fruit crops	Improved cultivars	Propagation method	Yield (kg/plant)
6 × 6 m spacing			
Bengal quince	Dhara Road, Faizabadi local, NB5, NB9, Pant urvashi, Pant aparna, Pant shivani and Pant sujata	Patch budding (May–July)	30–60
Indian cherry	--	Seeds and budding	40–150
Indian gooseberry	Chakiya, Kanchan, NA7, Krishna, Anand 2	Patch budding	40–150
Indian jujube	Gola, Mundia (early) Seb, Banarasi, Kaithli, Goma keerti (medium), Umran, Illaichi, Tikdi (late)	I-budding (July–August)	40–100
Orange	Kinnow	Budding (March-April)	30–50
Sweet orange	Mosambi and blood red	Budding (March–April)	30–50
5 × 5 m spacing			
Pomegranate	Jalore seedless, Ganesh, G137, G131, P26, P23, Mridula, Araktha, Bhagwa etc.	Hard wood cutting and air layering (July–August)	15–25
Sour lime	Kagzi lime, Vikram, Pramalini, etc.	Air layering and budding	20-30
4 x 4 m Spacing			
Karonda	Pant manohar, Pant suvarna, Pant sudarshan	Seeds and cutting (August)	10-20

Table 18.2 Suitable fruit varieties for semi arid tropical regions

Fruit Crops	Cultivars
Ber	Gola, Umran, Banarasi Karaka, Kaitli.
Pomegranate	Ganesh, Jyothi, P-26, Jalore seedless.
Mango	Banganapalli, Alampur Baneshan, Nelum, Mallika, Bombay Green, Amrapali, Kesar.
Sapota	Cricket Ball, Kalipatti.
Sweet orange	Mosambi, Kodur Sathgudi, Valencia, Blood Red ,Malta.
Lime	Tenali, Promalini, Vikram.
Custard apple	Bala Nagar, Arka Sahan.
Guava	Allahabad Safeda, Sardar, Arka Mridula.

Fruit Crops	Cultivars
Papaya	Coorg Honey Dew, Pusa Delicious, Pusa Majsty, Pusa Dwarf,Taiwan
Aonla	Kanchan, Krishna, Narendra –7.
Fig	Poona, Black Ischia.
Tamarind	PKM-1, Pratisthan, Yogeshwari.
Bael	Narendra Bael-5, Narendra Bael-9.
Passion fruit	Kaveri.

Source : Reddy and Singh (2002)

Table 18.3 Suitable vegetable varieties for semi arid tropical regions

Vegetable Crops	Varieties
Onion	Arka Niketan, Arka Kalyan, Pusa Red, Nasik Red, Pusa Ratnar, Pusa White Round, Pusa White Flat, Patna Red, Arka Pitambar (for export).
Tomato	Pusa Ruby, Pusa Early Dwarf, Swarna Mani,Vaishali, Naveen, Rupali, Rashmi
Brinjal	Arka Navneet, Pusa Purple Long, Pusa Purple Round, Pusa Kranthi, Arka Sheel, Arka Kusumakar, Arka Shirish, Swarna Shree, Swarna Manjari.
Chillies	G-5, G-3, Pusa Jwala, NP-46A, Arka Gaurav, Arka Lohit, Bharat, Sindhur.
Drumstick	PKM-1
Cowpea	Pusa Barsati, Pusa Rituraj, Pusa Dofasali
Cluster bean	Pusa Navbahar, Pusa Sadabahar
Amarnath	Chhoti Chaulai, Badi Chauli.
Okra	Arka Anamika, Arka Abhay, Parbhani Kranti, Pusa Makhmali.
Water melon	Arka Manik, Arka Jyothi, Sugar Baby.
Musk melon	Pusa Sharbati, Hara Madhu, Punjab Sunheri, Pusa Maduras.
Bitter gourd	Arka Harit, Priya, Kalyanpur Sona.
Ridge gourd	Swarna Manjari, Pusa Nasdar.
Round melon	Arka Tinda.
Cabbage	Pusa Mukta, Pride of India, Golden Acre, Pusa Synthetic, Pusa Drumhead, Shree Ganesh Gol.
Cauliflower	Pusa Deepali, Improved Japanese, Pusa Snowball.
Pumpkin	Arka Chandan, Arka Suryamukhi
Radish	Arka Nishant

Source: Reddy and Singh (2002)

Micro Catchment or Farm Pond Water Harvesting System

Heavy rains resulting in the heavy down pours is not uncommon resulting in runoff even in dry land regions. About 15-30 per cent runoff water could be capitalized for water harvesting and runoff recycling (Reddy *et al.*, 2002). Efficient utilization of harvesting water requires an elaborate consideration of selection of site, runoff inducement, storage, seepage, evaporation losses, water lifting and conveyance devices and their efficiencies. A farm pond of 150 m^3 capacity with side slopes of 1.5:1 is considered sufficient for each hectare of catchments area in the black soils with a provision of emptying it to accommodate subsequent events of runoff.

Micro Site Improvement

It is preferable to plant the fruit trees with the onset of monsoon in well prepared and filled in pits at suitable distances. Most of the above fruit species respond well in closed spacing except tamarind, goose berry, *Syzygium* and mango which prefer a wider spacing. The pits should be of one cu.m. dimension, filled with equal quantities of tank silt, well decomposed compost or Farm yard Manure and the good soil from the site, 100 g DAP and 50 g of BHC dust. Before filling the pit, dried leaves may be burnt in the pit to kill any germs inside. Application of 10 kg bentonite at the bottom of pit enhance availability of moisture to the root system.

Nutrient Management

Young fruit plants should be manured during rainy season every year. A dose of 50 kg FYM should be incorporated in the basin with the onset of monsoon. Depending upon the age of plants canopy development, soil moisture availability, chemical fertilizers should be applied in 2-3 splits after a rainfall incidence or watered. An estimate of fertilizer to be applied to different fruit plants is given below (Table 18.4).

Table 18.4 Recommended nutrition to the selected fruit crops (age wise) (Reddy, 2004)

I(a). Nutrient/ tree with SWC	Mango			Ber			Pomegranate			Custard apple		
	Years											
	1-2	5-7	> 10	1-2	5-7	> 10	1-2	5-7	> 10	1-2	5-7	> 10
FYM (kg)	20	40	75	10	20	30	5	10	20	10	20	30
N (g)	500	750	1000	150	500	625	125	150	300	100	200	325
P_2O_5(g)	250	500	750	100	250	300	100	150	300	75	150	250
K_2O (g)	500	750	1000	100	250	300	100	150	300	50	100	175
Zn SO_4 (g)	50	100	200	-	-	-	15	30	60	-	-	-
I(b). FYM (kg) with SWC	50	100	200	50	75	100	50	75	100	50	75	100
II. No SWC FYM (kg) (Control)	20	40	75	10	20	30	5	10	20	10	20	30

SWC: Soil and Water Conservation

Intercrops

Cenchrus, Stylo, cowpea, horse gram and sorghum were grown as intercrops in between orchard rows. Farmers' practice without SWC measures and without RDF involving simple application of FYM became the control treatment. In a silvi-pasture experiment, intercrops such as *Cenchrus*, Stylo and *Sorghum* were grown in *Acacia* or *Leucaena* as in Mahaboobnagar, *Dalbergia* or *Leucaena* in Ranga Reddy district, teak or *Eucalyptus* in Beed and neem or anjan (*Hardwickia*) in Sangli districts. All the treatments with swc measures improved the orchard fertility and yields of selected crops (Table 18.5 and 18.6).

Intercropping Annual Crops under Fruit Trees

The establishment of an orchard involves heavy investment and high recurring maintenance expenditure particularly under semi arid tropical as well as dryland conditions. Since the land is not fully covered during the initial 5-6 years of the plantation, it is remunerative to encourage intercropping with suitable annual crops like groundnut, cowpea and green gram. This will help in meeting the initial expenditure on the plantation besides generating more employment.

Table 18.5 Fodder species suitable in fruit crops under Horti-Pastoral cropping systems

Region / Grass	Rainfall (mm)	Soil type	Dry forage yield (t/ha)	Crude protein content (%)
Semi arid				
Schima nervosum	600-1000	Mixed red and black	3.5	5-8
Dicanthium annulatum	500-1000	Sandy loam ,Clay silty loam	2.5	4-7
Heteropogon contortus	600-1000	Mixed red and black, red soils	3.0	2-3
Chrysopogon fulvus	600-1000	Hilly areas and crevices of rocks	3.5	4-7
Iseilema laxum	700-1000	Low lying, clayey black soils.	3.0	4-6
Arid				
Lasiurus sindicus	100-150	Sandy	3.5	8-14
Cenchrus ciliaris	150-300	Sandy	4.0	8-9
Cenchrus setigerus	150-300	Sandy	3.0	8-9
Panicum antidotale	200-600	Sandy	3.0	9-14

Table 18.6 Legume fodder species suitable as intercrops in different orchards

Region / Legume	Soil preference	Dry forage yield (t/ha)
Semi-arid (600-1000 mm rainfall)		
Desmodium intertum	Versatile	3.8
Desmodium uncinatum	Versatile	3.0
Glycine weightii	Well drained soil	3.0
Stylosanthes guinensis	Versatile	3.6
Stylosanthes hamata	Well drained soil	3.5
Stylosanthes humilis	Well drained soil	3.2
Lablab purpureus	Versatile	3.0
Macroptilium ateropurpureum	Versatile	1.8
Arid (< 600 mm rainfall)		
Stylosanthes scabra	Versatile	2.5
Atylosia Sp.	Versatile	2.0

Moisture stress is one of the major constraints over a wide range of soil situations. Plants having xerophytic characteristics *viz;* deeper root system deciduous nature, reduced foliage, sunken or covered stomata, waxy coating or hairiness on leaf surface minimizes the evapo transpiration and makes plant amenable for their cultivation under moisture stress situations. Fruits *viz;* ber, aonla, tamarind, wood apple, cashew nut, custard apple, karonda mahua, few local indigenous plants like Khair (*Capparis decidua*), khejri (*Prosopis cineraria*), drumstick (*Moringa oleifera*), lasora (*Cordia dichotoma*), khirni (*Manilkara hexandra*) have xerophytic characteristics and can be cultivated under moisture stress situations (Table 18.7).

Table 18.7 Reaction of fruit varieties to moisture stress and sodicity

Fruit crop	Tolerant cultivar	Less tolerant cultivar
Aonla	Chakaiya, Francia Kanchan, NA-7, NA-6	Banarasi, Krishna, NA-10
Ber	Banarasi Karaka, Kaithli	Gola, Umran
Guava	L-49	Allahabad Safeda, Apple colour
Grape	Beauty Seedless	Kishmish Charni

Utilization of Tolerant Rootstock

Few fruit plants are susceptible to moisture stress situations but with the use of appropriate rootstock, their cultivation is possible under problem soils to a great extent. Rootstock must possess deeper root system and have the capacity to even when the little moisture is available. Few of the hardy rootstock which have been in use are enumerated below (Table 18.8).

Table 18.8 Rootstock reaction

Fruit crop	Characteristics	Rootstock
Mango	Salinity and drought	Kurukkan, Neleshwar Dwraf
Citrus	Drought or salinity	Cleopetra mandarin, Rangapur lime
Grape	Salinity	Dogridge, Salt Creek
Sapota	Moisture stress	Khirni
Fig	Moisture stress	Gular (*Ficus glumerata*)

Socio-Economic Issues

Adoption of horticulture based production systems can improve the socio-economic conditions of resource deficient farming community. These will provide an assured source of livelihood as perennial component will generate farm produce even during low rainfall or drought conditions. Many of these underutilized fruit species play an important role in the social economy and livelihoods of tribal, small, marginal and landless farmers.

Employment Generation

These production systems will certainly open an opportunity for additional employment for rural youth during most of the months compared to arable farming, which is exclusively dependent on rains and confined to a limited period.

Nutrition Component

The rural masses in arid regions do not have adequate fruits and vegetables in their diet. With large scale plantation of horticultural crops in their farm under integrated system, the inhabitants of region will certainly get nutrition in the form of vegetables and fruits.

Entrepreneurship

Adoption of these systems can also help in establishing village based cottage industries for making jam, murabba, pickles, jelly, juice, squash, *etc*. This will help in generating additional employment to school drop outs and women folk in addition to a regular source of income. Such agro-based industries have already come in to existence in the region for the last four decades.

Environment Issues

Soil erosion in desert areas is largely due to the removal of structure less topsoil by wind and rain. This can largely be checked by planting wind breaks, creating shelterbelts and stabilizing sandy tracts and dunes with adapted grasses and shrubs. *Ziziphus nummularia* shrubs have been shown to effectively check wind erosion, help in deposition of soil, and bring about a change in the microhabitat, causing favorable conditions for the appearance of successional species such as perennial grasses. Several species of *Ziziphus* can endure extreme stress caused by drought, salinity, and in some cases water logging.

Policy Related Issues

Frequent irrigation in sandy soils of arid regions always results in buildup of salinity thereby making the land unproductive. Therefore, the situation warrants the judicious use of irrigation and adoption of integrated farming system with component of perennial species (fruits, trees and grasses) to provide long term solution and sustainability in the region. Climate change is yet another issue for environmentalists and policy planners in the recent time, which is bound to adversely affect the productivity of region. Therefore, improvement in vegetation cover is also a matter of serious concern for all those who are concerned for arid zone development. Expansion of perennial component particularly those plants which can also provide livelihood security and nutrition to desert dwellers is required.

Arid region- Farming systems

Area under hot arid region in different states of India

The arid tropics or hot arid regions of India lies between 24-29^0 N latitude and 70-76^0 longitude covering an area 3170 Mha in the states Rajasthan, Gujarat, Punjab, Haryana, Andhra Pradesh, Karnataka and Maharashtra. The climatic conditions of arid Rajasthan are not very conducive to agricultural production especially during kharif season due to occurrence of frequent droughts. Thus the farmers go only for one season cropping due to lack of irrigation facilities. Now with the commencement of Indira Gandhi Nahar Paryojna (IGNP) and development of tube wells, efforts are being made to develop arid lands through agri-horti, agri-silvi and agri-pasture systems (Table 18.9).

Table 18.9 Recommend Agri- Horti crop components for Indian Arid regions

Growing conditions	Horticultural component			Crop component
	High storey	Medium storey	Ground storey	
Rainfed (150–300 mm)	Bordi and Indian mesquite	Jhar ber	Cucurbits and guar	Guar, moth bean, pearl millet and sesame
Rainfed (300–500 mm)	Indian cherry, Indian jujube and Indian mesquite	Jhar ber	Cowpea, cucurbits, guar and Indian bean	Cowpea, guar, green gram, moth bean, pearl millet and sesame
Irrigated	Bengal quince, Indian gooseberry Indian jujube and Indian mesquite	Guava, kinnow, karonda, lime, pomegranate and sweet orange	Brinjal, chilli, cole crops, cucurbits, garlic, okra, onion, peas, root/leafy vegetables and tomato	Chickpea, green gram, groundnut mustard and seed spices

Researchers have shown that growing location-specific crop in combination with tree/grasses not only mitigate the risk of total crop failure, but can also increase resource use efficiency and replenish soil fertility (Soni *et al.,* 2007). Integrated farming system (IFS) approach has been widely recognized and advocated as one of tool to harmonize use of inputs and their compounded responses to make the production system sustainable. Several studies conducted in different parts of country have revealed that an integrated farming system (IFS) approach besides increasing system productivity also envisages harnessing complementarities and synergies among different agricultural sub-systems/enterprises and augments the total productivity, profitability, sustainability and gainful employment for a household.

Farming Systems in Vogue

Farming system in arid region of India evolved through centuries of practicing and refining of farming, in consonance with prevailing climatic conditions, available natural resources. The knowledge and experience of people engaged in farming were passed on to successive generation in developing these systems. The arid farming system all through ages were predominantly livestock based. In arid Rajasthan <250 mm rainfall zone grasses and shrubs dominant the scenario and range/pasture development with livestock rearing is the main agricultural preposition. In area receiving rainfall between 250-350 mm besides grasses and shrubs, multi-purpose tree species dominates and mixed farming encompassing agro forestry system, mixed cropping, livestock and pasture management are main livelihood options. In area receiving rainfall >300 mm crops and cropping system diversification, agro forestry and livestock rearing are major system of sustenance of arid zone farmers (Bhati and Joshi, 2007).

There have been several changes in arid landscape in past few decades. There has also been unprecedented increase in human population, resource exploitation and development activities, all exerting immense pressure on resource base of region. This resulted in fragmentation of holding, shift in land use pattern with grassland and tree reserves converted to cultivated field, drastic reduction in fallowing practices, over-exploitation of groundwater resources and erosion of soil fertility and biodiversity. Over the years, economic considerations have overtaken the sustainability issues. Low and erratic rainfall, frequent drought, the increasing cost of cultivation, lower compensation of labor and inputs has made farming in arid region a challenging enterprise. Employment opportunities in sector other than agriculture have enticed many to cross the floor. The largest segment of farming community however is constrained to make a living from farm related activities. With the opening of market for international trade in farm commodities, the competition have toughened for the resource constrained farmers of arid region of the country.

Agri- Horticulture

Due to harsh edapho-climatic conditions arable crop production is risky in hot arid region and threatening the agriculture, Under such situation, horticulture based production system is considered effective strategy for improving productivity, employment opportunities, economic condition and nutritional security. Several drought hardy fruit crops like *Capparis decidua*, *Salvadora oleoides*, *Cordia dichotoma*, *Cordia gharaf*, *Ziziphus nummularia* var. *rotundifolia*, *Ziziphus mauritiana* are suitable for the area receiving rainfall <300 mm. Besides providing fruit these plant produce moisture laded nutritious leaves for animal. Several other fruit such as *Emblica officinalis*, *Punica granatum*, *Aegle marmelos, Phoenix dactylifera*, and *Tamarindus indica* can be grown in the area having irrigation facilities. Among the vegetable crops *Solanum melongena*, *Lagnaeria siceraria*, *Luffa acutangula*, *Luffa cylindrica*, *Citrullus lanatus*, *Citrullus lanatus* var. *fistulosus*, *Cucumis melo* var.*utillismus*, *Cucumis* melo var *momardica*, *Cucumis callosus*, *Moringa oleifera*, *Cymopsis tetragnoloba* and *Vigna ungiculata* are suitable for horticultural based farming systems.

In arid region, agri-horti system involving *Ziziphus rotundifolia* + *Vigna radiata* / *Vigna aconitifolia* / *Cymopsis tetragonoloba* and *Ziziphus mauritiana* + *Vigna radiata* / *Cymopsis tetragonoloba* have been found environmental friendly and economically viable even during drought years. In agri-horti system involving *Ziziphus* and *Vigna radiata* during subnormal year when rainfall was 51 per cent less than long term average of 360 mm, the yield of mung bean was reduced by 44 per cent whereas under sole crop mung bean yield was reduced by 51 per cent. The inventory of system showed that this agri-horti system can provide round the year supply of fodder for 5 goat/sheep/ha and fuel wood for family off 4 members, besides efficient nutrient cycling and increase in economic stability (Faroda, 1998). Gupta *et al.* (2000) reported that 3-yrs old plantation of *Ziziphus mauritiana* @ 400 plants/ha in association with green gram performed well with seasonal rainfall of 210 mm and fruit yield from intercropped increased net profit to Rs. 288.6/ha, this shows that agri-horti system minimize risk in arid regions and thus helps in imparting economic stability. This system is recommended for the region having rainfall <250-300 mm. *Cymopsis tetragonoloba – B. juncea* and Indian aloe as ground storey component in ber optimize productivity and profitability under arid ecosystem (Table 18.10).

Table 18.10 Vegetable crop components for cropping system in the Hot Arid region

Rainfall	High storey crop	Medium storey crop	Ground storey			Micro wind break, biofence
			Vegetable	Agronomic crop	Grasses	
Rainfed (rainfall < 150-300 mm)	Khejari, Ber	Ber, Kair	Materra, kachari, snape melon, tumba	Guar, moth, bajra, til	*Cenchrus, Lasirus*	Ker, Phog, Khimp, Jharber
Rainfed (rainfall < 300-500 mm)	Ber, Lasora, Khejari	Sehjana, Lasora	Materra, kachari, snape melon, tinda, brinjal, Indian bean, Cluster bean, cowpea	Guar moth, bajra, til	*Cenchrus, Dicanthium, Panicum*	Ker, Khimp, Jharber
Irrigated	Date palm, Ber, Aonla	Lime, guava, pomegranate	Cucurbits, chilli, tomato, brinjal, cole crops, peas, beans, onion, okra and leafy vegetables.	Cumin, isabgol, groundnut, mustard		Lasora, Shenjna, Karonda

Integrated Horticultural Management Practices for Different Climate Change Scenarios

Some of the fruit crops mentioned above can be grown successfully by few modifications and adoption of modern management practices which are enumerated as under:

1. Protection against Adverse Weather, Wind and Stray Cattle Damage

There is heavy damage to fruit crops in arid and semi arid tracts by frequent wind storms not only by transpiration losses but also by deposition of sand, mechanical damage to plants and soil erosion. Similarly stay cattle is also a menace in barren areas SAT regions, where generally the crop cover exists for four months particularly during summer. Wind breaks are narrow strips of trees planted against farms, gardens, orchards *etc.* to have protective depends upon the availability of land. fast growing deep rooted plants which can check or reduce the flow of air are preferred. Shelter belts are wide and can check or reduce the flow of air are preferred. Shelter belts are wide and long belts of several rows of trees and shrubs planted across the prevailing wind direction to deflect wind currents, to reduce wind velocity and provide general protection against sand movement over vast fields. Trees like Sisham (*Dalbergia sissoo*), Jamun *(Syzygium cuminii*), Jackfruit (*Artocarpus heterophyllus*), *Cassia siamia*, *Acacia tortilis* and *Prosopis Juliflora* as per suitability of the region may be selected. In case, bio-fencing is not possible, mechanical barrier with local material need to be developed.

2. Profile Modification

In marginal land normally tree growth is restricted, hence planting distance need to be reduced by 20-30 per cent of the normal planting distance of particular fruit/variety. Pit should be prepared as per physical and chemical soil properties. In sodic and rocky soils, the hard pan should be broken. Incorporation of gypsum 5-10 kg, or pyrite 4-8 kg well rotten FYM and 20 kg sand is helpful for better plant stand. In saline soils leaching of soluble salts is sufficient for better plant stand. Pit should be filled at least a month ahead of planting.

3. Use of Farm Yard Manure

Sandy soil with poor organic matter content generally get compacted and affect the seedling emergence and crop growth. The water holding capacity of the sandy soil is very poor due to high infiltration rate.

Contrary to this, in salt affected soil, the infiltration rate is poor and physiologically moisture is not available due to exoosmosis. Continuous application of FYM shall be helpful in improving the organic matter content of the soil and thus will result in improving microbial activity and its water holding capacity.

4. Use of Pond Sediments

Ponds and nadis are scattered in villages used to be the major source of drinking water for animals and to human beings. They get dry during summer and their sediments can be used for raising the productivity of the soils in the SAT regions. Its application improves the moisture retention capacity of soil. It also increases nitrogen and organic matter content of soil.

5. Popularization of *in situ* Orchard Establishment

It is matter of common experience that seedling plants have better and well developed root system. Therefore, it is advisable to sow the seeds or transplant poly bag / poly tube / root trainer, raised seedlings after the pit preparation. After the establishment of the plant, grafting / budding with scion shoots obtained from 'elite clones' need to be carried out in the same or following year. This practice shall encourage better plant establishment, besides cheaper for adaptation.

6. Intensification of Plant Density

Most of the perennial fruit crops have long gestation period, hence generally farmers are reluctant to go for orcharding. In order to ensure early income, reduce evaporation, minimize weed growth, suitable cropping models of two or even three tire need to be encouraged. The combination may vary as per soil, climate, farmer's choice and domestic or export markets.

7. Mulching

Covering of plant basin with organic waste materials, black polyethylene strips or emulsions is termed as mulching. Mulching reduces the evaporation by cutting radiation falling on the soil surface and thus delays drying and reduces soil thermal regime during day time. It also reduces the weed population and improves the microbial activity of soil by improving the environment along the root zone. Continuous use of organic mulches shall be helpful in improving the organic matter content of soil' and thus the water holding capacity of soil shall also improve. In mango, citrus, aonla, ber and guava mulching of tree basin with FYM, paddy straw, groundnut husk and locally available materials have shown positive response in maintaining optimum moisture regime, weed control, improving physical and chemical properties of sodic soils and thus inducing better tree vigor. Use of inorganic mulches is expensive and it does not incorporate organic matter content in the soil.

8. Water Harvesting in Relation to Fruit Cultivation

Water harvesting is one of the very old practice of collecting water in depressions for crop cultivation and drinking purposes. This is a practice of converting more rain water into soil water. Rain water either can be diverted to tree basin in situ or in suitable structures ex situ which can further be utilized as life saving irrigation. In sandy soils in situ conservation while in heavier soil ex situ conservation should be popularized (Reddy, 1999). The water thus collected remain stored deep into soil profile, escape from evaporative losses and is available during critical period of demand. A number of catchment cropped area ratios and degree of slopes have been tried at CAZRI, Jodhpur. For ber, 5 per cent slope with 54 m^2. of catchment has been found to be appropriate for conservation and proper utilization of rain water. Percentage slope and catchment area have been advocated for fruits like pomegranate, guava, fig, lasora, aonla, custard apple.

9. Irrigation

Irrigation affects tile soil environment making more water available for plant establishment and growth, by lowering soil temperature and soil strength. 'Moisture stress is the main limiting factor in arid and semi arid region of the country. Efforts should be made to work out proper schedule of irrigation for different fruit crops. Every care should be taken for the utilization of water, reducing unproductive losses of water and increasing soil environment and increasing crop production.

Amongst the modern methods of irrigation, drip system is gaining importance in arid and semi arid regions. It is method of watering plants at the rate equivalent to its consumptive use so that the plants would not experience any moisture stress throughout the life cycle. The water is conveyed from the source (*i.e*. tube well or farm pond) and release near the plant base. The main objective is to provide optimum quantity of water to the crop for maximum productivity and simultaneously saving the valuable water from wastage i.e. increasing the water use efficiency in the command area. Drip irrigation ensures uniform distribution of water, perfect control over water application, minimization of water losses during conveyance and seepage, reduces the weed population, keeping the harmful salts down below the root zone and minimizing the labour cost. In an aonla orchard established on sodic land, drip irrigation on alternate day with 0.6 CPE and mulching with FYM or paddy straw proved effective in improving the plant stand. It was also observed that because of continuous maintenance of optimum moisture in the feeder root zone, upward movement of Na, CI and SO_4 was minimized, besides, the harmful salts which get deposited from the irrigation channel are also minimized with drip irrigation.

10. Top Working / Frame Working

Seedling plants of ber (*Ziziphus* spp) are of common occurrence in arid and semiarid regions of the country. These plants are utilized for fodder and small fruit are either consumed fresh and or stored for chutney purpose. Similarly seedling plants of mango, aonla, bael, are also very common in the ravine areas. These may be converted to promising types by mass adoption of top working with scion shoots from the known cultivators.

Besides, strip sowing of vegetables like onion, garlic, brinjal, tomato, knolkhol and medicinal plants *viz.,* Asparagus, and Aswagandha and aromatic crops like Matricaria, vetiver, lemon grass have also shown promising response. There is urgent need to work out suitable combinations under various drought districts so that root and aerial competition could be minimized.

Future Thrust

1. Identification and characterization of micro-farming situations covering bio-physical and socio-economic parameters as sequel to the most happening climate change.
2. Developing sustainable farming system models in farmer participatory mode in accordance with resource endowment and need of farmers in the wake of fast changing climate.
3. Developing multidisciplinary team comprising biological, physical and social scientist to undertake research on farming system perspective with proper incentives to mitigate the effect of fast changing climate.
4. Preparation of a contingent planning to counteract the weather vagaries/climate threats under different farming situations across pan India.
5. Policy framework for logistic support to the farmers for quick and large scale adoption of Horticulture based production systems and models developed by the research and development institutions in India.

Smallholders' farmers are vulnerable to the impacts of climate extreme events. There is a wide array of agricultural practices that could help farmers improve their farming systems and increase the resiliency of their systems to climate change (Wezel *et al.,* 2014). Ecosystem-based Adaptation practices can help reduce or avoid these impacts. Existing experiences in promoting agroecology and agroforestry provide key lessons to promote adoption. Farmer's climate change adaptation is dependent upon farm systems heterogeneity. The limiting factors hypothesis can be applied to farm systems to understand adaptation. Water and temperature are different limiting factors depending on climate and farm systems (Meredith *et al.*, 2015).

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Chapter 19

Impact of Elevated Carbon Dioxide and Temperature on Crops and Trees

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Introduction

The greatest environmental threat that the society is expected to face in the coming decades will be the impacts of global warming, with the potential to disrupt the natural and social systems throughout the world. The increased anthropogenic emissions of Green House Gases (GHGs) into the atmosphere since the industrial era have led to altering atmospheric radiative balances and tend to warm the atmosphere, disturbing the natural climatic conditions. The global warming depends upon the total stock of GHGs in the atmosphere and continued emissions, beyond the earth's adsorptive capacity, necessarily imply a rise in temperature. General circulation models predict temperature rises of 1.4-5.8°C by 2100, associated with carbon dioxide increases to 540-970 parts per million. In recent years the atmospheric concentration of carbon dioxide- the most important anthropogenic greenhouse gas increasing at alarming rates (>2 ppm per year) than the natural range concentration growth rate. This could be due to enhanced usage of fossil fuel and changed land use pattern to some extent. Scientific projections indicate that changes in temperature, precipitation and extreme weather events are likely to occur in the coming decades and that intensity of these changes will vary between regions of the world (IPCC, 2007).

Potential Impacts on Agricultural Crops

Agriculture is one sector, which is immediately affected by climate change, and it is expected that the impact on global agricultural production may be small. However, regional vulnerabilities to food deficits may increase. Short or long-term fluctuations in weather patterns - climate variability and climate change - can influence crop yields and can force farmers to adopt new agricultural practices in response to altered climatic conditions. Climate variability / change, therefore, have a direct impact on food security. The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. Inter annual variations in temperature and precipitation was much higher than the predicted changes in temperature and precipitation. The crop losses may increase if the predicted climate change increases the climate variability. Different crops respond differently as the global warming will have a complex impact.

The carbon dioxide level in the atmosphere has been rising, and that this rise is due primarily to the burning of fossil fuels and to deforestation. Measured in terms of volume, there were about 280 parts of CO_2 in every million parts of air at the beginning of the Industrial Revolution, and there are 407 parts per million (ppm) today, a 40 per cent rise. The annual increase is 1.9 ppm, and if present trends continue, the concentration of CO_2 in the atmosphere will double to about 700 ppm in the latter half of the 21st century.

Carbon dioxide is the basic raw material that plants use in photosynthesis to convert solar energy into food, fiber, and other forms of biomass. In the presence of chlorophyll, plants use sunlight to convert carbon dioxide and water into carbohydrates that, directly or indirectly, supply almost all animal and human needs for food; oxygen and some water are released as by-products of this process. Voluminous scientific evidence shows that if CO_2 were to rise above its current ambient level of 407 parts per million, most plants would grow faster and larger because of more efficient photosynthesis and a reduction in water loss (Drake and González-Meler, 1997). There are two important reasons for this productivity boost at higher CO_2 levels. One is superior efficiency of photosynthesis. The other is a sharp reduction in water loss per unit of leaf area. A related benefit comes from the partial closing of pores in leaves that is associated with higher CO_2 levels. These pores, known as stomata, admit air into the leaf for photosynthesis, but they are also a major source of transpiration or moisture loss. By partially closing these pores, higher CO_2 levels greatly reduce the plants' water loss--a significant benefit in arid and semi arid climates where water is limiting the productivity.

There are marked variations in response to CO_2 among plant species. The biggest differences are among three broad categories of plants--C_3, C_4, and Crassulacean Acid Metabolism or CAM- each with a different pathway for photosynthetic fixation of carbon dioxide (Kimball *et al.*, 1995). Most green plants, including most major food crops use the C_3 pathway respond most dramatically to higher levels of CO_2. At current atmospheric levels of CO_2, up to half of the photosynthate in C_3 plants is typically lost and returned to the air by a process called photo-respiration, Elevated levels of atmospheric CO_2 virtually eliminate photo-respiration in C_3 plants, making photosynthesis much more efficient.

Corn, sugarcane, sorghum, millet, and some tropical grasses use the C_4 pathway, also experience a boost in photosynthetic efficiency in response to higher carbon dioxide levels, but because there is little photo-respiration in C_4 plants, the improvement is smaller than in C_3 plants (Ainsworth and Long, 2005). Instead, the largest benefit C_4 plants receive from higher CO_2 levels comes from reduced water loss (Vanaja *et al.,* 2011). Loss of water through stomata declines by about 33 per cent in C_4 plants with a doubling of the CO_2 concentration from its current atmospheric level. Since these crops are frequently grown under drought conditions of high temperatures and limited soil moisture, this superior efficiency in water use may improve yields when rainfall is even lower than normal. When there was no stress, elevated CO_2 reduced stomatal conductance by 21 and 16 per cent for C_3 and C_4 species respectively. The lowest response to higher CO_2 levels is usually from the CAM plants, which include pineapples, agaves, and many cacti and other succulents. CAM plants are also already well adapted for efficient water use.

The average response to a doubling of the CO_2 concentration from its current level is 32 per cent improvement in plant productivity, with varied manifestations in different species. In crop plants, a distinction has to be made between the increase in total biomass and increase in economic yield resulting from an elevated CO_2 supply (Vanaja *et al.*, 2012). Climate change is expected to increase future abiotic stresses on ecosystems through extreme weather events leading to more extreme drought and rainfall incidences. Field crops under drought often experience two quite different but related and simultaneous stresses: soil water deficit and high temperature stresses. Elevated atmospheric CO_2 concentration ameliorates to various degrees, the negative impacts of soil water deficit and high temperature stresses. Elevated CO_2 increase growth, grain yield and canopy photosynthesis while reducing evapo-transpiration. During drought stress cycles, this water savings under elevated CO_2 allow photosynthesis to continue for few more days compared with the ambient CO_2 so that increase drought avoidance.

The potential effect of climate change on agriculture is the shifts in the sowing time and length of growing seasons geographically, which would alter planting and harvesting dates of crops and varieties currently used in a particular area. Seasonal precipitation distribution patterns and amounts could change due to climate change. With warmer temperatures, evapo-transpiration rates would rise, which would call for much greater efficiency of water use (Prasad *et al.,* 2008). Also weed and insect pest ranges could shift. Perhaps most important of all, there is general agreement that in addition to changing climate, there would likely be increased variability in weather, which might mean more frequent extreme events such as heat waves, droughts, and floods.

Potential Impacts on Trees

The effects of rising atmospheric CO_2 concentrations on natural plant communities will depend upon the cumulative responses of plant growth and reproduction to gradual, incremental changes in climatic conditions. A particular tree species can only live in locations where temperatures, rainfall and soil conditions are just right. Majority of the potential impacts of elevated atmospheric CO_2 concentrations of tress are similar to that of crop plants such as enhanced photosynthetic rates, reduced transpirational water loss and improved growth and biomass (Urban *et al.,* 2012). However, the enhanced temperatures are expected to influence the biodiversity by changing the i) thermal regimes which may lead to extinction of sensitive species; ii) outburst of new pests and diseases; iii) changing precipitation coupled with high temperatures is expected to have prolonged dry spells or water logging conditions; iv) invasive species may pose competition for nutrients, light and space for native species.

Increased carbon dioxide may enhance growth rates. Water loss is reduced due to closure of leaf pores (Kallarackal and Roby, 2012). However it may reduce timber quality unless different species are used to those that we use currently. With increased growth rates may pose possible nutrient imbalances. Drought conditions become more severe and frequent – some tree species no longer suitable for commercial forestry. Stress caused by drought makes trees more susceptible to pests and diseases. Increased tree mortality particularly trees along the road side. "Drought crack" reduce the timber quality. Warmer temperatures leads to longer growing season in temperate regions results increased potential productivity and reduced periods in tropical areas are expected to have negative impact on the productivity. Some non native species may benefit from climate change and could become invasive in the future by out-competing native species (Ryan, 2010).

In case of forest ecosystems, concern has also been placed with respect to the possibility that taller trees might squeeze out certain understory plants due to increased shade resulting from CO_2-induced increases in the growth of upper-canopy foliage. The results from various experiments revealed that shade-tolerant trees were two to three times more responsive to atmospheric CO_2 enrichment than were sun-loving trees. Hence, even if the sunlight transmitted through the upper-canopy foliage of a forest ecosystem were to be dramatically reduced, the growth-enhancing effects of the rise in atmospheric CO_2 concentration would likely more than compensate for the reduced intensity of the transmitted solar radiation, thereby enabling the full complement of understory species to maintain viable niches in the forest ecosystem.

Another route by which atmospheric CO_2 enrichment may actually increase the species richness of an ecosystem begins with CO_2-induced increases in the exudation of organic matter into the soil and this phenomenon stimulates the proliferation of previously-dormant but viable microorganisms, including symbiotic soil fungi. These fungi, in turn, are highly selective in the species of plants they tend to support. In fact, many research findings demonstrated that increasing the number of fungal species in the soils of certain artificial ecosystems from 4 to 14 increased ecosystem plant diversity by 60 per cent.

Climate change as a result of human activity is a reality. Trees and forests have a clear role to play in helping to mitigate climate change. Trees store carbon. Forests can be an important and attractive part of the solution. More carbon is stored in global forest ecosystems than is contained in all of the world's remaining oil stocks, or in the atmosphere. Deforestation alone currently accounts for nearly 20 per cent of global carbon dioxide emissions. This is greater than the whole transport sector. Terrestrial higher plants exchange large amounts of CO_2 with the atmosphere each year; about 15 per cent of the atmospheric pool of C is assimilated in terrestrial-plant photosynthesis each year, with an about equal amount returned to the atmosphere as CO_2 in plant respiration and the decomposition of soil organic matter and plant litter.

One of the practical ways to combat climate change is to lock up or sequester more carbon from the atmosphere through planting more trees. Planting of trees called ‘carbon sinks’ could sequester some of the carbon that is emitted to the air by anthropogenic CO_2 emissions. Carbon sequestration is the process by which atmospheric carbon dioxide is taken up by trees, grasses, and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliage, and roots) and soils. The sink of carbon sequestration in forests and wood products helps to offset sources of carbon dioxide to the atmosphere, such as deforestation, forest fires, and fossil fuel emissions. Young trees absorb carbon dioxide quickly while they are growing, but as a tree ages a steady state are eventually reached. As long as the wood of their trunks and branches continues to exist, either in living forests or in a host of forest products, the wood of the new trees that we plant today will continue to have locked within it tomorrow untold tons upon tons of carbon that would otherwise have remained in the atmosphere. Any global change in plant C metabolism can potentially affect atmospheric CO_2 content during the course of years to decades. In particular, plant responses to the presently increasing atmospheric CO_2 concentration might influence the rate of atmospheric CO_2 increase.

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Chapter 20

Adaptation and Mitigation to Climate Change in Indian Agriculture through a Network Project: National Innovations in Climate Resilient Agriculture

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Introduction

The contribution of agriculture and allied sectors to national GDP, which was 51.9 per cent of GDP in 1950-51 has been declining at an alarming rate, owing to a shift from traditional agrarian economy to industry and service sectors on one hand and increased risk and vulnerability to climate change on the other. The whole of agricultural sector that engages 49 percent of the workforce of the country has contributed a mere 13.9 per cent of Gross Domestic Product (GDP) of the country during 2013-14, according to the Central Statistics Office and Economic Survey 2015, Government of India. Agriculture in India remains predominantly rainfed covering about 60 per cent of the country's net sown area and accounts for 40 per cent of the total food production. With increasing population and reducing cultivable land area, enhancing agricultural production and productivity are the daunting tasks to ensure food security.

Climate Change is one of the significant factors affecting agriculture, besides other factors like social and economic ones. Delayed monsoon, declined rainy days, increase in mean minimum and maximum temperatures, increased intensity of rainfalls etc. have been observed in recent decades across India, thus impacting agricultural productivity, food security and rural livelihoods. Green House Gas emissions from different crops and livestock are also matter of concern which prompted

As stated in the Fifth Assessment Report (AR5) of the Inter-Governmental Panel on Climate Change (IPCC, 2014), climate change will increase the risk of food insecurity and the breakdown of food systems through drought, flooding, and rain variability and extremes– particularly for poorer populations. The AR5 of IPCC also cautioned that by 2050, risk of hunger could increase by 20 per cent and child-malnutrition will be 20 per cent higher than it would have been without climate change. Hence, climate-resilient agriculture is the need of the hour.

On October 2nd 2016, India has ratified The *Paris Agreement on Climate Change*, the new global compact under the aegis of the United Nations Framework Convention on Climate Change (UNFCCC) for enhanced actions on climate change. As communicated to UNFCCC, India pledges an estimated cost of US$ 2.5 trillion for its climate-action plan *Intended Nationally Determined Contributions* (INDC), addressing all the elements including Adaptation, Mitigation, Finance, Technology Transfer, Capacity Building and Transparency of Action and Support.

National Mission for Sustainable Agriculture (NMSA) has been formulated in the year 2010 as one of the eight Missions under the National Action Plan on Climate Change (NAPCC) for enhancing agricultural productivity especially in rainfed areas focusing on integrated farming, water use efficiency, soil health management and synergizing resource conservation. NMSA has aimed at transforming Indian agriculture into a climate-resilient production system through suitable adaptation and mitigation measures in the domain of crops and animal husbandry. It envisages making agriculture more productive, sustainable, remunerative and climate resilient by promoting location specific Integrated / Composite Farming Systems.

The indisputable negative impacts of climate change have been projected to reduce agricultural yields in India by 4.5 to 9 per cent in medium-term (2010-2039), depending on the magnitude and distribution of warming. To sustain agricultural production, food security of the nation, and agriculture-dependent rural livelihoods in adaptation to climate change on one hand, and to mitigate the greenhouse gas (GHG) emissions from agriculture and allied sectors on the other, the ICAR has launched a major Project entitled, *National Initiative on Climate Resilient Agriculture* (NICRA) during 2010-11 with the following objectives.

- To enhance the resilience of Indian agriculture covering crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies
- To demonstrate site specific technology packages on farmers' fields for adapting to current climate risks
- To enhance the capacity building of scientists and other stakeholders in climate resilient agricultural research and its application.

Key Features of NICRA

- NICRA is a unique project, which brings all sectors *viz.,* crops, horticulture, livestock, fisheries, NRM and extension scientists on one platform.
- Critical assessment of different crops / zones in the country for vulnerability to climatic stresses and extreme events, in particular, intra seasonal variability of rainfall
- Installation of the state-of-the-art equipment like flux towers for measurement of GHGs in large field areas to understand the impact of management practices and contribute data on emissions as national responsibility.
- Rapid and large scale screening of crop germplasm including wild relatives for drought and heat tolerance through phenomics platforms for quick identification of promising lines and early development and release of heat / drought tolerant varieties.
- Comprehensive field evaluation of new and emerging approaches of paddy cultivation like aerobic rice and SRI for their contribution to reduce the GHG emissions and water saving.
- Special attention to livestock and fishery sectors including aquaculture which have not received enough attention in climate change research in the past. In particular, the documentation of adaptive traits in indigenous breeds is the most useful step.
- Thorough understanding of crop-pest / pathogen relationship and emergence of new biotypes due to climate change.
- Simultaneous up-scaling of the outputs both through KVKs and the National Mission

  on Sustainable Agriculture for wider adoption by the farmers

The Unique Features of NICRA

- Strengthening the existing net-work research on adaptation and mitigation (food crops, horticulture, livestock and fishery) with more infrastructure and capacity building
- Setting up of high throughput phenotyping platforms and temperature, CO_2, ozone gradient facilities at identified locations / institutions including North East region.

- Strengthening research on climate sensitive crops like cotton, maize, sugarcane, onion, etc. which are critical for India's farm GDP/exports
- Projected impacts on water availability at the river basin level and participatory action research at large number of sites on evolving coping strategies through water saving technologies
- Evolving a national level pest and disease monitoring system to assess the changing pest/disease dynamics under changed climate (both in crops and livestock)
- Strengthening crop simulation and climate scenario down-scaling modelling capabilities at major Institutes and a dedicated unit at IARI, New Delhi
- Piloting the operationalization of the district / block level agro-met advisory services through KVKs / district line departments and contingency plans during droughts and floods
- Expanding the technology demonstration and dissemination to 151 vulnerable districts of the country

To meet the challenges of sustaining domestic food production in the face of changing climate and generate information on adaptation and mitigation in agriculture to contribute to global fora like UNFCC, it is important to have concerted research on this important subject. With this background, Indian Council of Agricultural Research (ICAR), under the Ministry of Agriculture and Farmers Welfare launched a network '*National Innovations in Climate Resilient Agriculture*' (NICRA) during the year 2011. NICRA aims to evolve crop varieties tolerant to climatic stresses like floods, droughts, frost, inundation due to cyclones and heat waves. Under this project about 41 Institutes of ICAR are conducting research under Strategic Research Component covering various theme areas *viz.*, development of multiple stress tolerant crop genotypes, natural resource management, quantification of green house gas emissions in agriculture and the develop technologies for their reduction, climate resilient horticulture, marine, brackish and inland fisheries, heat tolerant livestock, mitigation and adaptation to changing climate in small ruminants and poultry. Sate of the art infrastructure required or climate change research such as high through-put phenotyping platforms, free air temperature elevation (FATE), carbon dioxide and temperature gradient tunnels (CTGC), high performance computers, automatic weather stations, growth chambers, rainout shelters, animal calorimeter, shipping vessel, flux towers and satellite receiving station were established in the research institutes across the country under NICRA project.

Technology Demonstration Component (TDC) under NICRA aims to demonstration of location specific practices and technologies to enable farmers cope with current climatic variability. Demonstration of available location-specific technologies related to natural resource management, crop production, livestock and fisheries is being taken up in the climatically vulnerable districts for enhancing the adaptive capacity and resilience against climatic variability. Technologies with a potential to cope with climate variability are being demonstrated under Technology Demonstration Component (TDC) in 121 most vulnerable districts selected across the country through Krishi Vigyan Kendras (KVKs) (Srinivasa Rao *et al.*, 2016).

Institutional intervention Component under NICRA aims at creating enabling support system in the village comprising of strengthening of existing institutions or initiating new ones (Village Level Climate Risk Management Committees (VCRMC)), establishment and management of Custom Hiring Centers (CHCs) for farm implements, seed bank, fodder bank, creation of commodity groups, water sharing groups, community nursery and initiating collective marketing by tapping value chains. 100 custom hiring centers (CHCs) for farm machinery were setup under NICRA project, which are being managed by Village Climate Risk Management Committee (VCRMC) comprising of villagers. Module on use of ICT for knowledge empowerment of the communities in terms of climate risk management is also being planned in select KVKs for generation of locally relevant content and its dissemination in text and voice enabled formats. 121 KVKs associated under NICRA projects have also taken initiatives such as participatory village level seed production of short duration, drought and flood tolerant varieties, establishment of seed banks involving these varieties were established in the KVKs, demonstration and of improved varieties of fodder seeds and establishment of fodder bank in NICRA villages. Details on the research under this project are as under.

Crop Improvement for Changing Climate

Efforts were made to screen large number of germplasm for different weather aberrations such as drought, heat, salinity, submergence etc. in different field and horticultural crops. Number of advance breeding materials was generated and evaluated at multi-locations for developing new cultivars. Germplasm lines of rice and wheat tolerant to drought and heat stress have been collected from different climatic hot-spot regions of India. So far a total of 184 rice accessions were collected. Evaluation of wheat germplasm for drought tolerance with 1485 accessions was conducted to identify drought tolerance lines based on 22 morpho-physiological traits. Based on the drought susceptible index a reference set will be developed for allele mining using micro satellite markers. Marker assisted back cross breeding was carried out using molecular markers link to the QTL governing drought tolerance into Pusa Basmati-1 rice varieties. Two rice genotypes for submergence tolerance was registered with National Bureau of Plant Genetic Resources (MBPGR), New Delhi. One salinity tolerant variety is in final year of All India Coordinated Research Project trials. Three superior heat tolerant hybrids were developed. Four drought tolerant rice varieties were released for Tripura. Two extra-early (50-55 days) green gram varieties were identified for summer cultivation (IPM 409-4, IPM 205-7) and one multiple stress tolerance red gram wild accession (*C. scarabaeoides*). A large number of soybean genotypes were evaluated for drought. Lines JS 97-52, EC 538828, EC 456548 and EC 602288 identified as relatively tolerant. These lines have been crossed among each other and with lines with superior agronomic background and are in F_{2-3} generations. Five heat tolerant and 12 drought tolerant genotypes in tomato. Number of mapping population in rice, wheat, maize were developed for identifying QTL for various abiotic stresses in these crops for utilization in maker assisted selection (MAS) breeding.

Management of Natural Resources

GHG emissions (CO_2, $CH_4$and N_2O) due to implementation of climate resilient interventions in various production systems (annual and / perennial crops, irrigated rice, inputs, livestock, forestry and land use change) were converted to an equivalent value (tone CO_2 equivalent) in 7 villages of Gujarat and Rajasthan, which were found to be negative suggesting a sink in GHG emissions. Direct-seeded rice (DSR) with mung bean residue incorporation, brown manuring (BM) with *Sesbania*, rice residue retention (RR) in zero till (ZT) wheat/rabi crops are important conservation agriculture (CA) practices. It was observed that mung bean residue (MBR) + DSR – ZTW – ZT summer mung bean (ZTSMB) gave highest system productivity, net return, water productivity and low GWP. In long term efforts to assess CA practices on productivity enhancement, nutrient use efficiency, soil health and quality, it was observed that seed (3.8 t/ha) and stover (5.6 t/ha) yields in maize in CA were on par with conventional system (CT). Also, significantly higher grain (5.3 t/ha), stover (6.5 t/ha) yields and harvest index (0.44) were realized with balanced fertilization with NPKSZnB. Analysis of Resource Conservation Technologies (RCT) in NEH zone indicated that conventional Tillage (CT) has higher cumulative soil respiration (> 18 per cent) compared to zero tillage. Agroforestry offset carbon dioxide from atmosphere is 0.77 tons of CO_2 ha^{-1} $year^{-1}$and agroforestry system are estimated to mitigate 109.34 million tones CO_2 annually from 142.0 Mha of agriculture land. Further, it is estimated to offset 33 per cent of total GHGs emissions from agriculture sector annually at country level. The net eco-system methane exchange during rice growth period was the highest between active tillering to maximum tillering stage in rice. The diurnal variations in mean Net Eco-system Exchange (NEE) in submerged rice eco-system in both dry and wet seasons varied from + 0.2 to - 1.2 and + 0.4 to - 0.8 mg $CO_2/m^2/s$. The cumulative seasonal methane emission was reduced by 75 per cent in aerobic rice as compared to continuously flooded rice. The seasonal emissions were lower in slow release N fertilizer, especially, when applied on the basis of customized leaf colour chart (CLCC). Zero tillage in wheat lowered the GWP as compared to tilled wheat. Similarly, CO_2, CH_4 and N_2O fluxes were influenced by tillage / anchored residue and anchored residues of 10 and 30 cm in zero till reduced the N_2O emissions in rainfed pigeon pea-castor system. In efforts on mitigation strategies by reducing carbon foot prints through conservation agriculture in rainfed regions, carbon foot print from various practices like decomposition of crop residues, application of synthetic N fertilizers, field operations and input production indicated that there is a scope to reduce carbon foot prints by reducing one tillage operation with harvesting at 10 cm height with minimal impact on the crop yields. Long-term conservation horticultural practices in mango orchards improved the quality of soils through enhancing the organic carbon fraction and biological status, especially near the surface. Soil aggregates and water stability improved under conservation treatments. Cover crop, Mucuna, could conserve maximum moisture and reported higher Glomalin content in soil indicating the improvement in soil aggregation. Assessment of biochar on productivity, nutrient use efficiency and C sequestration potential of maize based cropping system in North-Eastern Hill region indicated a higher soil microbial biomass carbon (SMBC), dehydrogenase enzyme activity (DHA) and soil organic carbon (SOC) with application of biochar @ 5.0 t/ha along with 75 per cent RDF + 4 t/ha FYM, while exchangeable aluminium and exchangeable acidity were reduced. GHG inventory for different cropping systems and production systems. GHG emissions quantified from Conservation Agriculture (CA) – 15 to 20 per cent reduction, Resource conservation technologies (Biochar, zero tillage, reduced tillage, mulching etc.). C Sequestration in different agroforestry systems (16-22 t C/ha)

Green house Gas Emission Reduction through Technological Interventions

Several climate resilient technologies enable to reduce green house gas emissions. As part of NICRA, various ICAR institutes such as Indian Agricultural Research Institute (IARI), New Delhi, Indian Institute of Farming Systems Research (IIFSR), Modipuram, Indian Institute Soil Science (IISS), Bhopal, Central Arid Zone Research Institute (CAZRI), Jodhpur, ICAR Research Complex for NEH Region (ICAR-NEH), Umiam are working on various themes related to the GHG emissions. Facilities like, Eddy Covariance towers are established at IARI, New Delhi and National Rice Research Institute (NRRI), Cuttack for continuously monitoring the GHG emissions from the crop fields during growing season so as to quantify precisely the extent of GHG emissions from the paddy systems. Research Facilities like Rainout shelter, Carbon dioxide Temperature Gradient Chamber (CTGC), Free Air Carbon dioxide Enrichment (FACE), Free Air Temperature Enrichment (FATE) etc. have been established to understand the impact of elevated carbon dioxide (eCO_2) and temperature and develop crop varieties that can withstand these stresses. Practices which can further reduce the GHG emissions such as improved systems of paddy cultivation, fertilizer management, improved fertilizer materials, crop diversification, etc. are explored for further reducing the GHG emissions from the paddy based systems. The proven mitigation practices, which can reduce the GHG emissions, are being demonstrated to farmers as part of the Technology Demonstration Component (TDC) of NICRA. The TDC of NICRA is being implemented in 121 climatically vulnerable districts of the country by taking one or cluster of villages in each of the vulnerable district.

Location specific, crop specific mitigation practices such as system of rice intensification, direct seeded rice cultivation (dry and wet methods of cultivation), soil test based fertilizer application, rational application of nitrogen, integration of trees especially fruit trees in the arable systems, efficient irrigation systems such as drip method and sprinkler method of application which can reduce the energy use while irrigating field crops, demonstration of zero tillage cultivation as an alternate to burning crop residues in rice-wheat systems of Punjab and Haryana where large quantities of rice residues are being burnt, integration of green manure crops in the existing cropping systems, promotion of green fodder crops and greater use of green fodder for livestock, etc. are being demonstrated as part of the technology demonstration component of NICRA in the 151 climatically vulnerable districts of the country. The proven resilient practices are being integrated in the development programs such as the Crop diversification in traditionally paddy growing regions as part of the National Food Security Mission (NFSM) wherein 1.02 lakh ha is being diversified from paddy to other less water consuming crops in the country during the year 2015-2016. Similarly the paddy systems of cultivation such as System of rice cultivation, direct seeded rice are being promoted by the development programs as part of the NFSM where in 1.63 lakh ha area was brought under these improved methods of paddy cultivation in the country during the year 2015-2016. Such kind of efforts would in long term, contribute to substrational reduction of GHG emissions in the country.

Adaptation and Mitigation to Climate Change in 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, where as 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. Under NICRA project research has been initiated at 5 ICAR Institutes *viz.*, Indian Institute of Horticultural Research (IIHR), Bengaluru, Indian Institute of Vegetable Research (IIVR), Varanasi, Central Potato Research Institute (CPRI), Shimla, Central Institute of Temperate Horticulture (CITH), Srinagar and Directorate of Onion and Garlic Research (DOGR), Pune. 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. 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. Environmentally safe protocol was developed for synchronizing flowering in mango, which is induced due to changing climate. A microbial inoculation with osmo tolerant bacterial strains have been developed to improve yield under limited moisture stress in tomato. Several resource conservation technologies *viz.*, mulching, zero tillage, reduced tillage, biochar etc. have been demonstrated in climatically vulnerable districts across the country through Krishi Vigyan Kendras (KVKs). Large-scale adoption of this climate resilient technologies enable 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.

Adaptation and Mitigation to Climate Change in Livestock

Under NICRA project climate change research facilities for livestock *viz.*, CO_2 Environmental Chambers, Thermal Imaging System, Animal Calorimeter, Custom Designed Animal Shed etc. have been established at ICAR-National Dairy Research Institute (NDRI), Karnal and ICAR-Indian Veterinary Research Institute (IVRI), Izatnagar. Biochemical, morphological and physiological characterization of indigenous cattle breeds were carried out and compared with exotic breeds. The traits identified in indigenous breed *viz.*, heat shock proteins, air coat colour, wooly hair etc. that impart tolerance to heat stress could be used in future animal breeding programs to develop breeds that can withstand high temperature. Different feed supplements have been identified and tested successfully to withstand heat stress in cattle. Studies on prilled feeding in cattle showed that they help lowering stress levels and methane emission. Custom designed shelters system and feed supplementation with chromium propionate, mineral supplements (Cu, Mg, Ca and Zn) both in feed and fodder significantly improved the ability to withstand heat stress. At ICAR-North Eastern Hill Region, Umiam, the local birds of Mizoram are predominantly black in colour, small size, crown appearance on head, light pink comb with black, poorly develop wattle, small ear lobe, shank is brown to black and elongated. The average annual egg production of local birds is 45-55 eggs. Local birds are more tolerant to common diseases of poultry. Innovative deep litter pig housing model was developed that offers the advantages of better micro-environment both summer and winter, better physiological adaptation, protecting animal welfare and behavior, faster growth rate of piglets and higher performance and productivity and low incidences of diseases / conditions. The performance of Vanaraja poultry under backyard farming at different altitude under diversified agro-climatic condition was evaluated. Vanaraja birds have high tolerance to incidence of diseases and showed wide adaptability under different altitude. Many of these climate resilient technologies *viz.,* feed supplement, shelter management, improved breeds, silage making, de-warming etc. have been demonstrated in the farmers field through KVKs in the 121 climatically vulnerable districts across the country. Up-scaling of these technologies through respective State Governments would enable the livestock farmers in the country cope with vagaries associated with climate change.

Adaptation and Mitigation to Climate Change in Fisheries

Under NICRA project climate change research facilities for Fisheries *viz.,* Research Vessel, Green House Gases analyzer Agilent 7890A GC Customized, Fish Biology Lab, CHNS/O analyzer, Automatic Weather Station installed etc. have been established at ICAR- Central Marine Fisheries Research Institute (CMFRI), Kochi, ICAR- Central Inland Fisheries Research Institute (CIFRI), Barrackpore, ICAR- Central Institute of Brackish water Aquaculture (CIBA), Chennai and ICAR- Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar. Relationship of temperature and spawning in marine and freshwater fisheries sector is being elucidated so that fish catch in different regions can be predicted by temperature monitoring. A shift in the spawning season of oil sardine was observed off the Chennai coast from January-March season to June-July. Optimum temperature for highest hatching percentage was determined in Cobia. A closed poly house technology was standardized for enhancing the hatching rate of common carp during winter season. An e-Atlas of freshwater inland capture fisheries was prepared which helps in contingency planning during aberrant weather. For the first time a green house gas emission measurement system was standardized for brackish water aquaculture ponds. Cost effective adaptation strategies like aeration and addition of immuno-stimulant in the high energy floating feed helped freshwater fish to cope with salinity stress as a result of seawater inundation in Sundarban islands. Relationship was established between increase in Surface Sea Temperature (SST) and catch and spawning in major marine fish species. Simulation modeling was used to understand the climate change and impacts at regional/national level.

Major Outcomes of NICRA

- Vulnerability assessment map prepared under NICRA is being used by different Ministries and several NGOs/CBOs.
- NICRA is also contributing to National missions like NMSA, Water mission, Green fund and INDC
- GHG inventory by NICRA partner institutes contributes to BUR reports (BUR, 2015).
- Outcome of NICRA project supported some of the policy issues in Sates of Maharashtra (BBF Technology), Million farm ponds in the Sates of Andhra Pradesh and Telangana, ground water recharge initiatives (Southern states), drought proofing in Odisha, NABARD action plans, NICRA model village expansion in Assam etc.
- Contingency planning workshops organized every year in different States helps in preparedness to face weather aberrations.

Conclusions

It is very important to sustain the efforts made in the past few years and take forward the project for some more years. NICRA is a unique project, which brings all sectors of agriculture *viz.*, crops, horticulture, livestock, fisheries, NRM and extension scientists on one platform for addressing climate concerns. Over the past six years, several infrastructure facilities have been established, standardized and put in to function in core institutes of ICAR to undertake the climate change research. Large numbers of manpower (Scientists, Research Fellows, Technical Officers and Students) have been trained to handle and operate these facilities. However, some of these precious research facilities are yet to be utilized to the full potential. In other words, a large platform related to climate change research has been created in the country. Crop improvement for multiple stresses takes several years of research and multi location testing. Efforts made under this project, resulted in development of varieties/hybrids ready for large-scale cultivation. Whereas, many are under different stages of development which may require few more years to be released as variety/hybrid/breed. Simulation modeling to assess the impact of climate change at regional level is still at initial stage. Standardization of minimum data sets and compilation of data from different sources have shown good progress. In the next phase, these data sets will be used for modeling. Capacity building for this activity will be emphasized and a dedicated group will be formulized. Research, essentially long term in nature, should continue further to achieve the intended outputs and outcomes. Technologies found to be performing under ICRA are getting fed into programs such as National Mission on Sustainable Agriculture (NMSA). There is still need to develop variety of adaptation options for different sub-sectors within agriculture, for different regions and for farmers with varying resource endowments. Such an effort is to be accompanied by identification of factors that help adopt technologies on a wider scale.

The commitments of the country to emission reductions require generate appropriate information and data on emissions as well as options that help reduce emissions. Techniques standardized so far under NICRA for estimation of GHG emissions from different management practices will be used for further reducing the carbon footprint of production systems in the country. Government of India has committed for the reduction of emission intensity of GDP by 32-35 per cent by 2030 from 2005 levels, and the outputs of NICRA project contributing to several national project reports i.e., Intended Nationally Determined Contribution (INDC), Biennial Update Report (BUR), Nationally Appropriate Mitigation Action (NAMAs), National Mission on Sustainable Agriculture (NMSA) and several other Missions under National Action Plan on Climate Change. The system-wide impacts and responses to climate change need to be understood better and more comprehensively. Over all, NICRA project is contributing towards developing adaptation and mitigation strategies in the country and enabling to make Indian agriculture more resilient to climate change.

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Chapter 21

District Wise Crop Contingency Plans for Climate Change

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Introduction

Agriculture is the source of livelihood for nearly two-thirds of the population in India. The sector currently accounts for 14.2 per cent of the GDP and employs 55 per cent of country's total workforce. Agriculture growth rate in GDP, was low in 2009-10 due to the unprecedented and widespread drought while it picked up again in 2010-11 due to a good monsoon. The sharp fluctuations in agricultural growth are mainly attributed to the vagaries of monsoon. Some part of the country or the other experiences monsoon failure almost every year but most states encounter drought once in 2 to 4 years.

The south west monsoon accounts for nearly 75 per cent of the natural precipitation received in the country and therefore exert a strong influence on *kharif* food grain production and the economy in terms of agricultural output, farmers' income and price stability. Both the amount of rainfall and its distribution are crucial factors influencing performance of agriculture. The probability of monsoon rains being erratic is 40 per cent of the time which implies that in 4 out of 10 years there would be an adverse impact on crop production in the absence of appropriate strategy to deal with such eventualities.

Monsoon failures result in drought which has serious implications for small and marginal farmers and livelihoods of the rural poor. Rainfed areas constitute nearly 58 per cent of the net cultivated area and account for 40 per cent of the country's food production and support 40 per cent of human and 60 per cent of the livestock population and are the most vulnerable to monsoon failures. It has been estimated that even after full irrigation potential is realized, nearly 70 Mha of cultivated area will continue to be under rainfed farming. For this reason, performance of rainfed agriculture is key to achieve growth, equity and sustainability of agricultural production in the country. The demand for water from agriculture and allied sectors is ever increasing. Insufficient rainfall and the growing disregard for prudent use of water resources within the renewable limits has compounded the problem of water shortages which is being felt even in the irrigated regions. Increase of variability in precipitation that is being witnessed at the regional level is likely to forcing us to enhance our preparedness to face monsoon aberrations in the irrigated regions.

Extreme weather events like heat wave, cold wave, untimely and high intensity rainfall, hailstorm and frost are increasingly being experienced in different parts of the country. For example heat wave during February-March in north India caused an estimated loss of 6 million tons of wheat in 2002-2003. A decline in production of 39 per cent in cocoa, 60 per cent in rapeseed and 50 per cent in linseed was observed in Himachal Pradesh due to heat wave in March 2004. Cold wave conditions in 2002-03 caused an estimated loss of 10-100 per cent in different crops. In Punjab, 40-100 per cent damage was recorded in Mango and Litchi in the Hoshiarpur district. In Rajasthan, about 20-30 per cent damage in tomato and in Haryana 15-25 per cent damage in Mustard were recorded. Other extreme events like heavy rains accompanied by hailstorm during March 2007 damaged wheat, sugarcane and oilseed crops in thousands of hectares in Punjab and Haryana. In Madhya Pradesh, entire pigeon pea crop in an area of 7000 hectares in Punjab and Haryana was damaged due to frost and extreme cold condition. In 2009, heavy rainfall in Raichur districts of Karnataka, Kurnool and Mahabubnagar districts of A.P damaged standing crops in lakhs of hectares due to floods and sand casting on river banks of Krishna and Tungabhadra rivers. During the same year, the areas affected by drought initially were also affected by floods later in the season resulting into contingency measures being taken up by respective district authorities. It is to be noted that the maximum expected flood limit in 100 years for Krishna river was exceeded during the same year due to very intense rainfall events of more than 250 mm per day in the catchment.

Drought during 1987 in Barmer district of Rajasthan (Livestock Census, 1989) resulted in reduction in population of cattle by 52 per cent, buffaloes by 15 per cent, sheep by 58 per cent and goats by 44 per cent. Super cyclone in Orissa (ODMM, 1989) on during October 1989 killed more than 3 lakhs each of large and small ruminants and more than 18 lakhs of poultry birds in 12 affected districts. The per day milk collection under the impact of the cyclone saw a 25 per cent fall. The Flood of 1996 affected all the costal districts of the AP resulting in the loss of more than 66,000 cattle. Summer floods in 2004 caused flare up of diseases such as Foot and Mouth and bovine diarrhea in the north eastern states (Sanjoy, 2006). Tsunami in 2004 affected shrimp hatcheries, loss of equipment and infrastructure in east coast. Alappuzha and Kollam districts were severely hit by the tsunami and the estimated loss to the marine fisheries sector was assessed at Rs.1000 million with the mechanized sector accounting for 64 per cent of the total loss. Nearly 10,880 fishing craft (18 per cent of the craft operating in the state) where destroyed or damaged. Incessant rains during 2010 monsoon resulted in severe blue tongue disease outbreak in costal districts of Tamil Nadu, Karnataka and Andhra Pradesh due to heavy breeding of the vector *Culicoides* spp.

The widespread failure of the monsoon in 2009 and increasing frequency of occurrence of extreme events in recent years have reinforced the need for better preparedness, planning and response to mitigate the adverse impacts of such events. Four coping strategies for preparedness for climatic risks are disaster preparedness; mitigation practices, contingency planning and responses, and disaster risk mainstreaming (Rathore and Stigter, 2007). Contingency planning is one of the major strategies of preparedness for what should be done after the aberrant weather events that could not be prevented.

Need for District Level Contingency Plans

District is the administrative unit for operationalisation of any action plan or developmental plan by the State or Central Government under various sponsored schemes / programmes. In many States, the contingency plans are currently available either at the agro-climatic zone of ICAR or at the State level prepared by respective SAUs or by other agencies in case of natural calamities. These plans are not directly amenable for implementation at the district level. Further, the existing plans do not contain information on allied sectors of agriculture such as horticulture, livestock, poultry and fisheries. The existing 126 agro-climatic zones in the country have been delineated by ICAR under National Agricultural Research Project on the basis of topography, rainfall, soils, cropping pattern and irrigation availability. The zones comprise of relatively homogeneous districts or part of districts and are useful for regional level planning. However, despite similarities in dominant cropping pattern, agricultural practices adopted by the local farming community tend to vary according to the location within these zones. These variations are best captured and optimized to resource endowments while planning at the district level. Many agro-climatic zones include whole or parts of at least two to three districts. Hence, the mismatch and pitfalls between the plan recommendations, their implementation and impact can be overcome by preparing district plans which cater to a contiguous unit.

Standard Template

As desired by the Parliamentary Consultative Committee the district-level contingency plans are to be prepared for all the major weather related aberrations including extreme events *viz.,* droughts, floods, heat wave, cold wave, untimely and high intensity rainfall, frost, hailstorm, pest and disease outbreaks. These plans need to integrate information for agriculture and allied sectors like horticulture, livestock, poultry and fishery. The template divided into two parts; 1) District agricultural profile with information on resource endowments such as rainfall, land use, soil types, irrigation sources, five most dominant crops and cropping systems and their sowing windows; livestock, poultry and fisheries resources; production and productivity statistics; major contingencies faced by the district and digital soil and rainfall maps 2) Detailed strategies for weather related contingencies in the case of crops / cropping systems starting with delay in onset of monsoon and mid season breaks resulting in drought both in rainfed and irrigated situations and strategies for untimely rains, floods, extreme events. This is followed by strategies for contingency situations in the case of livestock, poultry and fisheries sector.

Contingency Crop Planning for Monsoon Aberrations

In season monitoring of drought through monitoring of rainfall and progress in sowings is crucial for effective management of droughts and minimizing the adverse impacts on crop production. Early season drought due to delay in onset of monsoon is directly responsible for shortfalls in area sown under major crops compared to normal situation. Also, delay in onset often leads to poor inflows into reservoirs, water bodies or poor recharge of groundwater and contributes to delay in sowings.

Contingency crop planning refers to making available a plan for making alternate crop or cultivar choices in tune with the resource endowments of rainfall and soils in a given location. In rainfed areas, as a general rule early sowing of crops with the onset of monsoon is the best-bet practice that gives higher realizable yield. Major crops affected due to monsoon delays are those crops that have a narrow sowing window and therefore cannot be taken up if the delay is beyond this cut-off for sowing. Crops with wider sowing windows can still be taken up till the cut-off date without major penalty on crop yield and only the change warranted could be the choice of short duration cultivars. Beyond the sowing window, choice of alternate crops or cultivars depends on the farming situation, soil, rainfall and cropping pattern in the location and extent of delay in the onset of monsoon (2, 4, 6 and 8 weeks). Breaks in monsoon cause prolonged dry spells and are responsible for early, mid and terminal droughts. These aberrant situations often lead to poor crop performance and or total crop failures. While early season droughts have to be combated with operations like gap filling and re-sowing, mid and late season droughts have to be managed with appropriate contingency measures related to crop, soil nutrient management and moisture conservation measures. Drought also causes loss in livestock productivity due to shortage in fodder production. Appropriate location-specific fodder production strategies go a long way in reducing the adverse impact on livestock which is the major source of livelihood in dryland areas.

Weather Related Contingencies

Drought

Drought is a recurrent phenomenon resulting from deficit in soil moisture and or water both in rainfed and irrigated areas. The effect is pronounced due to delays in onset of monsoon, prolonged breaks in monsoon and deficit rainfall, poor inflows into water bodies or poor recharge leading to reduction in cropped area, cropping intensity, dip in crop and livestock productivity and sometimes total crop failures adversely impacting rural livelihoods and economy. Contingent planning for rainfed crops is important when the onset of monsoon is delayed. Generally the south west monsoon covers the whole of the country in 8 weeks time starting first of June. Historical monsoon behavior indicates the delays by 2 to 6 weeks across the country and in exceptional cases by 8 weeks. The contingency measures suggested against the normal crop / cropping systems are in the form of alternate choice of crop / cropping systems, appropriate cultivars and changes in agronomic practices. These measures are mostly related to sowing operations such as increase in seed rate, changes in spacing, intercropping in case of sole crops and inter terrace land management practices like ridges and furrows, dust mulching, broad bed furrow method of planting etc.

Normal Onset of Monsoon Followed by Early, Mid-Season and Terminal Droughts

The crop is sown under normal onset of monsoon. However, dry spells occur at various stages during the cropping season resulting in early, mid-season and terminal droughts adversely impacting performance of standing crops.

Early Season Drought due to 15-20 Days Dry Spell after Sowing

In case of normal onset followed by early season dry spell immediately after sowing leading to poor germination and poor crop establishment, re-sowing, gap filling, thinning may be necessary depending upon the crop and soil type. In addition, moisture conservation measures, nutrient management and life saving irrigation wherever possible are suggested. Examples include:

- Sesame and millets sown at a shallow depth of 1 to 3 cm are the most affected followed by pulses, sunflower and sorghum which are sown at a depth of 3 to 5 cm. Germination failures are more common in lighter soils than in heavy soils.
- If the moisture stress occurs at a very early stage i.e., within a week to 10 days after sowing, it is recommended to resow with subsequent rains for better plant stand.
- Thinning of plants is advocated in small seeded crops which are closely planted, to reduce crop stand to conserve soil moisture
- Undertake interculture to break soil crust, remove weeds and create soil mulch for conserving soil moisture. Use organic mulches such as weed biomass, subabul lopping, tree leaves, straw and other available crop residue or organic manures to conserve soil moisture
- Avoid top dressing of fertilizers till sufficient moisture is available in soil.
- Make conservation furrows at 10 to 15 m intervals or adopt ridge and furrow across the slope for effective conservation of soil moisture as well as rainwater in bold seeded, dibbled and wide spaced crops (>30 cm) such as cotton, maize, pigeon pea and oilseed crops. In medium deep black soils of north interior Karnataka and Maharashtra, take up compartmental bunding (bunds of 15 cm height formed on all the four sides to form a check basin of 6 x 5 m size) for better retention of soil moisture.
- In cotton sown in shallow and medium deep black soils in Maharashtra, Andhra Pradesh and Karnataka, pot watering may be taken up along with gap filling when the crop stand is less than 75 per cent. In case of non-availability of hybrid cotton seed, gap filling may be done with pigeon pea in Maharashtra to maintain adequate plant stand. When germination is less than 30 per cent, re-sowing may be taken up with a closer plant to plant spacing of 45 cm. Raising of cotton seedlings in polythene bags for transplanting when sufficient moisture is available after receipt of rains can be practiced to compensate loss in plant stand with seedlings of similar age.
- In northern dry zone of Karnataka, when the normal sown crops completely wither, sow alternate crops like sunflower, *Setaria*, *Dolichos*, horse gram soon after receipt of rains.
- In this zone after planting of *rabi* sorghum and safflower if the soil moisture is inadequate thin out the plant population.
- In Vidarbha, in sorghum, groundnut and chickpea spray 2 per cent urea during prolonged dry spells.

- In Vidarbha region, in case of failure of *kharif* crops, take up sowing of photo-insensitive crops such as pearl millet, sunflower, sesame and pigeon pea once adequate rains are received.
- Provide micro-irrigation with drip for wide spaced crops such as cotton, maize, chillies and vegetables and sprinklers for groundnut, maize and vegetables wherever ground/ surface water is available.

Mid-Season Drought at Vegetative and Reproductive Stages of Crop

In case of mid season drought, crop, soil nutrient management and moisture conservation measures are suggested. These include inter-cultivation for weed management, mulching and other *in situ* moisture conservation measures, protective irrigation, split or postponement of fertilizer application, foliar sprays of nutrients or anti-transpirants etc. Examples include:

- Take up repeated interculture to remove weeds and create soil mulch to conserve soil moisture.
- During 40-45 DAS, if there is a severe moisture stress, ratooning or thinning may be done in *kharif* sorghum and pearl millet. Thinning by removing every third row in *rabi* sorghum in black soils of Maharashtra and Karnataka is advantageous.
- Avoid top dressing of fertilizers until receipt of rains.
- Make conservation furrows for moisture conservation.
- Foliar spray of KNO_3 (2 per cent) or Urea (2 per cent) solution with water soluble fertilizers like 19-19-19, 20-20-20, 21-21-21 to supplement nutrition during dry spells.
- Prepare shallow furrow while hoeing by tying ropes to prongs, which will provide soil support to plants and conserve soil moisture.
- Open alternate furrows in row crops such as soybean or furrows for every 6-8 rows of pigeon pea with Balaram plough in medium to deep soils of Maharashtra. Open conservation furrows at 10-15 m interval in shallow to medium deep red and black soils.
- Adopt surface mulching with crop residue or tree loppings of *Gliricidia* wherever possible. If farm waste is not available, use blade to form a thin layer of soil mulch to avoid cracks.
- Apply 10 Kg N/ha in sorghum and oilseed crops soon after receipt of rains .
- Provide supplemental irrigation (10 mm depth) with harvested rain water in ponds by adopting micro-irrigation (sprinklers) wherever possible.
- Apply 2 sprays of Planofix 2 ml/9 lit of water at 45 and 55 DAS to prevent shedding of squares and small sized bolls in cotton grown in medium deep soils in north interior Karnataka. Practice topping to reduce transpirational losses or restrict excess growth by spraying growth regulator (NAA 4 ml/15 l of water) in cotton cultivated in medium to deep black soils.
- In medium to deep black soils and *rabi* cropping areas of Karnataka and Maharashtra, close the soil cracks by deep inter-cultivation in *rabi* sorghum and safflower.
- In castor and pigeon pea, if the drought affected plants to recoup with the revival of the rains, spray 2 to 3 per cent urea after the foliage is wetted with the rains.
- In deep black soils of Vidarbha, the land may be tilled properly in case *kharif* crop fails sow *rabi* crops like safflower, pigeon pea in September.
- In Madhya Maharashtra provide protective irrigation from the harvested water in farm pond or any other source, if available for eg: 5 cm to *rabi* sorghum during pre-boot stage (65-70 DAS).

Terminal Drought

In case of terminal drought in September to October due to dry spells or early withdrawal of the south west monsoon, crop management measures such as life saving irrigation are suggested as in the case of mid season drought wherever feasible. In case of impending crop failure, harvesting at physiological maturity or early harvest of grain crops and use as fodder for livestock are suggested. In case of total crop failure, early rabi crop planning with suitable crops/varieties is suggested. Examples include:

- Give life saving or supplemental irrigation, if available, from harvested pond water or other sources.
- Harvest at physiological maturity with some realizable yield or harvest for fodder and prepare for *rabi* sowing in double cropped areas.
- Ratoon maize or pearl millet or adopt relay crops as chickpea, safflower, *rabi* sorghum and sunflower with minimum tillage after soybean in medium to deep black soils in Maharashtra or take up contingency crops (horse gram / cowpea) or dual purpose forage crops on receipt of showers under receeding soil moisture conditions.

Unusual Rains (untimely, unseasonal) both in Rainfed and Irrigated Situations

In the recent past, continuous high rainfall in a short span leading to water logging and heavy rainfall coupled with high speed winds in a short span are being experienced at various growth stages of annual and perennial crops leading to serious crop losses, outbreak of pests and diseases and sometimes total crop failure. These events at post-harvest stages lead to huge economic losses due to low prices and marketing failures of poor quality or damaged produce. The livestock and poultry sector suffer due to short supply of quality feed and fodder. Suggested contingency measures include re-sowing, providing surface drainage, application of hormones / nutrient sprays to prevent flower drop or promote quick flowering / fruiting and plant protection measures against pest / disease outbreaks with need based prophylactic / curative interventions. At crop maturity stage suggested measures include prevention of seed germination and harvesting of produce. Post harvest measures include shifting of produce to safer place for drying and maintaining the quality of grain / fodder and protection against pest / disease damage in storage.

Floods

Floods are common in river basins and coastal areas of the country leading to physical loss of crop, human and livestock population. Also serious land degradation is an after effect which requires considerable effort to reclaim the land for cultivation. Heavy rainfall results in flash floods in streams and rivers, breach of embankments leading to transient water logging and continuous submergence of crop lands and entry of sea water into cultivated fields and intrusion of seawater into groundwater in coastal districts. Crop/field management depends on nature of material (sand or silt) deposited during floods. In sand deposited crop fields/ fallows ameliorative measures suggested include early removal or ploughing of sand (depending on the extent of deposit) for facilitating *rabi* crop or next kharif. In silt deposited Indo-Gangetic plains, early *rabi* crop plan is suggested in current cropped areas and current fallow lands. Other measures include drainage of stagnating water and strengthening of field bunds etc. In diara (flood prone) land areas, measures include alternate crop plans for receding situations. Usually rice cropped areas are flood prone causing loss of nurseries, delayed transplanting or damage to the already transplanted fields etc. Suggested measures include community nursery raising, scheduling bushenings, re-transplanting in damaged fields and transplanting new areas or direct seeding depending on seed availability so that the season is not lost. Other steps include prevention of pre-mature germination of submerged crop at maturity or of harvested produce by spraying of salt solution.

Other Extreme Events

Extreme weather events like heat wave, cold wave, frost, hailstorm and cyclone are climatic anomalies which have major impact on food, commercial and horticultural crops. In recent times the frequency of these events is increasing causing enormous damage not only to agriculture but also to other allied sectors like livestock, poultry and fisheries.

Heat Wave

In regions where the normal maximum temperature is more than 40^0C, if the day temperature exceeds 3^0C above normal for 5 days it is defined as heat wave. Similarly, in regions where the normal temperature is less than 40^0C, if the day temperature remains 5^0C above normal for 5 days, it is considered to be experiencing heat wave. Eastern Uttar Pradesh, Punjab, East Madhya Pradesh, Saurashtra and Kutch in Gujarat are highly heat prone areas and heat waves were experienced in recent years during 1998, 2002, 2003, 2004 and 2007. Generally affected crops due to heat wave are wheat, mustard, rapeseed, linseed, vegetables. Wheat production showed loss of 4-6 million tons in recent years due to increased temperature in February-March. A decline of 39 per cent in annual cocoa, 60 per cent in Rapeseed and 50 per cent in linseed yield was noticed in Himachal Pradesh due to heat wave in March 2004. Ameliorative measures include conserving soil moisture through appropriate tillage practices, frequent and light irrigations, use of efficient water harvesting techniques, choosing heat tolerant crop varieties (Golden Halna (K0424), heat tolerant variety of wheat developed at CSAUA and T, Kanpur), Provide shelter to young fruit plants and Shelter management for livestock and poultry to alleviate heat stress.

Cold Wave

In regions where normal minimum temperature remains 10^0C or above, if the minimum temperature remains 5^0C lower than normal continuously for 3 days or more it is considered as cold wave. Similarly in regions where normal minimum temperature is less than 10^0C, if the minimum temperature remains 3^0C lower than normal it is considered as cold wave. The adverse impacts observed are on growth, flowering, fruiting, delay in ripening and mortality of young and aged orchard plants. Poor growth rate is observed and disease outbreaks are experienced in case of fisheries. Jammu and Kashmir, Rajasthan, Uttar Pradesh, Haryana, Punjab are identified as frequent cold wave prone areas. Recently cold wave was experienced during 2000, 2001 and 2003.

Crop damage estimates due to cold wave during 2002-03 is 10-100 per cent depending upon crop and variety within the crop. In Hoshiarpur, Punjab 40-100 per cent damage was recorded in mango and litchi. In Jodhpur, Rajasthan 20-30 per cent damage in tomato and 5-10 per cent damage in Chilli was recorded In Hisar 15-25 per cent damage was recorded in Mustard. Mostly horticultural crops (*eg:* mango, papaya, banana, litchi, pomegranate *etc.*) are affected by cold wave. Suggested measures include Proper selection of fruit species / varieties which are cold tolerant, use of windbreaks or shelter belts, frequent smoking in the orchards and covering young fruit plants with thatches or plastic shelter

Frost

It is a condition that exists when the temperature of the earth's surface and earthbound objects falls below zero degree (freezing). Frost is mostly experienced in the month of January. Himachal Pradesh, Punjab, Haryana, Madhya Pradesh are frost prone areas (De *et al.*, 2005). Crop damage due to frost in Madhya Pradesh was 100 per cent in pigeon pea, sown in about 6990 hectare areas in 2011. Suggested measures include preference of frost tolerant varieties, change in planting time to avoid sensitive stages coinciding with frost periods, adopting shelter belts, shade trees, and use of mulches as ground cover to prevent loss of heat etc.

Hailstorm

Hailstorm frequencies are highest in Assam valley, Uttaranchal, Jharkhand and Vidarbha and its occurrence noticed 1997-98, 2005-06, 2007 and 2011. About of 0.46 Mha cropped area in the states Haryana, Punjab, Himachal Pradesh, Rajasthan, Uttar Pradesh, Maharashtra and Andhra Pradesh was badly hit during the year 1994-95 by hail storms. In Andhra Pradesh, hailstorm caused a huge loss in 77 thousand hectares area in the 2005-06. In March 2007, heavy rains accompanied by hailstorm damaged wheat, sugarcane and oilseed crops in thousands of hectares in Punjab and Haryana. Generally affected crops are Apple, Litchi, wheat and other fruit crops. Suggested measures include use of anti-hail guns and anti-hail nets, damaged fruits can be used in preparation of processed foods, crop insurance etc

Impact of Drought, Floods and Extreme Events on Livestock

Rainfall deficit or drought likely to affect livestock and crop sectors differently. In areas where crops and livestock occupy the same ecological niche, cropping is likely to be a more risky business, livestock being able to compensate for localized rainfall shortages by movement to better favored areas. Drought impact on livestock sector manifests after a series of years with below average rainfall, causing a mounting imbalance in the availability of grazing resources mainly dry fodder. Droughts are inevitable natural events particularly in arid and semi-arid zones, and therefore advanced planning to face the situation by livestock holders must be designed. Floods and cyclones result in loss of livestock and stored fodder reserves and also cause serious injury to the animals and destroy the animal sheds. Heat wave and cold wave also impact livestock. Higher ambient temperature substantially reduces feed intake, which results in loss of weight, production, anoestrus, premature calving etc. Exposure to extreme and particularly unexpected cold can cause pneumonia or death of livestock. Extreme heat or cold waves kill the plants and lead to famines. Among those animals which survived after natural disasters are threatened by non-availability of feed and shelter and associated disease epidemics.

Primary effects of natural disasters on livestock are

- Loss of livestock and animal sheds
- Less or no fodder for the livestock as the crops and stored fodder are adversely affected
- High cost of fodder with the reduced availability of fodder within the farm vicinity
- Increased expenses for transporting the fodder from neighboring areas
- Unavailability or high cost of drinking water for livestock
- Reduced milk and meat production
- Progressive decline in health status of livestock
- High incidence of contagious diseases
- Higher mortality rates.
- Distress sale of livestock

Effect of Drought

Drought affects the animal and animal production system in different ways like shortage for feed and fodder resources, drinking water and leads to loss of productive animals, draft animals and livelihoods of the rural poor.

Feed and Fodder Resources

A plunge in green fodder availability due to low rainfall is the first major effect of drought on livestock production systems. Low rainfall causes poor pasture growth and may also lead to a decline in fodder supplies from crop residues. During drought, plant growth and metabolism slows down as the available soil moisture declines progressively. Even under mild water deficit conditions, there is a reduction in cell division and protein synthesis and more lignifications. This results in reduction in the total amount of plant biomass and its quality as animal fodder in a given growing season. Water stress in addition to over grazing substantially affects the pasture growth in grazing lands and in severe cases, grazing lands completely dry up without a single blade of grass.

Livestock Management during Drought

The impact of drought can be minimized and livestock productivity can be maintained at optimum level by the following strategies.

Strengthening Fodder Resource Base

It is achieved through proper preservation of available crop residues at individual farmer level. Establish community fodder banks at village level with available dry fodder (Sorghum kutty / Bajra stover / wheat straw). Harvest and use the biomass of dried up crops (paddy / Sorghum / maize / Black gram / Green gram *etc.*) material as fodder during drought. Early *rabi* crop planning with fodder yielding cereals (Sorghum / Maize / Bajra) and leguminous crops (Lucerne, Horse gram, Cowpea) should be sown taking advantage of rains in North-East monsoon under prevalent areas. The available green maize fodder and sugar cane tops should be preserved as silage by the end of February for use during summer and early drought period. Silvopastoral models with suitable tree and understory grass component should be developed in CPRs. Encourage fodder production with short-term fodder crops like sun hemp, pilli pesara, horse gram etc. in farmer's lands. The capacity of the stakeholders and officials should be strengthened and also prepared well in advance to tackle the situation in effective way.

Feeding Management

Emergency grazing / feeding facilities (Cow-calf camps or other special arrangements to protect high productive and breeding stock) may be arranged during severe drought. Optimum ration should be provided for high producing, pregnant and breeding animals. Un productive, sick and aged animals should be culled. Encourage mixing of available kitchen waste with dry fodder while feeding to the milch animals. Harvest all the top fodder available (Subabul, *Gliricidia*, Agathi, *Prosopis* etc) and feed the livestock as supplement during drought. Concentrate ingredients such as grains, brans, chunnies and oilseed cakes, low grade grains etc. unfit for human consumption should be procured from Govt. godowns and supplied to the livestock owners for feeding as supplement for high productive animals during severe drought. All the hay should be enriched with 1 per cent Urea molasses solution or 1 per cent common salt solution and fed to livestock. Mineral and vitamins should be supplemented during drought as the green fodder is scarce. In prolonged drought, arrangements should be made for mobilization of small ruminants across the districts where there is no drought.

Rangeland Management

During drought, cut and carry system should be strictly followed to protect the growing grass from trampling. It also reduces the nutrient requirement of the animals as the animal does not spend any energy in search of grazing resources. Reseeding or planting of high yielding perennial grass species and bush clearing should be followed to enhance forage availability from range lands. Seeding of legumes like *Stylo* with onset of monsoon and application of Phosphorus as basal dose should be practiced for faster growth of pastures. Silvopastoral models with suitable tree and understory grass component should be developed in range lands with initial protection from grazing the planting material.

Augmenting Green Fodder when Rains Fail during Kharif

In case of complete or major failure of grain crops in *Kharif*, contingency strategies for ensuring fodder supplies include:

- Available stover from cereals may be preserved as hay and fields may be re-sown with short to medium duration fodder varieties of millets, pulses or forage crops such as:
- Sorghum - varieties / hybrids CSV-17 and CSH 14 in red soils; CSH 16, CSH 18 and CSH 21 in black soils.

- Bajra - short duration varieties like Rajko, JB, PSB-2, GHB-526, HHB-67, ICMH-356, Shraddha, GK-1004 or medium duration varieties like GHB-558, Proagro- 9443 and for late assured rainfall areas in light to medium soils of Marathwada region varieties like AHB-251
- Finger millet - medium duration varieties like GPU 28, PR 202, HR 911 and Pusa Composite 612, MP 480 for second fortnight of July to first fortnight of August; short duration varieties: GPU 26, GPU 45, GPU 48 and Indaf 9 for late sown conditions from second fortnight of August to 20th September
- Maize - African tall, APFM 8, PEHM-3 and FH-3077 which produce some grain and fodder
- Intercropping cowpea - varieties like Bundel Lobia-1, CO 5, CO (FC) 8, IFC 8401, UPC 8705, DFC 1 and UPC- 625 after 8 to 10 rows of finger millet
- *Rabi* fodder crops like berseem (Mescavi, Wardan, UPB 110), lucerne (CO 1, LLC
- 3, RL 88) should be sown in arable lands and tank beds.
- Current fallows should be used for fodder production by sowing short duration varieties of sorghum or bajra or ragi or maize or cowpea in *kharif* season and or berseem or lucerne in *rabi* season.
- In wastelands, grasses like *Cenchrus ciliaris, Cenchrus setigerus, Chloris gayana, Panicum maximum, Desmanthus virgatus, Stylosanthes scabra* can be taken up to increase forage production.
- In areas that receive north east monsoon rains, multi-cut fodder varieties of sorghum (CO 27, Pant Chari-5 (UPFS- 32), COFS- 29 or pearl millet (Co-8) or maize (African tall) are recommended
- In areas that receive summer rains, fodder crops like cowpea and maize are recommended

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Chapter 22

Remote Sensing of Pest and Disease Damage in Different Crops and Cropping Systems

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Introduction

Plants may respond to pest and disease stress in one or more of the following ways: including leaf curling, wilting, chlorosis or necrosis of photosynthetic plant parts, stunted growth, or in some cases reduction in leaf area due to severe defoliation. Many of these responses are difficult to visually quantify with acceptable levels of accuracy, precision, and speed. The same plant responses will also affect the amount and quality of electromagnetic radiation reflected from plant canopies. Remote sensing may provide a better means to objectively quantify crop stress than visual methods and it can be used repeatedly to collect sample measurements non-destructively and non-invasively (Nilsson, 1995; Nutter *et al*. 1990). Traditionally, pest and disease assessment of crop plants is being done by visual approach that they are often time consuming and labour intensive. Advances in the field of remote sensing offer scope for exploiting these technologies towards developing an alternate means that can enhance or supplement the traditional approaches. There are several reviews published from time to time on remote sensing of biotic stress (Jackson, 1986; Riley, 1989; Hatfield and Pinter, 1993; Nilsson, 1995; Everitt *et al*., 2003; West *et al*., 2003; Prabhakar *et al*., 2012).

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object under investigation. When electromagnetic energy is incident on any feature on the earth surface, three energy reactions with the feature are possible: reflection, absorption and/or transmission (Lillesand *et al*., 2004). The portion of energy reflected, absorbed or transmitted will vary for different earth features depending on their material type and condition. Even within a given feature type, the portion of reflected, absorbed and transmitted energy will vary at different wavelengths. Thus, two features may be distinguishable in one spectral range and be very different in another wavelength band. Because many remote sensing systems operate in the wavelength regions in which reflected energy predominates, the reflectance properties of earth surface are very important. The reflectance characteristics of earth surface features may be quantified by measuring the portion of incident energy that is reflected (Panda, 2005). Reflectance is measured as a function of wavelength and is called spectral reflectance. A graph of the spectral reflectance of an object as a function of wavelength is termed as ‘spectral reflectance curve’.

Accurate quantification of early symptoms are important in pest management point of view, and efforts at remotely detecting plant stress due to disease or insect activity utilize principles of biophysical remote sensing (Jensen, 1983). Plant stress usually results in an increase in visible reflectance (due to a decrease in chlorophyll and a resulting decrease in absorption of visible light), and a decrease in NIR reflectance from changes in the internal leaf structure (Hatfield and Pinter, 1993). Use of remote sensing techniques for detection crop pests and diseases is based on the assumption that stresses induced by them interferes with photosynthesis and physical structure of the plant and affects the absorption of light energy and thus alter the reflectance spectrum of the plants (Riley, 1989; Hatfield and Pinter, 1993; Moran *et al.*, 1997). Stress induction affects the physiological behavior of plants, resulting in differences in reflectance patterns and thus providing potential for remote sensing diagnosis of vegetation stress. Natural growth processes (*e.g.* increase of biomass, development, maturation, senescence, plant architecture and natural fluctuations in hydraulic properties) and the related biochemical changes, for instance the concentration of chlorophyll and other pigments, also have an impact on the amount of solar energy that is reflected, absorbed, and transmitted by plants (Carter, 1993; Lillesand *et al.*, 2004; Ustin *et al.*, 2002). Thus research into vegetative spectral reflectance can help to gain a better understanding of the physiological, chemical and physical processes in plants and to detect plant stress when remedial action may still be effective.

Types of Remote Sensing Platforms

Remote sensing platforms can be field-based (ground based), or mounted on aircraft (airborne) and satellites (space borne). Satellite RS is generally for large-scale study but it often cannot meet the requirement of spatial resolution in applications. Ground-based platform, such as hand held spectro-radiometer, is typically used for ground truth study. Airborne RS is flexible and able to achieve different spatial resolutions with different flight altitudes. Depending on the band width, number and contiguous nature of spectra recording spectral scanner scan be of two types *viz.*, multispectral or broad band and hyper spectral or narrow band. Multispectral scanners sense several wavebands in a wider range of discrete wavelengths while hyper spectral scanners provide the opportunity to sense many very narrow wavebands over a wide range of wavelengths with much greater number of sensors. Multispectral systems measure energy in specific, strategically restricted portions of the electromagnetic spectrum while hyper spectral systems measure several consecutive wavebands across a specified region of the electromagnetic spectrum. However, a major limitation of broadband RS products is that they use average spectral information over broadband widths resulting in loss of critical information available in specific narrow bands. Recent developments in hyper spectral RS or imaging spectrometry have provided additional bands within visible, NIR and shortwave infrared (SWIR). Most hyper spectral sensors acquire radiance information in less than 10 nm bandwidths from the visible to the SWIR (400-2500 nm). For example, the spectral shift of the red-edge (670-780 nm) slope associated with leaf chlorophyll content, phenological state and vegetation stress, is not accessible with broadband sensors (Fig 22.1).

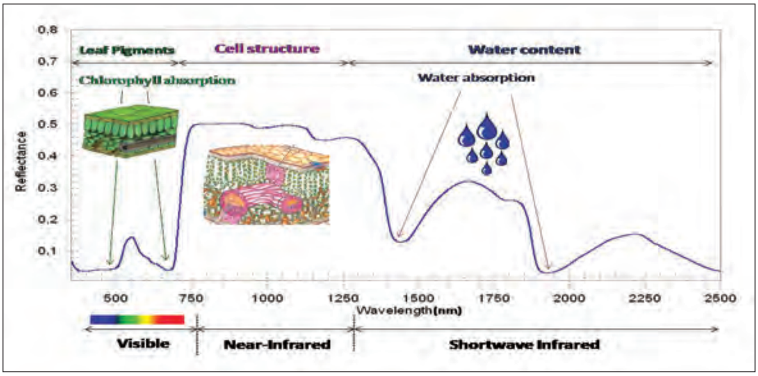

Fig 22.1 Typical spectra reflectance curve showing different regions of electromagnetic spectrum and major absorption features (Source: Prabhakar *et al.*, 2012)

The data the RS sensors capture is often characterized by four kinds of resolutions *viz.*, (i) spatial (the smallest resolvable unit is on the ground, also called the pixel), (ii) spectral (how sensitive the spectra is sampled), (iii) temporal (how often the data can be captured) and (iv) radiometric (the ability to discriminate very slight differences in reflected or emitted energy). The common pixel sizes are wide-ranging across different satellites. Weather satellites have pixel resolutions larger than 1 km; the AVHRR sensor, an early multispectral sensor still in use has a 1km pixel size; the series of Landsat sensor have 30 m pixels, and there are a range of newer commercial satellites (*e.g.* Quick bird and IKONOS) that have near and under 1 m spatial resolution. Sub-meter resolution imagery is increasingly common, especially with the use of aircraft-borne sensors. The spectral information contained in imagery can include multispectral (<10 bands of spectra, covering the visible and NIR portion of the spectrum), hyper spectral (10s to 100s of bands, covering a wider range of the spectrum) and thermal spectra (covering longer wave infrared emittance spectra).

Ground Based Remote Sensing of Pest and Disease Damage

Spectroradiometry is the technique of measuring the spectrum of radiation emitted by a source. In order to do this the radiation must be separated into its component wavebands and each band measured separately. It is achieved by using a diffraction grating in spectro-radiometers to split the radiation entering the system into its constituent wavebands. A suitable detector is then used to quantify the radiation of each wavelength. The field spectroscopy concerns measurement of the reflectance of composite surfaces in situ. Increasingly, spectral data are being incorporated into process-based models of the Earth's surface and atmosphere, and it is therefore necessary to acquire data from terrain surfaces, both to provide the data to parameterize models and to assist in scaling-up data from the leaf scale to that of the pixel. In most cases, the reflectance of a vegetation canopy or a soil surface is presented as a 'reflectance factor'.

Evidently, a limiting factor of ground based remote sensing is their applicability is for only for small areas when compared with aircraft and satellite sensors. However, using hand-held spectrometers to quantify the unknown spectral characteristics of un-infested and infested plant canopies due to insect feeding at a small-scale is needed because hand-held remote sensing devices have better temporal, spectral, and spatial resolutions, as well as the accuracy of collecting reflectance data over per unit area. Reflectance data obtained by hand-held instruments over small-areas provides information to understand spectral interactions between insect pests and their host plants, as well as fundamental ground-truth for interpretation of RS data measured from satellite and aircraft (Prabhakar *et al*., 2013). Therefore, a logical initial step is to use a field spectrometer for understanding the spectral response of crop stress.

Prasanna Kumar *et al.* (2014) were formulated the Brown plant hopper spectral indices (BPHI) by combining two or more sensitive wavelengths and also developed a multiple-linear regression model for assess the BPH damage in rice (Table 22.1). In black gram yellow mosaic disease prediction models were built using multinomial logistic regression (MLR) technique with reflectance data and validated with independent data set (Prabhakar *et al.*, 2013). Whereas, Saad Gazala *et al.* (2013) identifies the yellow mosaic sensitive band as R688 and R750/R445, which could be utilized for monitoring YMD affected soybean.

Jones *et al*. (2010) investigated the spectral signature of tomato bacterial leaf spot disease in the ultraviolet, visible, and NIR regions, and analyzed reflectance measurements of healthy and diseased samples using partial least squares regression, correlation coefficients and stepwise multiple linear regression. They identified important wavelength to distinguish diseased tomato leaves, developed disease prediction models, and reported an RMSD of 4.9 per cent in predicting disease severity in percent using the best prediction model. Mahlein *et al.* (2010; 2013) demonstrated the differentiation of foliar pathogens of sugar beet based on leaf reflectance of healthy and diseased. Building on these results, Rumpf *et al*. (2010) was able to detect early Cercospora leaf spot, powdery mildew, and rust-diseased sugar beets before the appearance of visible symptoms using SVMs.

In other plant pathogen systems, non-invasive spectral data proved to be useful for the monitoring of *Fusarium graminearum* in wheat (Bauriegel *et al*., 2011). Whereas, Delalieux *et al*. (2007) demonstrated the differentiation between *Venturia inaequalis*-infected and non-infected apple leaves using logistic regression classification, Partial least squares logistic discriminant analysis (PLS-LDA) and Tree-based modeling (TBM) are able to distinguish susceptible Braeburn apple plants infected with *Venturia inaequalis* from non-infected plants. Wang *et al*. (2008) developed a method to spectrally predict late blight infections on tomatoes based on artificial neural network (ANN). They also used SVIs for the assessment of apple scab due to *Venturia inaequalis* at different stages of disease development. While Steddom *et al*. (2005) calculated SVIs from multispectral data of sugar beet fields and compared these indices to disease severity visually rated by plant pathologists.

Furthermore, Bravo *et al*. (2003) used in-field spectral images for the early detection of yellow rust infected wheat. Soil borne diseases were successfully discriminated by Hillnhütter *et al*. (2011), who looked at the symptoms caused by the nematode *Heterodera schachtii* and the soilborne fungus *Rhizoctonia solani* in sugar beet fields. Moshou *et al*. (2004) used ANNs to classify healthy from diseased wheat plants. Whereas, Quin *et al*. (2009) differentiated healthy citrus fruits, canker diseased and damaged fruits with spectral information based algorithm, yielding in a classification accuracy of 96 per cent.

Table 22.1 Hyper spectral vegetation indices useful for pest damage assessment

Index	Formula	Reference
Simple Ratio (SR)	(R695/R420)	Carter (1994)
Normalized Difference Vegetation Index (NDVI)	(R800- R670)/ (R800+ R670)	Rouse *et al*. (1974)
Green Normalized Difference Vegetation Index (GNDVI)	(R750 -R550)/(R750+R550)	Gitelson *et al*. (1996)
Red Edge Position (REP)	700+40(RRE-R700)/(R740-R700) RRE= (R670+R780)/2	Guyot and Baret (1988)
Optimized Soil-Adjusted Vegetation Index (OSAVI)	(1+0.16) (R800 – R670)/ (R800 + R670 + 0.16)	Rondeaux *et al*. (1996)
Modified Chlorophyll Absorption Reflectance Index (MCARI)	[(R700 – R670)-0.2 (R700 – R550)] (R700/R670)	Daughtry *et al*. (2000)
Transformed Chlorophyll Absorption Reflectance Index (TCARI)	3 [(R700 – R670)-0.2 (R700 –R550)(R700/R670)]	Haboudane *et al*. (2002)
Ratio of TCARI and OSAVI	TCARI/OSAVI	Haboudane *et al*.(2002)
Photochemical Reflectance Index (PRI)	(R531-R570)/ (R531+R570)	Gamon *et al*. (1992)
Chlorophyll Index (CI)	(R415-R435)/(R415 + R435)	Barnes (1992)
Normalized Pigment Chlorophyll Index (NPCI)	(R680 – R430)/(R680 + R430)	Penuelas *et al*. (1995)
Zarco Tejada and Miller (ZTM)	(R750 /R710)	Zarco Tejada *et al*. (2001)
Disease Water Stress Index 2 (DWSI-2)	(R1660/R550)	Apan *et al*. (2004)
Aphid Index (AI)	(R761- R908)/(R712- R719)	Mirik *et al*.(2006b)
Damage Sensitive Spectral Index-2 (DSSI 2)	(R747- R901-R537-R572)/ (R747- R901)+(R537-R572)	Mirik *et al*. (2006a)
Nitrogen stress index-1 (NSI-1)	(R415/ R710)	Read *et al*. (2002)
Nitrogen stress index-2 (NSI-2)	(R517/R413)	Zhao *et al*. (2005)

Index	Formula	Reference
Chl stress index-1 (Chl SI-1)	(R415/R695)	Read *et al*. (2002)
Chl stress index-2 (Chl SI-2)	(R708/R915)	Zhao *et al*. (2005)
Chl stress index-3 (Chl SI-3)	(R551/R915)	Zhao *et al*. (2005)
Leaf Hopper Index-1 (LHI-1)	(R691/ R761)	Prabhakar *et al*. (2011)
Leaf Hopper Index-2 (LHI-2)	(R1124-R691)/ (R1124+R691)	Prabhakar *et al*. (2011)
Leaf Hopper Index-3 (LHI-3)	(R761-R691)/(R761+R715)	Prabhakar *et al*. (2011)
Leaf Hopper Index-4 (LHI-4)	(R761-R691)/(R550-R715)	Prabhakar *et al*. (2011)
Mealybug Stress Index-1 (MSI-1)	(R550 + R768 + R1454) [R1454/(R550 + R768)]	Prabhakar *et al*. (2013)
Mealybug Stress Index-2 (MSI-2)	(R550 + R768) (R1454 + R674)/(R550 + R768) + (R1454 + R674)	Prabhakar *et al*. (2013)
Mealybug Stress Index-3 (MSI-3)	(R550 R674)/(R550 + R674)	Prabhakar *et al*. (2013)
Brown plant hopper Index-1 (BPHI-1)	R1201/R961	Prasanna Kumar *et al.* (2014)
Brown plant hopper Index-2 (BPH-2)	(R764−R1164)/(R764)	Prasanna Kumar *et al.* (2014)
Brown plant hopper Index-3 (BPH-3)	(R1664−R1201/R1664+R1201)	Prasanna Kumar *et al.* (2014)

Airborne Remote Sensing of Pest and Disease Damage

Studies on the use of remote sensing for crop disease assessment started long time ago. For example, in the late 1920s, aerial photography was used in detecting cotton root rot. The use of infrared photographs was first reported in determining the prevalence of certain cereal crop diseases. In the early 1980s, Toler *et al.* (1981) used aerial colour infrared photography to detect root rot of cotton and wheat stem rust. In these studies, airborne cameras were used to record the reflected electromagnetic energy on analogue films covering broad spectral bands. Since then, RS technology as changed significantly. Everitt *et al.* (2003) provided an overview of aircraft remote sensing in integrated pest management with four exemplary examples *viz.*, black fly in citrus, silver whitefly in cotton, harvest ant infestations in rangelands and western pine beetle infestations in a forested area. They concluded that integration of remote sensing. GPS and GIS provide valuable tools that can enable resource managers to develop maps showing distribution of insect infestations over large areas. The digital imagery can serve as permanent data base for monitoring future contraction or spread of insect infestation over time. However, aircraft RS may suffer due to mismatching the image pixels with Russian wheat aphid spots on the ground for providing fundamental baseline data. Another possible drawback of airborne systems is the problem of spectral pixel mixing, which is the mixture of the signals from different objects such as soil, healthy and infested plants or vegetation, different species, and varying cover levels. Nevertheless, airborne multi-spectral imaging system has a great potential for use in area wide pest management systems.

Yang *et al*. (2005; 2010) monitored and mapped the progression of cotton root rot within and across growing seasons in south and central Texas using airborne multi-spectral imagery, as infected plants had higher red reflectance and lower NIR reflectance compared to non-infected plants. Whereas, Zhang *et al*. (2003) explored the feasibility of utilizing airborne multispectral imaging to detect tomato late blight disease. They developed the following five vegetation indices using red (R) and NIR bands, and also spectra collected by a handheld spectrometer from the field: R, NIR, NIR/R, NIR-R, and NDVI. With cluster analysis and classification process, they were able to identify the diseased plants with an average accuracy of 87 per cent.

Space Borne Remote Sensing of Pest and Disease Damage

A large number of satellite remote sensing products are available at present. Each satellite has different spectral, spatial, temporal and radiometric resolutions and the choice of product depends on application. Some of the new satellites with multispectral and hyper spectral sensors on board are swiftly generating vast amounts of data in a cost effective manner and at higher spatial and spectral resolutions. However the use of these RS from satellite platform for detection of pests and diseases is limited owing to high spatial and temporal resolution of data required for this purpose. More so, availability of cloud free data during the crop season is another issue that limits use of satellite RS for crop protection. Some of the successful applications for pest detection using space data are from the forestry and some plantation crops where the spatial spread of the pest damage large and thus suits well for its applications.

Landsat data in near infrared bands (MSS6 and MSS7) have been used to discriminate the rust-affected wheat from the healthy wheat. Fitzgerald *et al.* (1999) demonstrated that multispectral RS (MRS) would allow farmers to detect early infestation of mites in large scale cotton fields due to colour shifts and changes in canopy appearance over time. Areas identified on the map could be located with the help of portable GPS equipment by field scout, verify mite population in these areas and recommend regions in the field that require pesticide application. While other researchers have used Landsat (Nelson, 1983; Vogelmann and Rock, 1989; Goodwin *et al*., 2008) and SPOT satellite imagery with coarse spatial resolutions to detect and assess insect damage to forests. It has been demonstrated that by the use of Landsat TM data it was possible to assess mountain pine beetle (*Dendroctonus ponderosae*) in western Canada bark beetle damage in pine forests. A spatial model has been developed using Landsat imagery and field observations based on environmental factors such as topography and soil types to predict densities of wheat aphid, *Diuraphis noxia* (Merrill *et al*., 2009). This method appears to be one of the best currently available for identification and mapping disease incidence over large and remote areas by offering a repeatable, inexpensive, and synoptic strategy during the course of a growing season.

Ji *et al*. (2004) evaluated the potential of MODIS data to monitor locust outbreaks in China and showed that the NDVI reliably distinguished between before and peak damage situations for each category of damage. Areas where NDVI decreased could be clearly mapped and classified into light, moderate, and heavy damage categories according to the decrease in their NDVI value. High resolution multi-spectral data from Quick Bird were generally used to detect in-field heterogeneities of crop vigor but are only moderately suitable for early detection of crop infections by diseases. However Quick Bird imagery was used for detecting citrus orchards affected by sooty mould and wheat diseases caused by powdery mildew (*Blumeria graminis*) and leaf rust (*Puccinia recondita*). A regional level spatial distribution model of aphid (*Lipaphis erysimi*) growth in Indian mustard using satellite based remote sensing data has been developed. They employed near surface meteorological parameters derived from National Oceanic and Atmospheric Administration (NOAA) Television and Infrared Operational Satellites (TIROS) Operational Vertical Sounder (TOVS) data and field observations of pest infestation. Second order polynomials fits were found at two locations tested in India *i.e.*, Bharatpur and Kalyani between peak aphid count and TOVS cumulative air temperature at peak. Apan *et al*. (2004) successfully distinguished healthy and rust diseased by using EO-1 Hyperion imagery sugarcane using disease water stress indices developed from the narrow-bands related to leaf pigments, leaf internal structure, and leaf water content.

Conclusions

Remote sensing gives a synoptic view of the area and it can supplement many of the on-going field surveillance programs, which is often expensive, time consuming, laborious and often error prone. Hence remote sensing technology can reliably provide accurate and timely information to guide decision-making in crop protection. Extensive studies have been carried out world over for characterizing biotic stress using hand held multi spectral radiometry. However, with the advent of hyper spectral radiometry, it was possible to have in sights in to more details and have a better understanding of the crop stress induced by pests and diseases. It was also feasible to differentiate between biotic and abiotic stresses using hyper spectral radiometry. Ground based remote sensing using portable spectro radiometers provides vital information to understand spectral interactions between pests damage on the host plants and also ground-truth information required for interpretation of remote sensing data from space borne and airborne platforms. Airborne systems have a higher resolution and time flexibility and provide sufficient lead time for dissemination of crop protection advisory. Though airborne remote sensing finds applications in area wide pest damage assessment and precision farming, it is cost prohibitive in developing nations. It would be challenging to make airborne hyper spectral remote sensing a reality in near future. Satellite remote sensing provides sufficient data for large scale studies, but it has limitations such as temporal and spatial resolution and cloud cover. The other reason could be small farm holdings and diverse cropping systems. The narrow bands in the hyper spectral remote sensing are able to measure the characteristic absorption peaks of plant pigments more precisely and thereby provide better information related to plant health. But availability of hyper spectral data from satellite platforms is still in its infancy. Nevertheless, remote sensing is a rapid, effective technology that provides information for spatial variability, directs both the scouting efforts and crop protection advisory at regional scale.

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Chapter 23

Insect Pest Dynamics in Response to Climate Change

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Introduction

Global circulation models predicted that global-average surface temperature would increase further by 1.4 to 5.8°C by 2100 with atmospheric carbon dioxide (CO_2) concentrations expected to rise to between 540 and 970 ppm and with an altered precipitation over the same period (IPCC, 2014). It further reported that warming of climate system is now unequivocal. Though climate change is global in its occurrence and consequences, it is the developing countries like India that face more adverse impacts as majority of the population depends on agriculture with excessive pressure on natural resources and because of poor coping mechanisms. Since climate is the direct input into the agriculture production process, the agricultural sector has been a natural focus for research. Within agriculture, how the climate change impacts insect pests and diseases is an important area that is engaging the biological scientists. The extensive review of information on impact of elevated CO_2 on insect pests revealed that 57 per cent studies were confined to lepidopteran followed by homopteran (16 per cent) and coleopteran insects (6 per cent). The increased consumption, reduced growth rates, extension of larval durations were documented under elevated CO_2 conditions. The variations in insect survival, development, geographic range, no. of generations and population size etc., were reported due to increased temperature. Significantly lower leaf nitrogen, higher carbon, higher relative proportion of carbon to nitrogen (C: N) and higher polyphenols content expressed in terms of tannic acid equivalents were observed in crop foliage grown under elevated CO_2 levels.

Apart from the effects mentioned above, agriculture including plants-insect-parasitoid systems is likely to be affected by the climate change. The documented information on climate change interactions and insect pests indicated that majority of studies insect-plant interactions are from forest trees and grasses and mostly confined to abroad only. Few studies are available on cultivated plants and very few are on important global pest like *Helicoverpa armigera*, which is ubiquitous pest of international importance.

Agroforestry and Insect Pests

Agroforestry is an integrated approach of using the interactive benefits from combining trees and shrubs with crops and / or livestock. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy, and sustainable land-use systems. A narrow definition of agro forestry is “trees on farms”. Enhancing opportunities for biological pest control will become increasingly important and could be accomplished through agroforestry. For example, alfalfa intercropped with walnut supported twice as many predators and parasitic hymenoptera and half as many herbivores as did alfalfa alone (Stamps *et al.*, 2002). It was reported that the greater niche diversity of agro forestry may support greater numbers and/or diversity of natural enemy populations than even polycultural systems of annual crops. Many factors influence the distribution and abundance of insect pests including the availability of food resources, natural enemies, competitors and climate. Further, the interaction among these factors often determines insect population dynamics. Generalized predictions can also be based on the life-history characteristics of pests, such as where and when they feed, the number of generations per year (voltinism) and how they overwinter, because these characteristics can influence the likely nature and extent of the response to a warming and more unstable climate (David and Daegan, 2016).

Diversity of plant material in polycultural systems often leads to lower pest intensities. Taxonomically related plant species have a tendency to share common pests. The host range of phytophagous insects has a bearing on the extent of infestation on different plants in the assemblage. Polyphagous pests inflict greater injury to plants in a mixed vegetation system compared with monophagous insect pests. Changes in microclimate in a land unit on which trees and crops are co-cultivated influence insect activity within the system. The masking effect of odors released by different plant species in polycultural systems such as those of agro-forestry interfere with insects' orientation abilities. The benefits of agroforestry and crop -crop diversity are evident due to *in situ* culturing of natural enemies and habitat manipulation which in turn changes the microclimate. Hoehn *et al.* (2009) examined population dynamics of the wasp, *Rhynchium haemorrhoidale,* and its natural enemies in relation to season, climate and varying shade tree composition in cacao agro-forestry systems. High wasp densities in the wet season were associated with high diversity of the parasitoid species.

Climate Change and Insect Pests

Insects are cold-blooded organisms - the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing their behavior, distribution, development, survival, and reproduction. Generally the impacts of CO_2 on insects are thought to be indirect through the changes in the host crop *i.e.,* the host mediated one. The information on influence of three major factors of climate change *i.e.,* temperature and carbon dioxide on insects is discussed here.

Temperature

Temperature is the predominant abiotic factor that directly affects insect growth, development and reproduction. Over most of the temperature range to which particular species are adapted, there is a positive linear relationship between growth rate and temperature. Development of the different stages of an insect's life cycle is usually quantified as the thermal sum above a minimum developmental temperature that is required for completion of the life cycle. In a warmer climate this sum is accumulated earlier in the season, allowing some species to complete additional generations. This will result in additional periods of feeding damage during the season and may result in an overall increase in insect abundance.

Elevated temperature is known to alter the phytochemistry of the host plants and affect the insect growth and development directly or indirectly through effect on host plants. The effect of temperature on different host plants is reviewed hereunder-Differential response was noticed due to elevation of temperature in different species. Temperature caused a decrease in foliar nitrogen in *Quercus robur*, increased in *Cardamine hirsuta*, *Poa annua, Senecio vulgaris* and *Spergula arvensis* and had no effect on red maple, *A. rubrum* and sugar maple, *A. saccharum*. The concentrations of Cinnamoylquinic acids decreased and Salidroside decreased in white birch, *Betula pendula* leaves under elevated temperature conditions. Leaf water content of sugar maple leaves declined and condensed tannin content increased in *Quercus robur* .With warmer temperatures, insect pests and plant diseases are expected to increase due to range expansion, higher winter survival, and increased number of generations per season.

Effects on Herbivore Insects

Temperature is identified as dominant abiotic factor directly affecting herbivorous insects. Temperature directly affects the development, survival and abundance of insects. The influence of elevated temperature on various insect species is presented below. Many insects have an obligatory dormant or diapause period during the winter, but in some insects dormancy is influenced by local temperatures. In warmer weather, therefore, insects that have a year-round food resource such as those that feed on wood or bark could develop throughout the year, benefitting from a projected increase in winter as well as spring and summer temperatures. Nevertheless, some insects such as the two spotted oak buprestid (*Agrilus biguttatus*), a beetle that exploits declining oak trees, have restricted ranges that may increase in a warmer climate. Where range extension increases the overlap between species attacking the same host, the risk of damage to trees may be increased. The green spruce aphid (*Elatobium abietinum*), a multi-voltine pest with the ability to respond strongly to rising temperatures is a pest on Norway spruce (*Picea abies*) and Sitka spruce (*Picea sitchensis*). The abundance and damage caused by these aphids and related insects is likely to increase under climate change. In particular: i. Higher temperatures will increase the reproductive rate and those species that have multiple generations or can remain active throughout the winter are likely to benefit most. ii. Moderate drought stress of host trees through changes in the spatial and seasonal distribution of rainfall will be favorable for some species. iii. An increase in 'aphid load' on conifers may increase vulnerability to bark beetle attack (David and Daegan, 2016).

There was no effect of elevated temperature except early pupation on larvae of winter moth, *Operophtera brumata* feeding on oak leaves, *Quercus robur*. Larval development and adult fecundity of *Operophtera brumata* was adversely affected by increased temperatures on *Quercus robur*. The long-term exposure to a 3.5°C increase in temperature shortened insect development but had no effect on pupal weight. The larvae reared on elevated CO_2 grown leaves had reduced growth. Development time of the beetles *Octotoma championi* and *Octotoma scabripennis* feeding on *Lantana camara* was accelerated by approximately 10-13 days at the higher temperature. There was substantial mortality of the larvae under high temperature/ ambient CO_2 treatment due to premature leaf loss by *Lantana camara*. The temperature enhancement increased the relative growth rate (RGR) of the larvae of chrysomelid beetle, *Phratora vitellinae* feeding on *S. myrsinifolia*. The information on impact of increased temperature on insect pests was given by Srinivasa Rao *et al.* (2013).

The mechanisms by which climate change could alter disturbance patterns from insects and pathogens include: direct effects on the development and survival of herbivores and pathogens; physiological changes in tree defenses; and indirect effects from changes in abundances of natural enemies, mutualists and competitors. The first mechanism will presumably be most important in the case of invading, non-native species. The short life cycles, physiological sensitivity to temperature, mobility, and reproductive potential will allow forest insects and diseases (native and non-native) to respond rapidly to climate change. Direct effects of climate change on forest pests are realized as increased survival rates due to predicted warmer winter temperatures, and increased developmental rates due to warmer summer temperatures.

Impacts of Elevated CO_2

Among the host plants, forest trees and grasses have been extensively studied for insect-plant interactions under elevated CO_2 (eCO_2). Few studies are available on cultivated crops. In majority of studies the eCO_2 mentioned ranged from 530 ppm to 1050 ppm. Nitrogen concentration decreased in European white birch, *Betula pendula*, quaking aspen *Populus tremuloides*, condensed tannin increased levels in European white birch trees, quaking aspen, tremulacin levels increased in birch trees. Starch concentration increased in paper birch and pine trees, *Pinus taeda*.

As in case of forest trees nitrogen decreased in many of the grasses except annual blue grass in which there was no effect on nitrogen concentration. In erect brome, *Brumus erectus*, vernal sedge, *Carex caryophylla* and Fescue, *Festuca* spp; eCO_2 concentration resulted in increase in nonstructural carbohydrates and condensed tannins. C: N ratio increased in red fesue, *Festuca rubra*. Similarly, a decrease in nitrogen was observed in cultivated plants like cotton, *Gossypium hirsutum*, mung bean, *Vigna radiata*, spring wheat, *Triticum aestivum* and birds foot trefoil, *Lotus corniculatus*. C: N ratio increased in cotton and birds foot trefoil. Starch concentration increased in mung bean, wheat and common beet, *Beta vulgaris*. There was an increase in sugars in mung bean, wheat and birds foot trefoil.

Host- Mediated Effect on Insects

The impact of *e*CO_2 on host plants and insects is comprehensively reviewed by the various authors (Hunter, 2001; Srinivasa Rao *et al.*, 2012). Among the orders of class insecta, Lepidoptera was mainly studied with gypsy moth *Lymantria dispar* and forest tent caterpillar, *Malacosoma distrria* were studied exclusively. Elevated CO_2 had negative effect on performance of gypsy moth, which was studied extensively on an array of trees. Relative growth rate declined by 30 per cent on sessile oak, *Quercus petraea* and it increased by 29 per cent on hornbeem, *Carpinus betulus*. Decline in relative growth rate was more on yellow birch, *Betula allegheniens* compared to gray birch, *Betula populifolia*. The pupal mass declined by 38 per cent under eCO_2 on gray birch while there was no effect on pupal mass on yellow birch. The differential response was attributed to greater decline in nutritional quality of yellow birch than gray birch. The studies conducted with forest tent caterpillar, *Malacosoma disstria* indicate that larval feeding varies with host plant. Faster development time and 20 per cent decrease in growth rate was observed on quaking aspen. Larvae preferred aspen to paper birch under *e*CO_2 conditions. No effect on the performance of the larvae was noticed on quaking aspen and white oak, *Quercus alba*. Slower larval growth, increased lipid concentration and higher number of ovaries were observed in small heath, *Coenonympha pamphilus* feeding on grasses. Increased consumption by common blue butterfly, *Polyommatus icarus* larvae, shorter development time and increased pupal weight were noticed when feeding on birds foot trefoil, *Lotus corniculatus*. Increased consumption by *Spodoptera* spp was observed on mung bean, *Vigna radiata*, upland cotton, *Gossypium hirsutum* and tall fescue, *Festuca arundinacea*. Greater larval survival on common beet, *Beta vulgaris*, longer development time on upland cotton

The family aphididae in this order was widely studied, and mixed response of aphids was reported under *e*CO_2. As is evident from the reviewed information, cotton aphid, *Aphis gossypii* fecundity significantly increased on cotton. Local populations of grain aphid, *Sitobion avenae* on spring wheat, *Triticum avenae* and green peach aphid, *Myzus persicae* on annual blue grass, *Poa annua* increased under *e*CO_2. *Myzus persicae* population on bittersweet (*Solanum dulcamara*) increased by 120 per cent. Spittle bug (*Neophilaenus lineatus*) nymphal population was reduced by 20 per cent and delayed development when they were fed with *e*CO_2 grown heath rush (*Juncus squarrosus*). Among five aphid-plant interactions tested there was no effect of *e*CO_2 on three aphid-host plant interactions. *Aphis nerii* on common milkweed (*Asclepias syriaca*), *Aphis oenotherae* on common evening primose (*Oenothera biennis*) and *Aulacorthum solani* on white shooting star (*Nicotiana sylvestris*).

Findings of ICAR-CRIDA

Several experiments were conducted using open top chamber (OTC) facility to study the impact of *e*CO_2 levels on insects of annual crops. Three square type open top chambers (OTC) of 4 x 4 x 4 m dimensions, were constructed at ICAR- CRIDA, Hyderabad, two for maintaining *e*CO_2 concentrations of 700±25 ppm CO_2 and 550±25 ppm CO_2 and one for ambient CO_2. An automatic CO_2 enrichment technology was developed by adapting software SCADA to accurately maintain the desired levels of CO_2 inside the OTCs. The concentration of CO_2 in the chambers was monitored by a non-dispersive infrared (NDIR) gas analyzer. Castor, groundnut, cowpea and chickpea plants were grown in the three OTCs and also in the open, outside the OTCs.

- Larval duration or time from hatching to pupation in larvae of both the species (*Achaea janata* and *Spodoptera litura*) was significantly influenced by the CO_2 condition under which castor leaves offered to them. Larval duration of both species was extended by about two days when fed with *e*CO_2 foliage (Srinivasa Rao *et al*., 2009). Larvae ingested significantly higher quantity (62.6 per cent) of *e*CO_2 foliage compared to ambient CO_2 foliage. The relative consumption rate (RCR) by larvae was also higher in case of *e*CO_2 foliage resulted in considerably increased ingestion.

- The efficiency of conversion of digested food into body mass (ECD) was lower with *e*CO_2 castor foliage for both species of larvae. The digestibility (AD) of eCO_2 foliage was significantly higher than ambient CO_2 foliage for both the species, more so in case of *Spodoptera litura* (Srinivasa Rao *et al.*, 2009).
- Significant influence of *e*CO_2 on life history parameters of *Spodoptera litura* on groundnut indicated that the percent variation of these parameters was significant under *e*CO_2 compared with ambient CO_2.
- The percent reduction of nitrogen content and increased percent of carbon, C: N ratio and TAE (Tannic acid equivalents) was significant in groundnut and castor foliage under *e*$CO_{2.}$
- Under elevated CO_2 conditions the increased population of aphids, *Aphis craccivora* was increased with reduced generation time on cowpea.
- *Helicoverpa armigera* larvae consumed higher amount of chickpea foliage resulting increased larval weights under eCO_2 conditions. These larvae extended their duration by two days.

Conclusion

The information on effects of eCO_2 and temperature on insect-plant interactions indicate that substantial changes in phytochemistry of plants was mentioned by several workers under changing climate conditions. Decreased nitrogen (N), tremulacin, increased tannin, starch levels led to reduction in nutritional quality in array of plants exposed. To compensate these changes the consumption rate of larvae increased. Differential response was observed among various guilds of insects. In class Insecta, lepidopterans and homopterans were studied exclusively. Decreased relative growth rate, prolonged development time in lepidoptera (leaf chewers), increased abundance and fecundity in homoptera (sap suckers) were reported. The response of natural enemies in tritrophic interactions and the role of diversified ploy cultures under climate change scenarios are yet to be further investigated.

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Chapter 24

Disease Dynamics in Response to Climate Change in Farming Systems

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Introduction

Agro ecological regions of India are characterized by varying farming systems. A farming systems (FS) approach ensures to use space (horizontal) and time (vertical) dimensions of farm management efficiently so that maximum output is realized per unit area of production. However, the models of FS are decided by the natural resource base of the region, food habits, operative market forces, and socio-economic backdrop of the farmers. The traditional farming systems of India have co-evolved with the mankind and got established with time tested farm husbandry systems. However, in recent years, various factors have influenced considerably the crops and cropping systems. A farming system is an understanding of various component biological systems to go together harmoniously and thereby establish a dynamic equilibrium.

Crops in different farming systems are sensitive to a variety of pathogens. Host-pathogen systems are modulated by environmental practices, crop husbandry and crop-crop interactions. Over period of time, these interactions have stabilized resulting in specific crop pathogen distribution patterns. However, increasing pressure on food security demanded increased agricultural output and there by disturbing the conventional equilibrium. Hence, the global agriculture started experiencing the outbreak of epidemics of crop diseases leading to severe losses. While this development took place on one side, the environmental pollution has become additional variable to be reckoned with which had changed climatic patterns resulting in extreme weather events impacting on all biological systems. In some African countries, yields from rain-fed agriculture - the predominant form of agriculture in Africa - could be reduced by 50 per cent by 2020. Additionally, agricultural production in many African countries is projected to be severely compromised especially in drylands. About 70 per cent of Africans depend directly on dry and sub-humid lands for their daily livelihoods. In an effort to coping with extreme weather events and climatic variability, farmers living in harsh environments have developed and/or inherited complex farming systems that have the potential to bring solutions to many uncertainties facing humanity in an era of climate change. These systems have been managed in ingenious ways, allowing small farming families to meet subsistence needs in the midst of environmental variability without depending much on modern agricultural technologies.

Frequent dabbling with farming systems coupled with global warming have their toll in host-pathogen interactions as well. The elevated CO_2 levels coupled with increasing temperatures do affect host-pathogen interactions. In order to understand these extremely complicated situations, there is a need to understand intra-farming system interactions, crop-pathogen interactions as influenced by these interactions and finally the impacts of natural enemies. With the involvement of so many biological parameters, there is a great need to dissect the interactions and understand relationships among various players involved. An effort is made in this lecture to understand dynamics.

Elevated CO_2 and Host-Pathogen Interactions

Under elevated CO_2 levels, the morpho-physiology of the crop plants is significantly influenced. The bulk of the available data clearly suggests that atmospheric CO_2 enrichment asserts its greatest positive influence on infected as opposed to healthy plants. This influence in turn will modulate the balance of co-evolution between the host and the pathogen as well as pathogen and biocontrol agent. Elevated carbon dioxide [ECO_2] and associated climate change have the potential to accelerate plant pathogen evolution, which may, in turn, affect virulence. Plant–pathogen interactions under increasing CO_2 concentrations have the potential to disrupt both agricultural and natural systems severely, yet the lack of experimental data and the subsequent ability to predict future outcomes constitutes a fundamental knowledge gap. Furthermore, nothing is known about the mechanistic bases of increasing pathogen aggressiveness. Under elevated CO_2 conditions, mobilization of resources into host resistance through various mechanisms such as reduced stomatal density and conductance, (Hibberd *et al*., 1996b); greater accumulation of carbohydrates in leaves; more waxes, extra layers of epidermal cells and increased fibre content (Owensby, 1994); greater number of mesophyll cells (Bowes, 1993); and increased biosynthesis of phenolics (Hartley *et al*., 2000), increased tannin content (Parsons *et al*., 2003) have been reported. Malmstrom and Field (1997) reported that CO_2 enrichment in oats may reduce losses of infected plants to drought and may enable yellow dwarf diseased plants to compete better with healthy neighbors. On the contrary, in tomato, the yields were at par (Jwa and Walling, 2001). Similarly, Tiedemann and Firsching (2000) reported yield enhancement in spring wheat infected with rust incubated under elevated CO_2 and ozone conditions. Chakraborty and Datta (2003) reported loss of aggressiveness of *Colletotrichum gloeosporioides* on *Stylosanthes scabra* over 25 infection cycles under elevated CO_2 conditions. On the contrary, pathogen fecundity increased due to altered canopy environment. McElrone *et al*. (2005) found that exponential growth rates of *Phyllosticta minima* were 17 per cent greater under elevated CO_2. Simultaneously, in the host *Acer rubrum*, the infection process was hampered due to stomatal conductance was reduced by 21-36 per cent and thereby leading to smaller openings for infecting germ tubes and altered leaf chemistry. Reduced incidence of Potato virus Y on tobacco (Matros *et al*., 2006), enhanced glyocellins (phytoalexins) after elicitation with ß-glucan in soybeans against stem canker (Braga *et al*., 2006) and reduced leafspot in stiff goldenrod due to reduced leaf nitrogen content that imparted resistance (Strengbom and Reich, 2006). Lake and Wade (2009) have shown that *Erysiphe cichoracearum* aggressiveness increased under elevated CO_2, together with changes in the leaf epidermal characteristics of the model plant *Arabidopsis thaliana*. Stomatal density, guard cell length, and trichome numbers on leaves developing post-infection are increased under ECO_2 in direct contrast to non-infected responses. As many plant pathogens utilize epidermal features for successful infection, these responses provide a positive feedback mechanism facilitating an enhanced susceptibility of newly developed leaves to further pathogen attack. Furthermore, screening of resistant and susceptible ecotypes suggests inherent differences in epidermal responses to elevated CO_2. Gamper *et al*. (2004) noted that colonization levels of arbuscular mycorrhizae tended to be high and on *Lolium perenne* and *Trifolium repens* which may help in increased protection against stresses.

Impacts of Elevated Temperature and High Intensity Rainfall

Hannukkala *et al.* (2007) have reported increased and early occurrence of epidemics of late blight of potato in Finland due to climate change and lack of crop rotation. Under drought stress, the disease symptoms may be reduced but at the same time the resistance of the host can also be modified thus leading to higher disease incidence. Drought impacted disease resistant plant types showed loss of resistance. Some pathogens could also enhance their ability to exhibit variability with which their fitness to the changed environment is enabled. Such kind of variability has also been suggested as an early indicator of environmental change because of their short generation times.

Plant Diseases and Farming Systems

Models on plant diseases indicate that climate change could alter stages and rates of development of certain pathogens, modify host resistance, and result in changes in the physiology of host-pathogen interactions. The most likely consequences are shifts in the geographical distribution of host and pathogen and increased crop losses, caused in part by changes in the efficacy of control strategies. Altered wind patterns may change the spread of bacteria and fungi that are the agents of wind-borne plant diseases. The limited literature in this area suggests that the most likely impact of climate change will be felt in three areas: in losses from plant diseases, in the efficacy of disease management strategies and in the geographical distribution of plant diseases. Climate change could have positive, negative or no impact on individual plant diseases, but with increased temperatures and humidity many pathogens are predicted to increase in severity.

The crop-crop interactions in farming systems have a substantial role in deciding the plant-pathogen interactions of that system. In cropping systems perspective, the host range of pathogens could matter a lot as compared to specific host-pathogen interaction. Pathogens like *Alternaria* with wide host range could be devastating as they could harbor more than one host and so could easily perpetuate. On the other hand, there is a possibility of shifts in obligate pathogen distributions which need specific hosts. While drought and high temperature conditions could be helpful to pathogens such as *Macrophomina* which proliferate under these conditions, wet and high intense rainfall conditions may be conducive for *Phytophthora* and *Pythium*. Dry conditions The possible increases in pest and disease infestations may bring about greater use of chemical pesticides to control them, a situation that may enhance production costs and also increase environmental problems associated with agrochemical use. Of course, this may not be the case with farmers who use polycultures, agroforestry or other forms of diversified cropping systems that prevent insect pest buildup either because one crop may be planted as a diversionary host, protecting other, more susceptible or more economically valuable crops from serious damage, or because crops grown simultaneously enhance the abundance of predators and parasites which provide biological suppression of pest densities.

Adaptation Strategies and Research Needs

The adaptation strategies considering the scenarios above would necessarily include a revisit package of practices for management of diseases. A multi-pronged approach to manage disease in crop communities should include continuous survey and surveillance which will help in recording shifts in pathogen distribution patterns. The time-tested physical and cultural practices for management diseases should be improvised for increasing their efficacy. Germplasm evaluation must be given a high priority to identify sources of resistance to alien pathogens. For instance, UG99a race of wheat stem rust is alien to India and any time, it can attack the wheat populations in India which do not have resistance against this race. However, the early efforts taken in India have yielded fruitful results in developing resistant wheat varieties that can withstand onslaught of this race in future. Such preparedness is more so required in perennial horticultural crops where developing a variety needs more time than in annual field crops. Novel molecules with broad spectrum efficacy based on modern science tools such as proteomics etc. against plant pathogens have been identified and such efforts should be future thrust areas. Care must be taken while introducing new plant types either at international or at domestic level with proper pre- and post-quarantining so that alien species are not introduced.

Management of natural enemies is another vital area to be focused. With the recent advances in biocontrol research, potential formulations have been developed and successfully deployed at farmer level for management of stubborn pathogens like *Sclerotium rolfsii*, *Rhizoctonia solani* etc which are causing potential crop losses. During last decade, plant-pathogen-natural enemy tritrophic interactions have been better understood as compared to early days of biological control and they could be exploited for integrated crop health management. Species of *Trichoderma*, *Pseudomonas*, *Bacillus*, and *Glomus* etc. have been well characterized for their ability to suppress plant pathogens, promote plant growth, supplement nutrients and induce disease resistance.

Impact of climate change on plant diseases is poorly understood due to the paucity of studies in this area. Research has started only recently to understand the impacts of climate change on agricultural systems. Under these conditions, adding farming systems perspective will be challenging but is required. A process-based approach is required to quantify the impact on pathogen/disease cycle and is potentially the most useful in defining the impact of elevated CO_2 on plant diseases. The projections for the future depict that appropriate adaptation and mitigation strategies should be developed to meet worst possible scenarios. In view of the variable changes in pathogen behavior at elevated levels of atmospheric CO_2, it is difficult to know the ultimate outcome for specific host-pathogen relationships. More research, especially under near realistic field conditions, will be needed to clarify the situation; and, of course, different results are likely to be observed for different host-pathogen associations. Similarly, the relationships between biocontrol agents and the pathogens need to be studied in relation to enhanced CO_2 to assimilate the ultimate effects on a systems basis for different climatic conditions.

Conclusion

Over the centuries, generations of farmers and herders have developed complex, diverse and locally adapted agricultural systems, managed with time-tested, ingenious combinations of techniques and practices that lead to community food security and the conservation of natural resources and biodiversity. Observations of agricultural performance after extreme climatic events in the last two decades have revealed that resiliency to climate disasters is closely linked to levels of farm biodiversity. In summary, farming systems are influenced by climate change and so crop-pathogen-natural enemy interactions. To understand these dynamics, there is a need for basic, strategic and anticipated research on various aspects of host-pathogen interactions including disease development in populations. Simulation of models with future climatic conditions will help to identify emerging diseases including alien species. However, care must be taken to understand emerging farming systems and thereby deducing probable disease scenarios. The available data clearly suggests that atmospheric CO_2 enrichment asserts its greatest positive influence on *infected* as opposed to *healthy* plants. Moreover, it would appear that elevated CO_2 has the ability to significantly ameliorate the deleterious effects of various stresses imposed upon plants by numerous pathogenic invaders. Consequently, as the atmosphere's CO_2 concentration continues its upward climb, earth's vegetation should be increasingly better equipped to successfully deal with pathogenic organisms and the damage they have traditionally done to mankind's crops, as well as to the plants that sustain the rest of the planet's animal life.

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Chapter 25

Climate Smart Farm Machinery for Agroforestry

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Introduction

Establishment of Agroforestry system needs some of the field operations similar to the field cropping system. Apart from this, the land configuration also demands use some of the heavy machinery for land preparation operations. Coupled by this, the cultivation of field crops is also a common practice in this module. Hence it is necessary to reduce the direct and indirect Green house Gas emissions with least disturbance to the soil apart from increasing the energy efficiency in the system. Land preparation is the major activity in which some of the high power machinery like earth mowers, excavators and other leveling equipment are normally used which produces more emissions. The other operations like soil and water conservation, digging, land management, trenching, sowing, weeding, pest and disease control and harvesting are the main contributes of emissions.

Development of every Agroforestry system involves specific operational requirements based on the trees and field crops selected. However, all these systems contain some of the common operations like land development, digging and planting which uses medium to heavy farm implements. Hence the emission reduction from the utilization of direct and indirect energy on field plays a vital role in mitigating the climate change. Adoption of recommended management practices for agriculture involves off-farm or external input which are carbon (C)-based operations and products (Pimentel, 1992; Marland *et al.*, 2003). Production, formulation, storage, distribution of these inputs and application with tractor drawn equipment lead to combustion of fossil fuel, and use of energy from alternate sources, which also emits CO_2 and other greenhouse gases (GHGs) into the atmosphere. Thus, an understanding of the emissions expressed in kilograms of carbon equivalent (kg CE) for different farming operations, and usage of different inputs and their saving when different farm implements used makes key contribution for energy conservation. The other way, promoting biofuels and renewable energy sources will definitely help in developing the clean environment.

Off late, residue management and conservation agriculture between the tree plantations is gaining importance as one of the mitigation options. With reference to C emissions, agricultural practices may be grouped into primary, secondary and tertiary sources (Gifford, 1984). Primary sources of C emissions are either due to mobile operations (*e.g.*, tillage, sowing, harvesting and transport) or stationary operations (*e.g.*, pumping water, grain drying). Secondary sources of C emission comprise manufacturing, packaging and storing fertilizers and pesticides. Tertiary sources of C emission include acquisition of raw materials and fabrication of equipment and farm buildings, etc. Therefore, reducing emissions implies enhancing use efficiency of all these inputs by decreasing losses, and using other C-efficient alternatives. The fuel requirement increases with increase in depth of plowing and tractor speed (Collins *et al.,* 1976), and also differs among the type of equipment used. The direct fuel consumption is also more for heavy than light- textured soils, and increases with increase in soil's cone index (Collins *et al.*, 1976). Koller (1996) reported that the diesel fuel consumption was 49.4 l/ha for moldboard plow, 31.3 l/ha for chisel plow, 28.4

l/ha for disk plow, 25.2 l/ha for ridge plant and 13.4 l/ ha for no-till system of seedbed preparation. Thus, reduction in fuel consumption in comparison with plow-based tillage system was 37 per cent for chisel plow, 43 per cent for disk plow, 49 per cent for ridge plant and 73 per cent for no-till.

Many of the agroforestry systems like amla + field crop, Tamarind + field crop, *Eucalyptus* + field crop and forestry tree + fodder crop needs various types of farm machinery from plantation to harvest. However, the selection of suitable machinery available nearby locations plays a key role in maximizing the benefits. In addition to this, present scenario pushes us to go for climate smart machinery keeping the cost of operations in view. As the review indicates that the land preparation and tillage operations uses higher amount of energy compared to the other operations which in turn produces more GHG emissions, it is better to curtail the tillage operations as much as possible. Reduced tillage is wide-ranging concept which requires detailed specification of the actual methods and machinery components appropriate for individual situations. Selection of tillage implements mostly depends on the type of soil in which we operate. The soil tool interaction not only effects on the energy input, it also influences the crop growth. This has been observed in the rainfed cropping systems, where the moisture conservation is much sought after the land preparation. The general strategy of reduced tillage aims at increasing the decomposition of straw and stubble residue by using a shallow stubble cultivator immediately after harvest. For the semi arid regions of Indian conditions maintaining the straw in the field becomes difficult as the fodder value of many of the rainfed crops interferes with the prime objective of reduced cultivation. In normal course, farmers are advised or rather choose to go for agro forestry where ever the soil conditions inhibit them to choose normal crop. Hence many of the soils are undulated or degraded or hard in nature for which the selection of implements becomes a challenge. Often, using a heavy earth moving equipment and leveling machinery which uses 75-200 h.p. power becomes necessary for the land development activities at initial stage. It necessitates consuming 15 litre to 50 litre of diesel in one hour based on the operation. It means that the single operation emits 40.5 to 220.0 kg of CO_2/hour. The other operations like digging pits and basing making for forestry plants consumes 30 to 45 litres/hour where the tractor drawn hole diggers and other equipment are used. It is estimated that the average consumption of diesel attributed to arable farming is 107 l/ha, represting a CO_2 emission of 284 kg/ha Hence the inter crop in between the forestry plants also contributes significant of emissions. In this context, By reducing the number of machinery operations for soil preparation, the emissions can also be reduced. A study (Wiedemann *et al.,* 1986) aimed to reduce the number of tillage passes by adapting the tractor and implements and optimizing the overall driving pattern in the field showed that a 35 per cent reduction in fuel consumption as well as a 27 per cent reduction in the power requirement when cultivating cotton in Texas.

Apart from reducing the farming operations, it is also necessary to cut down the inputs like fertilizer, herbicides and pesticides which uses considerable amount of direct and indirect energy. Adopting the latest agronomical recommendations like ridge and furrow farming, paired row forming, broad bed furrow system and permanent bed planting system not only brings down the energy usages at farm level, they also increases the input use efficiency very significantly besides contributing to the reduction in emission levels. This article discusses some of the available climate smart farm machinery suitable for the Indian conditions.

Land Preparation Activities

Manipulation of land to make it suitable for agroforestry is the first step in the series of farming operations. Using low energy excavators suitable to the land conditions always a big challenge during the selection. The farmers often go for high input energy based equipment because of non availability. It is better to follow the contour trenching or bunding in the agroforestry farms without much disturbance to the natural soil conditions. Laser land levers are advised for the less sloppy land to conserve the water. Self propelled and Tractor drawn levelers can do the operation with low energy input compared to the big earth moving equipment.

Tillage Equipment

Most of primary tillage implements such as m.b. plough, disc plough are two bottom type and are suitable for 25-35 hp size tractor. Three bottom implements are suitable for 35-45 hp size tractors. Field capacity varies from 0.2 to 0.3 ha/h for plough (for single bottom) and 0.4- 0.5 ha/h for disc harrows. Depth of operation is in the range of 100-150mm. As the size of the tractor increases, the emission level at field is liable to increase.

Bed-Furrow Formers

Though animal drawn bed –furrow formers are available, their efficiency is very less. The tractor drawn be-furrow former (Fig 25.1) is capable of forming alternate beds and channels. It saves 90 per cent of labour. These beds are suitable for planting crops like sorghum maize, cotton. This seedbed and furrow system is ideal for efficient irrigation management. It conserves the water apart from making the ideal seed bed. This single tool reduces extra operations of making beds after conventional tillage.

Fig 25.1 Tractor drawn bed and furrow farmer

Rotavators and Residue Incorporation Implements

Rotavators (Fig 25.2) are best suitable for pulverization of the soil after primary tillage and also for incorporating the residue which is left in the ground as well as green residue if any grown on the surface of the soils. Field capacity of the rotavator is around 0.45-0.65 ha/hr. It is driven by the tractor PTO shft. Blades with different shapes can be used in the rotavator. A 35-hp tractor can be sufficient enough to use these implements. A rotavator always play role in reduction emissions on a well maintained land by reducing the number of operation required in primary and secondary tillage. It is estimated that if properly operated, it saves 30 per cent energy during tillage when compared to the conventional method.

Fig 25.2 Residue incorporation with rotavator

Sowing Equipment for Inter Cropping in Agroforestry Model

The basic objective of sowing operation is to put the seed and fertilizer in rows at desired depth and seed to seed spacing, cover the seeds with soil and provide proper compaction over the seed. The recommended row to row spacing, seed rate, , seed to seed spacing and depth of seed placement vary from crop to crop and for different agro-climatic conditions to achieve optimum yields.

Normally seed drills are needed to maintain the timeliness and precision application of seed and fertilizer to get the higher productivity and profitability. These seed cum fertilizer drill reduces the labour cost, covers more area per hour and reduces the input cost. Studies show that the yields are increased by 20 -25 per cent and 40-50 per cent of saving is observed in labour cost. Planting machinery can be powered by bullock or tractor or self propelled machinery.

Functions of the seed drill:

1. Meter seeds of different sizes and shapes
2. Place the seed in the acceptable pattern of distribution in the field
3. Place the seed accurately and uniformly at the desired depth in the soil
4. Cover the seed and compact the soil around it to enhance germination and emergence.

Different types of seed cum fertilizer drills are available in the market. Some of the seed drills opens the soil with 10-15 cm furrow and others work on the basis of low till, reduced till drill, strip till drill and precision planter concepts.

Three Row Bullock Drawn Planter

It is recommended for the small farms where the operational size of land holding is very small. The seed falls in a narrow furrow formed by the soil opener. As there is no direct fuel energy involved in the operation, it may be recommended for conservation farming between the agroforestry plantations. It can cover 0.1 -0.15 ha/ hour with 30 per cent seed and 15 per cent fertilizer saving.

Tractor Drawn 6- Row Planter

This equipment (Fig 25.3) is most suitable for the medium to large size farms. It is also used in small farms often to meet the labour scarcity during the peak season. It can cover 0.4 -0.6 ha/hour apart from contributing to seed and fertilizer saving. It is observed that the yields are improved by 15 to 30 per cent because of timeliness and precision in operation. Since it uses the inclined plate seed metering mechanism, we need a separate plate for each crop. This also enables us to change the required crop geometry by modifying the metering plate design to suit the farmer need based on the location or crop requirement. The fuel requirement may vary from 2.5 to 3.5 litre diesel.

Fig 25.3 CRIDA 6-row planter

No-Till and Strip Till Drills

No till and strip till drills play a key role in conservation agriculture there by reduction in emissions. It is observed that the soil continues to emit the GHGs if disturbed. Hence the reduced or no opening brings down the emission levels significantly. Usage of the No-till or strip till drill limits the opening of soil to very minimum levels there by gives the scope for residue cover on the soil surface. No-till drill makes a narrow slit in the soil in which the seed and fertilizer are dropped at recommended depth. Strip till drill makes a small strip in which a small furrow openers keeps the seed and fertilizer in the soil. Both the mechanisms are climate friendly if operated properly. It is estimated from the field trials that 15-25 per cent emissions are reduced with the reduced and zero tillage in many of the cropping system. However, both mechanisms are selectively used in rainfed cropping systems with proper maintenance of soil and residue.

Precision Planter cum Herbicide Applicator

As the labour is becoming very expensive input during the present scenario, farmers are choosing to till their lands heavily to avoid the weed problems at least for 30 to 40 days after sowing. This makes them to go for 3 to 4 tillage operations and 2 interculture operations which is consuming more energy apart from increase in operational cost. In addition to that many of the rainfed farms are two way undulated in nature for which proper leveling is needed. Hence it adds to increase in energy apart from removing the top soil in many places which finally effects the germination. In this context a separate planter by combining the herbicide application, seeding and fertilizer placement operations is designed and tested in the field. The machine mainly consists of rigid frame attached with individual seed cum fertilizer boxes on the top and spring loaded swinging type tynes with slit type furrow openers at the bottom to open the soil very narrowly in which the seed and fertilizer are dropped at the recommended spacing and depth (Fig.25.4). The seed is dropped with the help of a well controlled inclined plate seed metering mechanism and the fertilizer is dropped with a spring auger. The herbicide is stored in a tank mounted on the rigid frame. A pump with 150 w capacity gets the power from an inverter which in turn gets the power from the battery. The nozzles mounted on a pipe behind the planter sprays the adjusted dose of herbicide all along the width of the planter. It is observed that the 30 per cent energy saving is observed in all these three operations because of least disturbance to the soil and herbicide application along with sowing.

Fig 25.4 Precision planter cum herbicide applicator

Raised Bed and Ridger Planters for Resource Conservation

It is always preferred to conserve the resources in farming system to reduce the emissions. Hence the ridge and furrow technique always has high priority in rainfed farming which conserves the water and also saves the energy in other operations. It is always advised to sow the seeds in permanent beds in which lot of resources are conserved. We can harvest the rainwater during season and the furrows can also be used as drainage channels to pull out the excess rain water during heavy down pours. CRIDA has developed one such type of ridger planter (Fig 25.5) which is specifically designed to meet the requirements of Rainfed Agriculture in which the soil and water conservation plays a major role in crop production. This helps in in-situ rain water at on farm level during the season apart from sowing the seed and placing the fertilizer on the ridges at proper depth and placement. The broad furrows formed by the planter helps in conserving the rain water during the season and also work as drainage channels to drain out the excess water if heavy downpour occurs to save the crop during the initial drought and from excess flooding. The ridger planter was successfully used for sowing th e castor, groundnut, maize, sorghum and cotton. It is observed that the yields are increased by 15 per cent with the ridger planter when compared to the conventional sowing.

Fig 25.5 CRIDA 3-row ridger planter

Weeding and Interculture Equipment

It is always better to use the low doses and herbicide to control the weeds so that the energy requirement for the weeding operations is minimized. However, tractor drawn power weeders are also available which uses the lesser energy compared to multiple tillage operations which are normally done to control the weeds. Rotary weeder (Fig 25.6) is one such type of example which reduces the number of weeding and earthing operations in the field. It is always recommended to use low width tractor tyres to control the weeds in low row to row spacing crops.

Fig 25.6 Rotary power weeder (courtesy: NRC soyabean)

Plant Protection

Fig 25.7 Orchard sprayer in operation

Plant protection operation uses the direct and indirect energy in the field. Hence it is always advised to save the pesticide and cover the crop canopy in lesser time to save the fuel there by emissions. Hence it is recommended to use the high coverage sprayers like boom or Orchad sprayers. Row crop sprayers are recommended to control the pest incidence in inter -crop between the agroforestry plantations. Orchad sprayer (Fig 25.7) alone will save the 30 per cent pesticide by covering the entire crop canopy minimum size droplets.

Harvesting

Usage of combine harvesters is becoming popular because of labour scarcity in many areas. These heavy machinery uses higher powered tractors are self propelled systems which consumes lot of energy. In this context, using small scale self propelled reapers are to be encouraged in the field to save considerable amount of energy.

Overall, it can be concluded that the reduction in emission is only possible by reducing the number of farm operations apart from selection of suitable low energy farm machinery. Considerable efforts in resource conservation play a major role in reducing the indirect energy input in the agroforestry system. This can only possible with understanding the intricacies machinery needs at on farm level and their energy input apart from precision levels of the operational requirement.

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Chapter 26

Agroforestry and *Eucalyptus* Plantation: Its Social, Economic and Environmental Impacts

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Introduction

To meet growing wood requirement, Forest Departments, Forest Development Corporations and Pulp and Paper industry joined hands together, leading to creation of a sustainable wood resource base of more than 3 Mha of plantations in last 25 years. This is achieved mainly by raising plantations on farm lands under farm / agro forestry models promoted by Paper Industry, 70 per cent of which is *Eucalyptus* plantation. This could be made possible by massive investment of resources by the industry and the Corporations, to bring in genetic improvement and development of highly productive and disease resistant clones, which increased plantation productivity by more than 400 per cent, making these plantations extremely viable for farmers, in terms of competitive land use. Multiplication of clonal plants to raise *Eucalyptus* farm /agro forestry plantation, is done with root trainer technology, which promotes lateral root system / multiple root system (V/s tap root system of seed based plants).

Every year approximately 1.5 lakh ha of *Eucalyptus* plantation are raised in India, creating around 70 million man day's employment in the rural areas. As per Agarwal and Saxena (2017), *Eucalyptus* plantation yields more net income/ha/annum to farmers than almost 60-70 per cent of the agriculture crops, and can play a major role in increasing future farm level income, on the back of new productive clones, under development by the industry. *Eucalyptus* plantation water use has been found to be 785 litres/kg of total biomass, which is one of the lowest if we compare with tree species such as *Acacia* (1323 litres/kg), *Dalbergia* (1484 litres/kg) and agricultural crops such as Paddy Rice (2000 litres/kg), Cotton (3200 litres/kg).

***Eucalyptus* clonal plantation**

Clonal Technology and Root Structure

Eucalyptus clonal plantations are fast growing and high yielding due to its site specific selection and insect-pest and disease resistant. ITC has developed more than 100 high yielding, site specific and disease resistant clones of *Eucalyptus* which are grown throughout the length and breadth of India. *Eucalyptus* clonal plantation has a root depth of 1.5-2.0 meter on an average and the root system is more specifically adapted to using rain-fed soil moisture from the upper soil profile, rather than from the groundwater table at considerable depth. Also, *Eucalyptus* is not a water intensive species and does not drain waterlogged areas, as indicated by plantations raised in such areas in UP.

***Eucalyptus* clonal root system**

Water Consumption by *Eucalyptus*

Sharma *et al.* (1984) states that: *Eucalyptus* is a xerophytic species, i.e. plant adapted to life in a dry or physiologically dry habitat by means of mechanism to prevent water loss and as such has low rates of transpiration. Further, *Eucalyptus* has the ability to tolerate water stress by way of regulating its photosynthetic rate in the green leaves, thus, it can survive with less available water. It may be noted that when it does not rain and the other trees turn yellow and parched, the *Eucalyptus* stays green not because it has enormous reserves of water which is hoarded, but because it shuts off the stomas, and does not allow the water to escape through them. In other words, *Eucalyptus* does not lose as much water by way of transpiration as other trees.

Environmental Impact

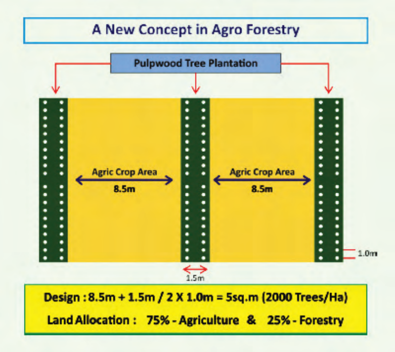
Report published by Patil, (1995) mentions that:

- *Eucalyptus* does not compete for ground water and other nutrients with crops in its vicinity
- *Eucalyptus* does not need plenty of water and does not drain away subsoil water
- *Eucalyptus* does not cause degradation of land and does not hamper soil fertility

It is therefore critical that *Eucalyptus* plantations are raised, given its significant impact on wood availability, livelihood generation and carbon sequestration that addresses the challenges of global warming and climate change. It would be important to note that *Eucalyptus* plantations under the Farm forestry / Agro forestry models are not guzzlers of water as has been wrongly perceived by few ill-informed people.

A New Concept in Agroforestry

ITC PSPD is promoting wider spacing agroforestry models to sustain farm profitability since land is limited and converting farm lands in to block plantations will have negative impact on Nations food security. These innovative models are developed taking into consideration the wood and food security. In this model 75 per cent of land is allocated to agriculture crop and 25 per cent to forestry plantation. By adopting these design farmers can harvest the same wood yield as in block plantation from an acre and agriculture crop will be a bonus. This novel concept in agroforestry is based on paired row design. Two rows of *Eucalyptus* are planted at 1.5m with tree to tree spacing of 1m in the lines. Two pairs of *Eucalyptus* are placed at 8.5m apart to create sufficient room for agriculture crop cultivation independently. In this wider spacing paired row design farmer can grow agriculture crop successfully throughout 4 years of cycle without much impact on its yield. This model can definitely improve farm profitability on sustainable basis. A few pictures of real plantations are shared below.



Bund Planting – Value Addition

Farmers are encouraged to raise *Eucalyptus* plantations on farm boundaries and field bunds to generate additional income without any effect on regular agricultural crop production.

The ideal tree spacing in paired row planting on bunds is one meter between the rows and two meters from tree to tree. In this way 100 trees can be grown on 100 m long bund. Spacing in single line tree planting on farm boundaries should be 2.0 m from tree to tree.

Benefits of Agroforestry Plantation

1. Improved productivity and profitability of farm lands
2. Increased diversity in farm lands usage
3. No additional inputs required for tree growth
4. Land use throughout the year in rain-fed conditions
5. Trees act as insect barriers
6. Higher carbon sequestration
7. Reduced risk due to Crop failure or Natural Disasters
8. Higher economic returns to the farmers
9. Contributing to the food and wood security
10. Mitigating the climate change

Eucalyptus Plantation – Recent Developments

Order dated 23.02.17 by Karnataka Government has banned growing of *Eucalyptus* plantations in private land in the State, including the plantations under farm forestry and agro forestry. Under pressure of ill-informed people, similar move has been started in the states of Kerala and Tamil Nadu. These actions would have severe social, economic, industrial and environmental consequences and would also go against the objectives of National Forest Policy, 1988 as well as National Agroforestry Policy, 2014.

***Eucalyptus* with Chilli**

***Eucalyptus* with Cotton**

Suggestion (Ministry of Environment and Forests directions)

Based on the presentation of the studies and facts mentioned below by IPMA, Ministry of Environment and Forests vide its letter dated 08.06.2017, has directed the Karnataka Government to reconsider its decision of banning *Eucalyptus* plantation as there are no concrete studies to conclusively establish ill effects of plantation of *Eucalyptus*. In fact, many studies have pointed out that *Eucalyptus* plantations do not absorb ground water and has no adverse impact on water table.

National Green Tribunal Observation

National Green Tribunal (NGT) in its order dated 20th July, 2015 in Original Application No.9 of 2014, in para31 stated that based on studies conducted in different countries, growing of *Eucalyptus*, one of the major farm forestry species, has no adverse environmental impact nor is it disastrous for water table, as it consumes less water per Kg of total biomass generated vs. many tree and agricultural crops as indicated above.

***Eucalyptus* with Maize**

***Eucalyptus* with Banana – Paired Row**

***Eucalyptus* with Watermelon**

***Eucalyptus* with Wheat**

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Chapter 27

Agroforestry Systems for Climate Resilient Small Ruminant Production in Rainfed Areas

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Introduction

Climate change with increased variability in rainfall pattern is not only aggravating the challenges that farmers are already facing in rainfed areas, but also putting people in new situations never faced before. However, rainfed agro-ecosystem has a distinct place in Indian agriculture, occupying 67 per cent of the cultivated area, contributing 44 per cent of the food grains and supporting 40 per cent of the human and 65 per cent of the livestock population (Venkateswarlu, 2005). The farming systems in these areas are quite diverse with a variety of crops, cropping systems, agroforestry, horticulture and livestock production. Among the livestock, small ruminants are very important resources and contribute meat, milk, fiber and other functions that are significant to the productivity, stability and sustenance of many farming systems more so on dry lands. These animals are primarily maintained on natural pasture lands / waste lands with *in situ* grazing and the productivity is constrained by the low quality of native grasses as well as the shortage of good quality forage, especially during the dry season. Tree leaves and pods have been traditionally used as source of feed for livestock in Asia, Africa and the Pacific and serves as protein banks to supplement grass or crop residues in dry season (Bhatta *et al*., 2005). In general, farmers develop plantation trees for timber and orchards for fresh fruit production and the inter tree spaces are not considered as potential grazing resources. Hence, it is vital to develop agroforestry systems or models by introducing trees/shrubs into natural pasturelands/waste lands and pastures in fruit/ timber plantations in order to provide nutritious feed and fodder throughout the year (Singh, 1995) and thereby increase resilience of animal based production systems in rainfed areas, where crop production is a risk-prone enterprise due to uncertain rainfall and frequent draughts. Agroforestry diversifies the environmental and economic functions of small scale farming systems, and is therefore considered more resilient than monocropping to external stress (Simelton and Hoang, 2011). The important elements of animal based agroforestry systems that can play a significant role in the adaptation to climate change include opportunities for diversification of the agricultural systems, improving use efficiency of soil, water and other natural resources, contributing to soil organic buildup, reducing carbon emissions and increasing sequestration.

There are three core animal based integrated land use management agroforestry systems, where in agricultural crops, horticultural / forest tree species and or livestock are simultaneously developed on the same unit of land, which results in an increase of overall production.

1. Silvipastoral system (Forestry + Pasture + Livestock)
2. Agrisilvipastoral system (Agriculture + Forestry + Pasture + Livestock)
3. Horti-pastoral system (Orchards+ Pasture+ Livestock)

These (Silvipasture and Agrisilvipastoral) systems are otherwise called as "Animal agroforestry" a generic name for all agroforestry systems that includes livestock as component.

Silvipastoral system, where in the inter spaces between forest trees species are utilized for cultivation of grasses and grass legume mixtures, which provides a two tier grazing under *in situ*. During rainy seasons the animals prefer to graze green grass, but during dry seasons when there is no blade of grass available, they utilize foliage of the trees along with stock piled forage.

Agrisilvipastoral system, where in agricultural crops, forest tree species and grass are grown on the same land simultaneously, which provides food to the farmer and feed and fodder to the livestock. During cropping seasons the animals are fed with stored straw (hay) and supplemented with grass and foliage of the trees.

Horti-pastoral system, where in the inter spaces between fruit trees species are utilized for cultivation of grasses and grass legume mixtures. Only during dormant season of the fruit tree, the livestock are allowed to graze on the available pasture for a period of 4-5 months in a year.

Grass, Shrub and Tree Species for Development of Agroforestry Systems

Many species make excellent fodder tree components, but those species establish readily, grow fast, out-compete weeds, produce high-quality fodder, remain productive under repeated harvest, remain productive during dry seasons, survive on poor soils, tolerance to shading and drought should be selected. The following considerations should be kept in view for increasing the productivity from different Agroforestry Systems.

Arid Desert and Sand Dunes

About 30 Mha area under arid zone of the Thar desert is sandy plains, sandy hummocks and sand dunes. The forage production from these areas can be increased from 0.50 to 3.6 t/ha by growing suitable grasses (*Lasiurus sindicus, Cenchrus ciliaris, Cenchrus setigerus*), legumes *(Clitoria ternatea, Lablab purpureus, Atylosia scarabaeoides*), shrubs (*Ziziphus nummularia*) and trees *(Prosopis cineraria, Prosopis juliflora, Azadirachta indica* and *Acacia tortilis*) with improved management practices.

Semi-Arid, Rocky and Gravelly Areas

A vast area of the country comes under semi-arid zones, where lot of area is rocky and gravelly. Simple management practices *viz.*, protection and eradication of bushes increased production of grasslands from 0.80 t/ha to 3.5 t/ha and introduction of legumes (*Atylosia scarabaeoides, Stylosanthes hamata, Stylosanthes humilis, Macroptilium atropurpureum, Macroptilium lathyroides, Lablab purpureus*) in natural grassland (*Heteropogon contortus and Schima nervosum*) further, increased production from little over 3 t/ha to 5 t/ha. The suitable tree species found in this region were *Hardiwickia binata, Albizia amara, Albizia lebbeck, Albizia procera, Dalbergia sissoo, Leucaena leucocephala, Acacia tortilis, Dichrostachys cinerea, Emblica officinalis, Ziziphus mauritiana and Aegle marmelos*.

Cold Desert

About 10 Mha cold desert lies in the north of Great Himalayas and have only short-lived species, which provide 1-2 months grazing during summer. Several indigenous species of grasses (*Agropyron, Agrostis, Alopecurus, Bromus, Cicer, Lespedeza, Lotus, Medicago, Melilotus, Trifolium*, etc. spp) are found in Ladakh region. Recently a potential hay species namely *Pronges pabularis* is identified and able to produce 1 to 1.5 t/ha with 10.4 per cent protein.

Ravine Soils

About 4 Mha area is ravenous and confined largely to the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat, which could be developed as silvopastoral systems by introducing different grasses (*Cenchrus spp., Panicum antidotale, Pennisetum pedicellatum and Dichanthium annulatum*), legumes (*Macroptilium atropurpureum, Clitoria ternatea, Atylosia scarabaeoides, Alysicarpus monilifer, Stizolobium deeringianum*), bushes (*Dichrostachys species, Ziziphus nummularia, Capparis zeylanica*), and trees (*Acacia spp., Ficus spp. Dendrocalamus strictus, Prosopis cineraria, Dalbergia sissoo, Bauhinia purpurea*).

Saline Sodic Soils

About 8 Mha area is affected by salinity and alkalinity in different parts of India. These soils can be developed as silvopastoral models by introducing salt tolerant grasses (*Brachiaria mutica, Diplachea fusca, Iseilema laxum, Paspalum notatum, Paspalum dilatatum, Bothriochloa intermedia, Chloris guayana, Sporobolus marginatus, Cynodon dactylon, Panicum maximum*), legumes (*Rhynchosia minima, Clitoria ternatea, Mimosa invisa, Macroptilium atropurpureum*) and shrubs (*Sesbania, Atriplex, Acacia* and *Albizia spp.*).

Acidic Soils

Acidic soils are most commonly seen in eastern states of India and these can be suitably developed as silvopastoral models by introduction of grasses (*Pennisetum polystachyon, Pennisetum pedicellatum, Pennisetum clandestinum, Paspalum notatum*), legumes (*Centrosema pubescens, Stylosanthes guianensis, Calopogonium muconoides, Pueraria phaseoloides, Desmodium spp*) and trees (*Ficus numeralis, Albizia chinensis, Morus cerrata, Ulmus repalensis, Bucklandia pupulrea*).

Swampy and Wet Lands

The extent of wetlands is more than 6 Mha apart from the permanent water bodies posing different kind of problems. Marshlands and swamps are usually found in southern and eastern India. Biomass production from such areas can be improved by growing suitable species of grasses (*Brachiaria mutica, Iseilema laxum, Dichanthium caricosum, Paspalum notatum, Brachiaria decumbens*), legumes (*Sesbania spp., Lotononis bainesii, Desmanthus virgatus, Pueraria phaseoloides, Glycine weightii*) and trees (*Salix tetrasperma, Lagerstroemia flosreginae, Dalbergia latifolia, Eucalyptus robusta, Barringtonia acutangula, Populus euphratic, Gliricidia maculata*) to increase green forage production from 20 to 40 t/ha.

Cho and Riverbed affected Soils

The shallow hill torrents have seasonal flows, which are called Cho's and are largely observed in the sub-mountain regions of the Himalayan. These soils need a permanent vegetation cover of economic importance like fuel cum fodder trees. Grasses (*Chrysopogon fulvus, Dichanthium annulatum, Bothriochloa pertusa, Pennisetum pedicellatum, Eulalopsis binata*), legumes (*Stylosanthes guianensis, Calapogonlum mueunoldes*) and trees (*Salix spp. Dalbergia sissoo, Gliricidia maculata, Acacia catechu, Ziziphus spp., Psidium guajava*) have shown great promise in such situations (Singh, 1987).

Mine's affected Areas

In India, coal mines affected large area and these soils could be developed by introducing suitable grasses (*Chrysopogon fulvus, Bothriochloa pertusa, Dichanthium annulatum, Pennisetum pedicellatum, Panicum maximum*), legumes (*Stylosanthes hamata, Atylosia scarabaeoides, Macroptilium atropurpureum*) and trees (*Acacia species, Albizia spp. Azadirachta indica, Dichrostachys cinerea, Ziziphus mauritiana*).

Spacing and Design of Fodder Shrubs and Trees Species in Agroforestry Systems

Spacing of 1 x 1 m is ideal for many species. Fodder production and accessibility can be improved by using double rows of fodder tree / shrubs at wider spacing. Rows are established about 50 cm apart with 1-1.5 meters between double rows. In row spacing of tree / shrubs varies from 5-50 cm. Ideally, rows are oriented along the contours in an east-west direction. Once the fodder tree / shrubs are well established, grass should be allowed to grow in the area between double rows. Competition between tree/shrub and grass should be monitored constantly so that fodder production may not be compromised.

Management of Fodder Shrubs and Trees Species in Agroforestry Systems

Age at First Harvest

In most circumstances, the first harvest should be delayed until the fodder tree / shrub is 12-18 months old depending on the species. Under arid or poor soil conditions, growth will be slow and the first harvest should be further delayed. When growth is fast, the first harvest may be advanced. The goal is to allow fodder tree species to establish deep roots and thick trunk diameters.

Grazing

Ruminants can directly graze fodder tree / shrubs. This system saves labor and effort but can lead to plant damage and fodder waste from trampling. The key to direct grazing is subdivision of the fodder plot into paddocks and following rotational grazing. Grazing periods are generally 1-2 weeks, followed by recuperation periods of 3-6 week (or three times the grazing period). Under arid conditions the recuperation period may be further extended depending on the situation.

Cut-and-Carry

Most fodder tree / shrubs are managed through a cut-and-carry system in which the fodder is harvested and then ‘carried’ to feed the small ruminants maintained under intensive system. A cut-and-carry system decreases fodder waste from animal damage and the necessity to monitor animals. However, labor inputs would be higher than the direct grazing systems. Important management factors to consider for a cut-and-carry system are cutting height, cutting frequency, and dry season management.

- **Cutting height*:*** It would be better to have a cutting height of 50-150 cm depending upon the tree/ shrub species for optimum growth and yield.
- **Cutting frequency**. The most common recommended cutting frequencies are 6-18 weeks. Generally, longer cutting frequencies (12-18 weeks) generate more total biomass but increase the proportion of small wood production. Shorter cutting frequency (6-12 weeks) results in better fodder quality and yields
- **Dry-season management:** Six to eight weeks before the beginning of the dry-season, trees should be pruned so that geometry of tree branches is maintained. Remove crossing branches and branches that grow back towards the center of the tree but don’t cut back the leader. The new foliage produced after pruning will serve as fodder for dry-season when it is most needed. When the dry-season is very long, the pre-dry-season harvest should also be stockpiled. This will assure fodder availability throughout the dry-season.

Means and Ways of Increasing Forage and Fodder from Agroforestry system

- Fertilizer: *Cenchrus ciliaris* responds highly to Phosphorous application
- Grass-legume mixture: At least 20-30 per cent legume component is maintained as mixed pasture for meeting the protein requirements of grazing animals
- Association: *Pennisetum* grass under *Acacia* trees is around two times higher productive than any other grass, hence best compatible combination of tree / shrub and forage species should be selected
- Shrub and tree spacing: High density would result in a little more top fodder and less forage, hence optimum shrub and tree spacing should be beneficial

- Weed control: Regular weeding makes more nutrients available for the growing nutritious forage and higher forage production
- Irrigation: Especially under severe drought conditions, the growing tree/shrub/forage species require moisture and irrigation results in more biomass production from the system.

Production Potential of Agroforestry Systems

Forage Production

The degraded waste lands (shallow red gravelly soils) under semi arid condition at Jhansi producing 1 t/ha/year have been improved to produce upto 10 t/ha/year at a 10 years rotation through silvopastoral systems (Pathak *et al*., 1996). Besides yield improvement by 8 to 10 times, the quality of mixed forage has also improved by 6 to 7 times. The comparative study at NRCAF, Jhansi on forage and / or top feed production from silvopastoral system and natural grassland for 8 years revealed that on an average 5.06 t/ ha/year (4.55 t from pasture + 0.51 t from tree leaves and pods through pruning) from silvopastoral system, which is about 2 times higher than yield obtained from natural grassland. These results showed that it is possible to get more biomass through established silvopasture from the same land, which is producing less than 2 t/ha/year forage through natural vegetation. Similarly, studies at CSWRI, Avikanagar, Rajasthan under semi arid conditions also showed maximum average forage production (t/ha) (2.78 dry forage from pasture + 0.95 green tree leaves) from three (*Cenchrus* + *Ailanthus excelsa* + *Dichrostachys cinerea*) tier systems followed by two tier (*Cenchrus* + *Ailanthus excelsa*), and single tier (*Cenchrus* pasture alone) compared with natural pasture.

Silvopastoral system consisting of *Acacia nilotica* + *Cenchrus ciliaris* and *Acacia tortilis* + *Cenchrus ciliaris* planted at 3 x 3 m spacing produced on an average biomass yield (ha/year) of 2.5 t and 2.7 t, respectively. Studies on the production potential of pasture alone (*Cenchrus ciliaris*), fodder trees alone (*Hardiwickia binata* + *Colophospermum mopane*) and silvopastoral system (*Cenchrus ciliaris* + *Hardiwickia binata* + *Colophospermum mopane*) at CAZRI, Jodhpur for nine years also revealed that silvopastoral system was better for higher average forage production and livestock maintenance (4.1 ACU/ ha) followed by pure pasture and pure trees block (Harsh *et al*., 1992). In alkali soils at Karnal, Singh (1995) reported that 0.81 t pod + 7.7 t green forage/ha/year was obtained from silvopasture (*Prosopis juliflora* + *Leptochloa fusca*) as compared to sole planting of *Prosopis juliflora* (0.85 t pod/ha/year) at 6th year of plantation.

Top Feed Production

The leaf fodder yield per tree varies considerably and it depends on species, initial age, lopping intensity and interval as well as agro-climatic conditions. In semi-arid conditions from 8-9 years old silvopastoral system, mean green and dry leaf fodder production of 9.63 and 5.28 t/ha, respectively was reported (Deb Roy, 1990) with annual lopping at 1/3 intensity in *Albizia procera*, where as 6.24 and 2.78 t/ha, respectively in case of *Albizia lebbeck* through biannual lopping at 2/3 intensity. Similarly, from 8-10 years old *Acacia tortilis* - *Cenchrus* silvopastoral system, top feed yield of 2.75 to 3.50 kg/tree was recorded on annual lopping. Annual lopping (2/3 intensity) of *Albizia amara* produced 10.9 t/ha (green) or 5.6 t/ha (dry) leaf fodder. A five years old plant of *Dichrostachys cinerea* provided dry leaf fodder of 2.4 kg/tree/year when biannual lopping was done at 50 per cent intensity (Roy *et al.*, 1987).

A five year old *Bauhinia purpurea* yielded green leaf fodder of 10.02 kg/tree/year at Jhansi (Roy and Deb Roy, 1983). Top feed production (kg/tree) from six fodder trees of Bundelkhand region showed the maximum dry leaf fodder of 11.38 with *Albizia procera* followed by *Albizia amara* (11.20), *Albizia lebbeck* (4.21), *Hardiwickia binata* (3.67) and *Dichrostachys cinerea* (2.76) and a minimum of 0.51 with *Acacia tortilis*, respectively in 10 years old plantation. In *Sesbania grandiflora* and *Sesbania sesban*, the dry leaf fodder yield of 0.3 kg/tree was recorded after 3.5 years of establishment when grown at a density of 5000 trees/ha (Gupta *et al*., 1983).

Evaluation of tree species under natural grassland in red gravelly soils of semi-arid region showed mean maximum dry leaf fodder yield of 2.69 and 3.80 kg/tree when pruned upto 50 and 75 per cent of the tree height, respectively with *Leucaena leucocephala* followed by *Albizia procera* and minimum yield was observed with *Albizia pendula*. Similarly in medium black soils, under rangeland condition produced a mean maximum dry leaf fodder yield of 0.31 and 0.58 kg/tree with *Leucaena leucocephala* when pruning was done upto 50 and 75 per cent height, respectively followed by *Albizia amara*, *Dichrostachys cinerea*, *Acacia tortilis, Dendrocalamus strictus*. Harvesting of multipurpose tree species at 8 years of growth showed a maximum dry leaf fodder yield of 10.6 kg/tree with *Albizia lebbeck* followed by *L. leucocephala* (5.4 kg/tree), *Albizia amara* and *Pongamia pinnata* (Rai, 1999). Similarly, harvesting of tree species grown in red gravelly soils for 10 years produced a maximum dry leaf fodder yield of 3.81 t/ha with *Albizia procera* followed by *Leucaena leucocephala* (3.7 t/ha) and *Dalbergia sissoo* (2.52 t/ha)

In Rajasthan, a full grown tree of *Prosopis cineraria* was reported to yield 59 kg green leaf per tree on complete lopping leaving the central leading shoot, where as 28 kg/tree when lower 2/3 crown is lopped and 20 kg/tree when lower 1/3 crown is lopped (Bhimaya *et al*., 1964). Over 30 years age, *Prosopis cineraria* with well spread crown produced 25 kg air dried leaves, 5 kg pods and 2 kg seed/tree/year in 300-400 mm rainfall zone.

Nutritive Value of Top Feed from Agroforestry Systems

In many parts of India, livestock also being fed on shrubs and trees along with surface fodders like grasses and grass-legume pastures especially during lean season. Top feed is a rich source of crude protein and may be useful as protein supplement when low quality fodder and or straws are being fed to the animals. The dry matter (DM) content of the various tree leaves ranges from 20 to 40 per cent, with 8 to 23 per cent crude protein (DM basis). The ether extract fraction is also fairly high compared with annual and perennial, natural and cultivated grasses and hays. The tree leaves contain comparatively low percentage of crude fibre than grasses and hays. A wide variation was observed in the concentration of fibre fractions (neutral detergent fibre (NDF), acid detergent fibre (ADF), hemi-cellulose and cellulose). The leaf fibre is so complex and highly lignified at maturity. Similarly, crude protein content decreases and crude fibre content increases as the season progress. Dry matter (DM) digestibility ranges from 50 to 88 per cent and crude protein (CP) digestibility from 38 to 91 per cent (Ramana *et al.*, 2000). *In vivo* digestibility trial conducted at Kattupakkam, Tamil Nadu revealed that the species like *Lannea coromandelica*, *Artocarpus heterophyllus, Albizia lebbeck, Leucaena leucocephala, Ficus bengalensis, Gliricidia sepium and Millingtonia hortensis* had a better nutritive value and all these species leaves found to be useful in feeding small ruminants. Calcium content of the tree leaves is 2-3 times more than that of the cultivated fodder and grasses. The phosphorus content in general is low, resulting in wide calcium to phosphorus ratios in top fodder. No significant variation was observed in the major mineral concentration of tree leaves collected from drought prone and non- drought prone areas and also legume and non-legume tree leaves (Valli and Murugan, 1998). Palatability, digestibility and nutritive value of the tree fodder decreases as the leaf advances in maturity. Tree leaves are more palatable, digestible and more nutritive for goats than sheep (Bohra and Ghosh, 1980).

Animal Productivity in Agroforestry Systems

The comparative growth performance of sheep and goats were studied at NRCAF, Jhansi on 15 months old silvopastoral system consisting of *Albizia amara* and *Leucaena leucocephala* as tree component and *Dichrostachys cinerea* as shrub. The under story vegetation of the silvopastoral system consists of perennial grasses such as *Chrysopogon fulvus* and pasture legumes as *Stylosanthes hamata* and *Stylosanthes scabra*, while *Schima - Heteropogon* as natural grassland. Results showed that goats and sheep grazed on silvopastoral system gained (head/day) in their body weight at the rate of 28.6 and 2.1 g, whereas on natural grassland the gain was 10.8 g in goats. However, sheep lost their weight (head/day) at the rate of 27.4 g in a total grazing period of 241 days even after supplementation of 1.5 kg (head/day) of *Leucaena leucocephala* as top feed (Rai *et al*., 1994).

Feeding trial conducted at Institute of animal nutrition, Kattupakkam on performance and nutrient utilization in small ruminants fed with top feeds revealed significant (P<0.01) increase in feed efficiency and reduction in feed cost per kg body weight gain when 50 per cent of the DM requirement was met with tree leaves mixture (TLM) contained equal proportion of *Albizia lebbeck, Gliricidia sepium, Leucaena leucocephala* and *Ficus bengalensis* leaves than green grass. In another trial, highest average daily weight gain was observed in Madras Red ram lambs fed with a ration in which 50 per cent of green grass was replaced with TLM contained equal proportion of the leaves of *Albizia lebbeck, Leucaena leucocephala* and *Ficus bengalensis.* Feeding grass and tree leaves each at 50 per cent level was found economically superior than feeding grass and concentrate mixture in lambs (Parthasarathy *et.al.*, 1998). The performance of sheep was found better when integrated with the Bajra+ Neem agrisilvi system, where Bajra was raised as fodder and supplemented with tree leaves.

A live weight gain of 20-22 kg with average daily gain (head/day) of 56-61 g and 93-102 g in lambs and kids, respectively were recorded on two tier (*Cenchrus ciliaris + Ailanthus excelsa*) and three tier (*Cenchrus ciliaris + Dichrostachys cinerea + Ailanthus excelsa*) silvopastoral systems with stocking density of 14 animals/ha (lambs and kids). Silvopastoral system with rotational grazing was found to be adequate for ewes during pregnancy and lactation (Sankhyan *et al*., 1997). Small ruminants (lambs and kids) gained optimum live weight when maintained on silvopastoral system consisting of *Leucaena leucocephala* as a tree component and *Dichrostachys cinerea* as shrub along with natural vegetation at NRCAF, Jhansi. The performance of kids were better than lambs and grazing was found better than stall feeding to achieve maximum live weight gain (Ramana *et al*., 2000). A total of 12 kids and 6 lambs were added to the flock by kidding and lambing, respectively over a period of 12 months on 2 ha silvopastoral system. A daily weight gain (g/head) of 72.04 and 104.29 was also observed, respectively in newborn kids and lambs for a period of 4 months.

Studies on established *Leucaena leucocephala* based silvopastoral system demonstrated that the stockpiled foliage and forage from the silvopastoral system would meet the nutrient requirements of Deccani ram lambs even during drier months of the year (Rao *et al*., 2013). Total forage production, nutritive value and lambs average daily gain (ADG) was significantly (P<0.01) higher in silvipasture than natural pasture. Silvipasture system (4.11 t/ha) produced more (P<0.01) forage than the natural pasture (1.36 t/ha). When the foliage of *Leucaena leucocephala* was excluded, the silvipasture system still produced higher (P<0.01) crude protein (CP) than natural pasture. Higher average daily gain (P<0.01) was observed in the ram lambs reared under silvipasture (87.2g) compared to the natural pasture (59.1 g). Lambs weight gain per ha was greater (P<0.01) in the silvipasture than the natural pasture (236 vs. 160 kg) during grazing season.

Productivity of Nellore Zodpi ram lambs under Hortipastoral Systems (mango and sweet orange orchards above 5 years old with *Cenchrus ciliaris, Stylosanthes hamata* and *Cenchrus ciliaris + Stylosanthes hamata* established pastures and boundary plantation of *Leucaena leucocephala*) developed by the farmers in rainfed areas of Telangana state shown that complementary grazing on established pasture or supplemented with *Leucaena leucocephala* foliage in addition to grazing on natural pasture significantly (P<0.01) enhanced live weight gain in ram lambs when compared to grazed solely on natural pasture. This is because of availability of sufficient quality foliage and forage from the established pastures compared to natural under orchards. Supplementation of plant protein sources, which contain medium to high CP levels (Kaitho *et al.*, 1997) will alleviate CP deficiency of fibrous feeds, reduce feed retention time and improve feed intake (Solomon Melaku *et al.*, 2005). Further, Kronberg and Malechek (1997) reported CP intake was probably more essential for maintenance and production needs of the sheep. Significantly ($P<0.01$) higher ADG was observed with complementary grazing on *Stylosanthes hamata* and *Cenchrus ciliaris* + *Stylosanthes hamata* forage. This could be due to relatively high content of nitrogen and carbohydrate fractions featured by slow-rate of degradation of *Stylosanthes hamata* forage. Relatively lower ADG observed in the lambs supplemented with *Leucaena leucocephala* foliage than complementary grazing on *Stylosanthes hamata* forage although the former had higher CP. The *Leucaena leucocephala* foliage contained phenolics (18.6 g/kg DM) and tannins (23.5 g/kg DM) (Ramana *et al.*, 2000) and these antinutritional factors lower feed digestibility (Makkar, 1989) and nutrient utilization in ruminants. The differences in ADG among the different group of animals could be due to the differences in availability of pasture in terms of quality and available nutrients. Low pasture quality impairs the productivity of ruminant livestock especially when grazing is the main feeding system (Devendra and Burns, 1983; Pamo *et al*., 2001). Further, it could be due to decreased intake rate of forage by lambs with changing maturity from the vegetative to reproductive stage and that effects the availability of nutrients in forage (Gong *et al*., 1996). Income from ram lamb production under hortipastoral systems seems to be quite remunerative and Net gain (Rs/ha) ranged from 6000 to 8000 through ram lamb production. Further, higher income was observed with complementary grazing on established pasture or supplementation of *Leucaena leucocephala* foliage from the orchards (Ramana *et al*., 2011).

Technology Transfer Issues

Resilience of animal based agroforestry systems is affected by many factors, such as farmers' access to resources, availability of knowledge and skills, consumer demands, national and international policies and social aspects. Low adoption rates of technologies by stake holders are at least partly due to differences among farmers in terms of their access to resources, such as land, water, livestock and credit and personal values, status, food habits, and to cultural barriers. Many development programmes lack a proper perspective on the local resources, the environment and the needs of the farmers (Van den Ban and Hawkins, 1988; Chambers *et al*., 1989; Röling, 1996). What is useful for one farmer may not be useful for another, and certain technologies can even have negative trade-offs. Hence, basket of technological options interms of fodder varieties and fodder trees and compatible animal species with site specific and problem targeted should be made available to the stake holders, so as to choose according to their resources and environmental conditions.

Policy Issues

There exist major opportunities for the use of improved policy issues. These relate to institutions, services and delivery systems that affect animal based agroforestry production systems. In view of the bio-physical focus among the ruminant production systems, despite the economic benefits of added value, integrated systems with trees remain underestimated. Policy interventions are required to stimulate more integration with animals, for example through strengthening animal husbandry services, tax incentives, leasing community land and also encouraging increased private sector investments in animal based agroforestry systems development for exploiting available certified emission reductions (CERs) options at global level.

Conclusions

Agroforestry systems may be developed through participatory approach to address the needs for both environmentally and economically viable diversification and that is resilient to climate pressure by (i) Making use of traditional indigenous and also scientific knowledge to identify the better species for inclusion in existing farming systems, (ii) Scientific experiences may be combined with the most sensitive indicators for developing scaling up mechanisms for successful agroforestry systems in areas where they have social acceptance and economic and environmental potential. This approach would enhance the supply of nutritious fodder year-round and meet the feeding requirements of ruminants and results in higher production and maximum return to the farmer.

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Chapter 28

DNDC Model Initiation for Calibration and Validation for Soil Organic Carbon

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Introduction

Accurate simulation of soil organic carbon (SOC) dynamics is vitally important in researching the carbon cycle in terrestrial ecosystems. Especially, the application of SOC model at the regional scale has major implications for regional and global carbon cycling (Shi *et al.*, 2009). The DNDC (Denitrification and Decomposition) model, developed by Li *et al.* (1992), is a process-orientated simulation tool of soil carbon and nitrogen based on biogeochemistry cycles and this model is one among the most widely used models in the world.

The C stored in soils is mainly in form of organic matter. SOC content is highly dynamic affected by ecological drivers (*e.g.*, climate, vegetation, and anthropogenic activity), soil environmental factors (*e.g.*, temperature, moisture, pH, redox potential, and substrate concentration gradients), and biochemical or geochemical reactions (*e.g.*, decomposition, assimilation, leaching etc.) (Li, 2000; 2001). Soil organic carbon (SOC) have received attention in past few years in terms of the potential role they can play in mitigating the effect of elevated atmospheric CO_2. Process-based soil organic C (SOC) models are widely used for simulating, monitoring, and verifying soil C change (Basso *et al.*, 2011). Soil organic matter (SOM) turnover models are very effective at simulating changes in SOM associated with different agricultural management systems or with climatic changes. Among the existing SOM models, the Denitrification-Decomposition (DNDC) model developed by Li *et al.* (1992) has been widely used for simulation of soil carbon dynamics. The DNDC model is a process-base model of carbon (C) and nitrogen (N) biogeochemistry in agricultural ecosystems. The entire model is driven by four primary ecological drivers, namely climate, soil, vegetation, and management practices. It is inherently important for a successful simulation to obtain adequate and accurate input data about the four primary drivers. The Denitrification-Decomposition (DNDC) model is a process-oriented computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems.

As described in detail by Li *et al.* (1992, 1994, 2003), and in the user's guide, the DNDC model consists of two components. The first component, consisting of the soil climate, crop growth and decomposition sub-models, predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles driven by ecological drivers (*e.g.*, climate, soil, vegetation and anthropogenic activity). The second component, consisting of the nitrification, denitrification and fermentation sub-models, predicts emissions of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitric oxide (NO), nitrous oxide (N_2O) and dinitrogen (N_2) from the plant-soil systems. The entire model forms a bridge between the C and N biogeochemical cycles and the primary ecological drivers (Li *et al.*, 1992, 1994; Li, 2000).

Input Files Required for DNDC Model Initiation

For initializing and running the model at regional scale, there is a requirement of adequate data sets. Applying the DNDC model to estimate the SOC storage in arable land requires spatial databases of soil properties, daily weather, cropping and other data of agricultural management practices.

Some of the input files / datset required for running the DNDC model is mentioned below.

Climate

Minimum- daily mean air temperature (in°C), daily rainfall (in mm), Optional- daily minimum air temperature (in °C), daily maximum air temperature (in°C), solar radiation ($MJ/m^2/day$) wind speed

Soil

Minimum- land use type (upland crop field, rice paddy field, moist grassland/pasture, dry grassland/ pasture, pristine wetland), soil texture (sand, loamy sand, sandy loam silt loam, loam, sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay, clay, organic soil), bulk density (in g/cm^3), soil pH, field capacity (water filled pore space, 0-1), wilting point (water filled pore space, 0-1), clay fraction (in per cent, 0 - 1), hydraulic conductivity (in cm/min), soil organic carbon (in kg C/kg), NH^{4+} and NO_3^- concentrations (in mg N/kg), slope (in per cent) microbial activity index (0 - 1)

Optional-SOC partitioning (in per cent, into very labile litter, labile litter, resistant litter, humads and humus)

Management

Crop

Minimum- crops per year crop type default maximum biomass production (kg dry matter/ha), planting date, harvest date, Fraction of leaves and stems left in the field (in per cent)

Optional- initial biomass (kg dry matter/ha), initial photosynthesis, efficiency maximum photosynthesis rate (in kg CO_2/ha/hr), development rate in vegetative state, development rate in reproductive state

Tillage

Number of applications per year, tilling date, tilling method (mulching, ploughing slightly, ploughing with disk or chisel, ploughing with mould board)

Fertilization

Minimum-number of applications per year, fertilizer date, fertilizer type (urea, anhydrous ammonia, ammonia bicarbonate, NH_4NO_3, $(NH_4)_2SO_4$, Nitrate, $(NH_4)_2HPO_4$), fertilizer amount

Optional-Release Control Nitrification Inhibition

Manure Amendment

Number of applications per year fertilizer, date, manure type (farmyard manure, green manure, straw, slurry animal waste, compost), manure amount

Weeding

Weeding problem (not existing, moderate, serious), number of applications per year, weeding date

Flooding

Number of times per year, starting date, end date, water leaking rate, flood water, pH

Irrigation

Number of irrigation events per year, irrigation date, irrigation amount, irrigation water pH

Grassland

Number of grazing and/or cuttings, starting date (grazing), end date (grazing), application date (cutting)

An example of data input required for DNDC simulation

Some of the steps should be followed for initiation of DNDC model is expressed below.

1. **Creation of climate file-** one can use note pad for creation of climate file. An example is given below. First column is day of a year, 2nd column is maximum temperature (°C), third column is minimum temperature (°C) and last (4th) column is rainfall in cm.

2. **Soil information-**The data on soil related parameters has to be generated which includes, soil type, depth clay content, pH, bulk density, soil carbon content and carbon allocation in different pools.

3. **Farming management-** The data on crop related activities has to be generated which includes crop type, sowing and harvesting date, tillage and fertilization details and also irrigation scheduling with amount.

Jabalpur_2001			
1	24.2	12.2	1.8
2	17.2	11.7	0.0
3	17.5	11.1	0.0
4	16.2	6.1	0.0
5	20.2	6.7	0.0
6	17.0	2.9	0.0
365	23.7	7.1	0.0

An example of data requirement for initiation of DNDC model

Site name	Jabalpur
Latitude (N)	………....
Longitude (E)	………….
Soil name	Black soil
Experimental period (years)	2001-2010
Topsoil depth (cm)	100
Clay content (per cent)	52
Bulk density (Mg/m)	1 .30
pH	7.8
Initial topsoil SOC (kg C/kg)	0.0072
Kharif crop	Soybean
Sowing date	6/25(6/20-6/30)
Tillage date	5/3, 6/20
Total N applied (kg/ha)	20 (20-0)
Harvest date	9/25 (9/15-9/25)
Rabi crop Wheat	
Planting date (s)	11/15 (11/10-11/20)
Harvesting date (s)	3/30 (3/25-4/05)
Tillage date	09/20, 10/05, 10/11
Total N applied (kg/ha)	120
Number of N application times	3
Date of straw application	no
Amount of straw applied (kg C/ha)	no

The DNDC model has been validated throughout the world by using long-term and short-term experimental data to test its behavior on the modeling of the carbon biogeochemical process in agricultural soils (Li, 2000). The sensitivity studies are carried out to ascertain DNDC behavior in simulating soil carbon response to changing of climate, soils, and agricultural practices. The input parameters for running the model can be easily be collected. Caution to be exercised, in defining the model carbon pools as the final output of SOC is sensitive to carbon allocation in different pools of soil organic matter. The model must be calibrated with respect to soil organic carbon before using it for simulation purpose. For calibration of the model, datasets of long term experiments should be used.

Carbon Dynamics using DNDC Model (Case Study LTFE, Jabalpur)

Soil organic carbon in DNDC model is divided into three major pools *i.e.* Litter, Humad and Humus. Each of the SOM pools has a specific decomposition rate subject to temperature, moisture and N availability. The organic matter in the litter pools will be broken down by the soil microbes. When the microbes die, their biomass will turn into humads pool. Humads can be further utilized by the soil microbes and turned into passive humus. During the sequential decomposition processes, a part of the organic C becomes CO_2, and a part of the organic N becomes ammonium (Zhang *et al.*, 2006).

Depending on the partitioning of soil C into the different pools, decomposition of SOC during a growing season may result in very low or very rapid rates of mineralization and supply of nutrients. Thus, for the same initial total SOC value, the model may simulate vastly different yields under identical environmental and management conditions depending on how the SOC is partitioned into different pools (Basso *et al.*, 2011). The inappropriate initialization of SOC pools can also lead to inaccurate assessment of inter-annual variability (Yeluripati *et al.*, 2009). Typical values of the C fractions in each pool may be provided by model developers, but caution should be used because such information may prove to be unreliable for the soil and cropping system being simulated (Basso *et al.*, 2011). In DNDC model, the model assumes default value for fraction of soil organic carbon in litter, humad and humus (active, slow and resistant pool) irrespective of soil texture class. We have determined the different carbon pools of soils under different treatments of Jabalpur and the same was calibrated with respect to DNDC model.

Long-term incubation study was carried out to ascertain carbon distribution in different carbon pools. Soil organic carbon content was divided into 3 pools (active, slow and resistant pool). The carbon in active slow pool also known as the acid-hydrolyzable pool was computed by subtracting acid non-hydrolyzable carbon (bio-chemically stabilized carbon) from the TOC content of soil. SOC pools are divided into active and slow pools according to their turnover time on the assumption that a negligible amount of CO_2 was evolved from the acid non-hydrolyzable fraction (Cr) during the incubation period. In Jabalpur (the C content of the acid non-hydrolysable fraction was higher than the cumulative C in the acid-hydrolyzable pools (active (Ca) + slow (Cs)) for all the three treatments. The proportion of carbon in the acid non-hydrolysable fraction was 52, 65 and 66 per cent under the control, NPK and NPK+FYM treatments. There was 18 per cent depletion in C content of the slow pool of TOC over the control in the treatment of chemical fertilization (NPK). We suggest that additional C input in the NPK and NPK+FYM treatments contributed C more towards the acid non-hydrolysable fraction in fine textured soil. NPK+FYM increased the C content of the active, slow and acid non-hydrolysable fractions by 99, 22 and 33 per cent, respectively over the NPK treatment. The increase in Cr at Jabalpur even with NPK alone indicates that the resistant C content of soils could be increased even without the application of FYM in heavy textured soils owing to their high carbon stabilization capacity.

DNDC simulates SOC dynamics by tracking the turnover of four SOC pools, namely plant residue (or litter), microbial biomass, humads (or active humus), and passive humus. Each pool consists of two or three sub-pools with specific decomposition rates subject to temperature, moisture, redox potential and N availability in the soil. As soon as fresh crop residue is incorporated into the soil, DNDC will partition the residue into very labile, labile and resistant litter pools based on C/N ratio of the residue. The lower the C/N ratio, the more of the residue will be partitioned into very labile or labile pool. Each of the SOM pools has a specific decomposition rate subject to temperature, moisture and N availability. The DNDC model has been validated throughout the world by using long-term and short-term experimental data to test its behavior on the modeling of the carbon biogeochemical process in agricultural soils (Li, 2000). The sensitivity studies are carried out to ascertain DNDC behavior in simulating soil carbon response to changing of climate, soils, and agricultural practices. The input parameters for running the model can be easily be collected. Caution to be exercised, in defining the model carbon pools as the final output of SOC is sensitive to carbon allocation in different pools of soil organic matter. The model must be calibrated with respect to soil organic carbon before using it for simulation purpose. For calibration of the model, datasets of long term experiments should be used.

Implications Related to Model Initiation

Simulation accuracy of global bio-geochemical carbon model depends on the initial carbon content of soil and their relative distribution of soil carbon pools. No definite method of quantification of soil carbon pools differentiation has been proposed by the model developer. Basso *et al.* (2011) developed iterative procedure for computation of soil carbon pools for initialization of DSSAT-Century model. Predicted changes in SOC should also be compared with measured data that represent the spatial and temporal range of model inferences to assess uncertainty and bias (Falloon and Smith, 2003; Ogle *et al.*, 2007). The availability of reliable measurements of total SOC may not be sufficient to properly initialize soil C models.

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