Model Training Course on

Impact of Climate Change in Rainfed Agriculture and Adaptation strategies

September 26 to 03 October 2013

Training Manual

Sponsored By
D.O.E., Min. of Agri. Govt. of India, New Delhi.

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CRIDA

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Impact of Climate Change in Rainfed Agriculture and Adaptation strategies

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COMPENDIUM OF LECTURE NOTES

Model Training Course on

"Impact of Climate Change in Rainfed Agriculture and Adaptation Strategies"

(Sponsored by D.O.E., Ministry of Agriculture, Govt. of India, New Delhi)

Government of India

September 26-October 03,2013

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Transfer of Technology Section

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Model Training Course on

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COURSE OUTLINE

Venue	:	CRIDA, Hyderabad.
Period	:	**September 26-October 03, 2013**
Participants	:	Subject Matter Specialists & Extension Functionaries from line departments like Dept. of Agri/Horti/AH.
Course Director(s)	:	**Dr. M.S. Prasad** **Principal Scientist (Agril.Extn.) & Head, TOT** **&** **Dr.K. Nagasree, Senior Scientist (Agril. Extn.)**
Co-Directors	:	**Dr. G. Nirmala, Senior Scientist (Agril.Extn.)** **Dr. K. Ravi Shankar, Senior Scientist (Agril.Extn.)** **Dr. Manoranjan Kumar, Senior Scientist (S&WCE)** **Dr. B.M.K. Raju, Senior Scientist (Agril. Statistics)** **Dr. N. Ravi Kumar, Senior Scientist (Computer applications)** **Dr.A.V.M. Subba Rao, Scientist (Sr. Sc.)(Agrometeorology)**

Objectives:

i. To introduce the concept of climate change and its potential impact in rainfed agriculture to the participants including adaptation strategies

ii. To give exposure to the participants about the GHG emissions from agriculture and allied sectors, various types of mitigation measures for reducing GHG emissions

iii. To provide insights of carbon trading, clean development mechanism and the issues of global warming

CONTENTS

GOVT. & ICAR INITIATIVES ON CLIMATE CHANGE AND ADAPTATION & MITIGATION STRATEGIES

B. Venkateswarlu, Director, Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad – 500 059

Evidence over the past few decades has conclusively established that significant changes in climate are taking place worldwide as a result of enhanced anthropogenic activities. The fast pace of development and industrialization and indiscriminate destruction of natural environment, more so in the last century, have altered the concentration of atmospheric gases that lead to global warming. The major cause for climate change and global warming has been ascribed to the increased levels of greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) etc. beyond their natural levels due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants, and enhanced agricultural related practices.

The IPCC (2007) report has projected that by 2100 earth's mean temperature will rise by 1.4 to 5.8 ^{0}C, precipitation will decrease in the sub-tropical areas, and frequency of extreme events will increase significantly. As of now, in reality, in the past 100 years, the global mean temperature has increased by 0.74 ^{0}C. IPCC reported that eleven of the last twelve years (between 1995 to 2009) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans which has already started affecting the climatic phenomenon in different parts of world. Melting of glaciers, rising sea level are some of the most important manifestations of it. IPCC (2007) have further reported change in their frequency and /or intensity of extreme events over the last 50 years. The report has made the following significant observations:

- It is very likely that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent
- It is likely that heat waves have become more frequent over most land areas.
- It is likely that the frequency of heavy precipitation events has increased over most areas.
- It is likely that the incidence of extreme high sea level has increased at a broad range of sites worldwide since 1975.

Since climate is central to many critical agricultural decisions ranging from farm to policy level (Venkateswarlu and Shanker, 2009), it is also imperative to realize that most of these decisions have to be made well in advance to counter the impacts of climate change at the earliest. Therefore, the Indian Government has taken a stance to address climate issues by fully participating in international conventions such as the United Nation Framework Convention on Climate Change (UNFCCC) and, secondly, developing National Climate Change Response Policies. At the domestic level, it is essential to develop Programs and Policies that increase farm productivity and incomes; make agriculture climate resilient and promote stability and security for the farmers; ensure that the agriculture sector becomes a part of the solution to the climate change problems rather than the cause and there is a need to make climate change adaptation and mitigation measures as an integral part of overall planning and development strategy of the country on long term.

A National Action Plan on Climate Change (NAPCC) was unveiled by the Hon'ble Prime Minister of India in June 2008. It outlined a national strategy which would enable the country to adapt to climate change and ensure that development and ecological sustainability go hand in hand. This National Action Plan consists of eight missions *viz*. National Solar Mission; National Energy Efficiency Mission; National Sustainable Habitat Mission; National Water Mission; National Sustaining Himalayas Mission; A Green India Mission; National Sustainable Agriculture Mission; and National Strategic Knowledge Mission. At least three of them have a bearing on Indian Agriculture *viz*., National Water Mission, National Mission on Green India, National Mission for Sustaining the Himalayan Ecosystem, in addition to the National Mission for Sustainable Agriculture.
Building state of the art infrastructure for research and training of scientists in frontier areas and tools, increasing climate change literacy to different levels of stakeholders, mainly farmers; enhancement of national capacity on decision support systems developing best weather insurance products for vulnerable areas and farmers and carbon trading in agriculture; and international collaboration are some other key areas through which challenges of climate change and global warming can be tackled. The Indian Council of Agricultural Research (ICAR) has recently launched a mega project entitled "National Initiative on Climate Resilient Agriculture" which includes all these components of strategic research, strengthening R&D infrastructure, capacity building and technology demonstration on farmer's fields.

Since the beginning of 21st Century, India has experienced droughts in quick succession, of which the 2009 one was the most recent one that significantly affected *kharif* crop production. It was the 2nd largest all India monsoon rainfall deficit since 1972 (23% below normal). Incidentally, 2009 also achieved the distinction of being the warmest year in past several centuries across the world. However, after 2009, 2010 proved to the warmest year on record since 1850. 2011 is now the 11th warmest year on record since 1850 (Fig. 1). Apart from that, 1998 was one of the warmest years; 2003 experienced unprecedented heat and cold waves across the globe; occurrence of high temperature in March 2004 adversely affected crops like wheat, apple, potato etc. across northern India; 2005 witnessed destructive hurricanes/cyclones across the globe and again, 2007 was as warm as 1998 in the entire northern hemisphere and unusual summer rains and floods were experienced in many parts of India. Besides that, the amount and distribution of rainfall is becoming more and more erratic which is causing greater incidences of droughts and floods globally. The increase in frequency of heavy rainfall events in last 50 years over Central India points towards a significant change in climate pattern in India (Goswami, 2006).The data clears indicates increase in heavy (>10 cm) and very heavy (>15cm) rainfall events and decrease in light to moderate rainfall events. The projected change in seasonal temperature and rainfall for the 2030 scenario has been shown in Fig 2.

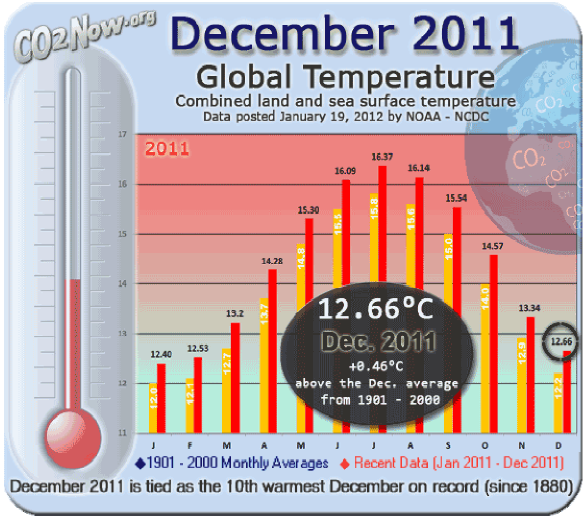


Fig 1. Current status of annual global temperature (Annually, 2011 is the 11th warmest year on record. The year 2010 tied with 2005 as the warmest year)

Seasonal mean minimum temperature (°C) **Seasonal mean maximum temperature (°C)** **Seasonal Rainfall (%)**

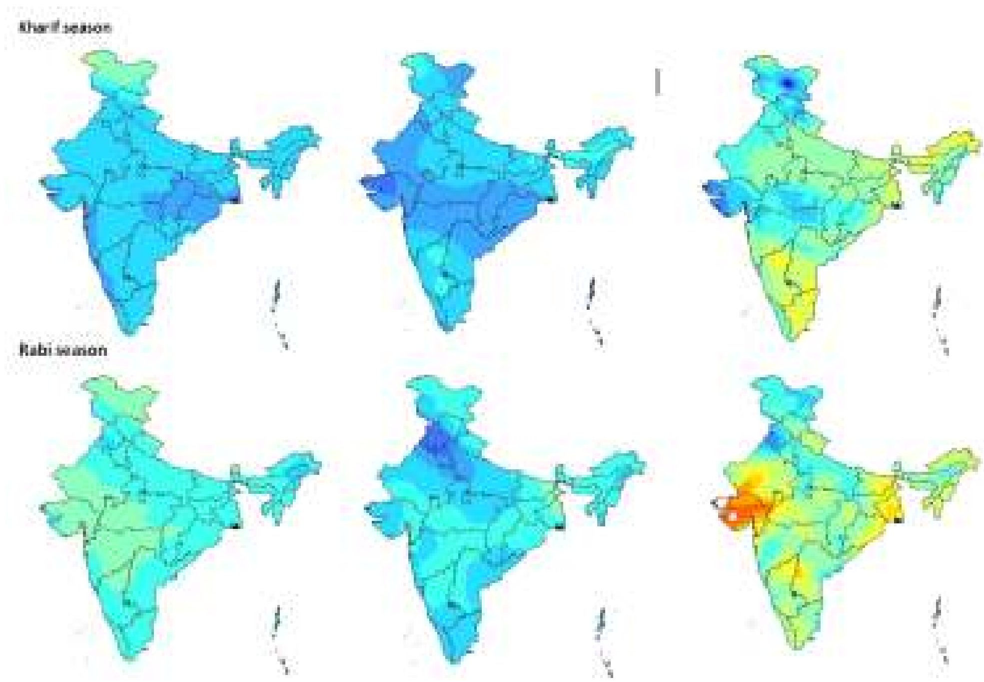


Fig 2. Projected change in seasonal maximum and minimum temperatures and rainfall in India in A1B 2030 scenario

A change in ocean acidity is likely to reduce the ocean's capacity to absorb CO_2 from the atmosphere, thus compounding the effects of climate change, and that will affect the entire marine food chain. Large-scale, irreversible system disruption and the destabilization of the Antarctic ice sheets are serious risks: changes to polar ice, glaciers and rainfall regimes have already occurred.

The rainfall analysis of India (Rao *et al.*, 2008) showed that significant negative trends of rainfall were observed in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Jharkhand, U.P., and northeast India. Lal (2001) reported that annual mean area-averaged surface warming over the Indian sub-continent is to likely to range between 3.5 and 5.5 ^{0}C by 2080s. These projections showed more warming in winter season over summer. The spatial distribution of surface warming suggests a mean annual rise in surface temperatures in North India by 3 ^{0}C or more by 2050. The study also indicated that during winter, the surface mean air temperature could rise by 3 ^{0}C in Northern and Central parts, while it would rise by 2 ^{0}C in Southern parts by the same period. In case of rainfall, a marginal increase of 7-10% in annual rainfall is projected over the sub-continent by 2080. Nevertheless, the study suggests a fall in rainfall by 5-25% in winter, while it would increase by 10-15% in summer, Marked variability is seen even in the onset and withdrawal of monsoon over the period. The glaciers and the snowfields in the Himalayas are on the decline as a result of climate variability. The rate of retreat of the snow of Gangotri glacier demonstrated a sharp rise in the first half of the 20th century. Glacial melt would lead to increased summer river flow and floods over the next few decades, followed by a serious reduction in flows thereafter.

Role of green house gases

The increasing levels of green house gases (GHG's) in the atmosphere have been attributed as one of the major driving force behind the rapid climate change phenomenon. The main GHGs contributing to this phenomenon are CO_2, CH_4 and N_2O. Apart from fossil fuel burning, the frequent volcanic eruptions are also contributing to this increase in concentration, in the atmosphere. Though the increase in the level of CO_2 is expected to produce some beneficial effects on crop dry matter production, it may soon be nullified by associated water and thermal stresses leading to overall deterioration of agro-climatic conditions for food production systems. At the global scale, the historical temperature-yield relationships indicate that warming from 1981 to 2002 is very likely to offset some of the yield gains from technological advance, rising CO_2 and other non-climatic factors (Lobell and Field, 2007). The recent release of Greenhouse gas inventory by Indian government revealed that the Net Greenhouse Gas (GHG) emissions from India in 2007, including LULUCF, were 1727.71 million tons of CO_2 equivalent (eq) of which CO_2 emissions were 1221.76 million tons, CH_4 emissions were 20.56 million tons; and N_2O emissions were 0.24 million tons. GHG emissions from Energy, Industry, Agriculture and Waste sectors constituted 58%, 22%, 17% and 3% of the net CO_2 eq emissions, respectively. The energy sector emitted 1100.06 million tons of CO_2 eq, of which 719.31 million tons of CO_2 eq were emitted from electricity generation and 142.04 million tons of CO_2 eq from the transport sector. The industrial sector emitted 412.55 million tons of CO_2 eq. The concentration of CO_2 in the atmosphere has been increasing continuously and had reached a concentration of 392 ppm in 2011 (Fig. 3). If the CO_2 concentration continues to increase at this rate, the "point of no return" may be reached within a very short time span.

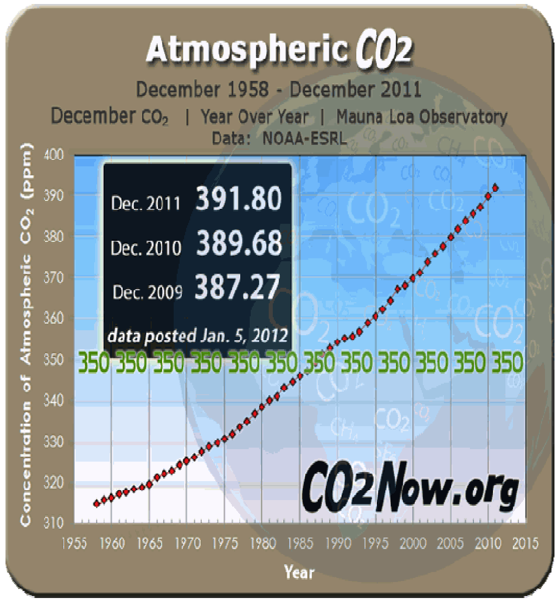


Fig 3. Current global CO_2 concentration levels

Role of carbon dioxide

A growing body of research suggests that atmospheric carbon dioxide levels may affect water availability through its influence on vegetation. Controlled experiments indicate that elevated CO_2 concentrations increase the resistance of plant "pores," that is stomata, to water vapor transport. Experiments suggest that a doubling of CO_2 would increase stomatal resistance and reduce the rate of transpiration -- the passage of water vapor from plants by about 50 percent on average. The resulting decrease in transpiration would tend to increase runoff. On the other hand, CO_2 also has been demonstrated to increase plant growth, leading to a larger area of transpiring tissue and a corresponding increase in transpiration. Other factors that might offset increases in plant water-use efficiency associated with a CO_2 -enriched atmosphere are a potential increase in leaf temperatures caused by reduced transpiration rates and species changes in vegetation communities. The net effect of opposing influences on water supplies would depend on the type of vegetation and other interacting factors, such as soil type and climate.

The management and labour costs of farm production will rise to a great level owing to increased incidences of pests and diseases as well as weeds. Additionally, extreme events like hails and frosts will also negatively impact crop production. As of now, most of the developing countries, including India, are not fully prepared to deal with the adverse impacts expected as a consequence of climate change and are therefore relatively vulnerable.

Impact on water resources

A warmer climate will modify the hydrologic cycle, altering rainfall, magnitude and timing of run-off. Warm air holds more moisture and increases evaporation of surface moisture. With more moisture in the atmosphere, rainfall and snowfall events tend to be more intense, increasing the potential for floods. However, if there is little or no moisture in the soil to evaporate, the incident solar radiation will lead to increase in the temperature, contributing to longer and more severe droughts (Trenberth, 1999). Therefore, change in climate will affect the soil moisture, groundwater recharge and frequency of flood or drought episodes and finally groundwater level in different areas.

At present, available statistics on water demand show that the agriculture sector is the largest consumer of water in India using more than 80% of the available water. The quantity of water used for agriculture has increased progressively through the years as more and more areas were brought under irrigation. Since 1950-51, the net irrigated area in India rose from 28.85 to 62.29 million ha up to 2007-08. Contribution of surface water and groundwater resources for irrigation has played a significant role in India attaining self-sufficiency in food production during the past three decades, but water is likely to become more scarce and critical input in future. By judicious utilization, the demand for water from farm sector can be pegged at 68% by the year 2050, but agriculture will still remain the largest consumer. In order to meet this demand, augmentation of the existing water resources by development of additional sources of water or conservation of the existing resources through impounding more water in the existing water bodies and their conjunctive use will be needed (Mall *et al.*, 2006). Table 1 (adopted from Mall *et al.*, 2006) summarizes the possible impacts of climate change on water resources during the next century over India. The enhanced surface warming over the Indian subcontinent by the end of the next century would result in an increase in pre-monsoonal and monsoonal rainfall and no substantial change in winter rainfall over the central plains. This would result in an increase in the monsoonal and annual run-off in the central plains, with no substantial change in winter run-off and increase in evaporation and soil wetness during the monsoon on an annual basis.

Table 1. Impact of climate change on water resources during the next century over India (adopted from Mall *et al.*, 2006)

Region/location	**Impact**
Indian subcontinent	• Increase in monsoonal and annual run-off in the central plains • No substantial change in winter run-off • Increase in evaporation and soil wetness during monsoon and on an annual basis
Orissa and West Bengal	One metre sea-level rise would inundate 1700 km^2 of prime agricultural land
Indian coastline	One metre sea-level rise on the Indian coastline is likely to affect a total area of 5763 km^2 and put 7.1 million people at risk
All-India	Increases in potential evaporation across India
Central India	Basin located in a comparatively drier region is more sensitive to climatic changes
Kosi Basin	Decrease in discharge on the Kosi River Decrease in run-off by 2–8%
Southern and Central India	Soil moisture increases marginally by 15–20% during monsoon months

Chenab River	Increase in discharge in the Chenab River
River basins of India	General reduction in the quantity of the available run-off, increase in Mahanadi and Brahmini basins
Damodar Basin	Decreased river flow
Rajasthan	Increase in evapotranspiration

In another study made by IITM, Pune in collaboration with DEFRA, UK reported that there will be an increase in annual rainfall and annual flow in Godavari and Ganga basins by 2071-2100 period.

Impact on agriculture, livestock and fisheries

Agriculture Sector

The impact of climate change on agriculture will be one of the major deciding factors influencing future food security of the world including India. A major part of the agriculture in India is rainfed (~80 million ha out of 142 million ha net cultivated area) and will remain so for at least for a foreseeable future. Rainfed agriculture in India contributes to 44% of total foodgrain production. Around 66% of livestock population is also dependent on rainfed areas. The crop losses due to climate variability will vary from region to region depending on regional climate, crop and cropping systems, soils and management practices. Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature. The major crops like wheat and rice are expected to undergo all the weather aberrations and their sustainability will be determined by crop's capacity of natural adaptability as well as appropriate mitigation measures adopted.

The impact of climate change on agriculture may accentuate at regional level creating more vulnerability in food security rather than the global level as a whole. The potential impact will be felt in shifts of sowing time and length of growing seasons, which may necessitate effective adjustment in sowing and harvesting dates, change in genetic traits of cultivars and sometimes total adjustment of cropping system itself. With warmer environment associated with erratic rainfall distribution, the rate of evapotranspiration will increase and quick depletion of soil nutrient reservoir would call for much greater efficiency in use of water and nutrients to sustain crop productivity. Apart from these, tackling frequent and more intense extreme events like heat and cold waves, droughts and floods may become a "norm" for the common farming community (IPCC, 2001). Such phenomena will impact agriculture considerably through their direct and indirect effects on crops, livestock, and incidences of pest-disease-weeds, increasing deterioration of soil health in totality, and, thereby, threatening the food security like never before.

The Indian Council of Agricultural Research indicated an All India Network Project on Climate Change in 2004 to study the impact of climate change on major crops, livestock, fisheries, soils and other biotic factors as well as to understand different natural adaptation capabilities of both flora and fauna. The possible interventions to increase the adaptability of crop-livestock systems and mitigation measures to minimize the adverse impacts were studied across length and breadth of different agro-ecosystems of India (Naresh Kumar et al., 2012).

Assessment of climate change impact over Indian agriculture (Aggarwal, 2009) so far has indicated that a marginal 1 ^{0}C increase in atmospheric temperature along with increase in CO_2 concentration would cause very minimal reduction in wheat production of India if simple adaptation strategies like adjustment of planting date, increased fertilizer use, irrigation water availability and varieties are adopted uniformly. But in absence of any adaptive mechanism, the yield loss in wheat may cross 4-5 million tons.

The availability of viable pollen, sufficient numbers of germinating pollen grains and successful growth of pollen tube to the ovule are of fundamental importance in grain formation. The Network study on wheat and rice suggested that high temperature around flowering reduced fertility of pollen grains as well as pollen germination on stigma. These effects were more pronounced in *Basmati* rice as well as *Durum* wheat cultivars. A positive finding of the study was that the *Aestivum* wheat cultivars were more or less tolerant to such adverse affects. But differential impact of increasing temperatures were observed with respect to grain quality of wheat where it was found that *Aestivum* wheat cultivars are more prone to reduced grain quality due to increasing temperature during the fruit setting stage than *Durum* cultivars. Field experiments, using advanced 'Temperature gradient tunnels' with different dates of sowing to study the impact of rising temperature on growth and development of different crops, revealed that an increase of temperature from 1 to 4 ^{0}C reduced the grain yield of rice (0-49%), potato (5-40%), green gram (13-30%) and soybean (11-36%). However, one of the important pulses, chickpea, registered 7-25% increase in grain yield by an increase in temperature up to 3 ^{0}C, but was reduced by 13% with a further 1 ^{0}C rise in temperature. The increase in crop productivity due to higher CO_2 in the atmosphere is likely to be negated by rising temperature.

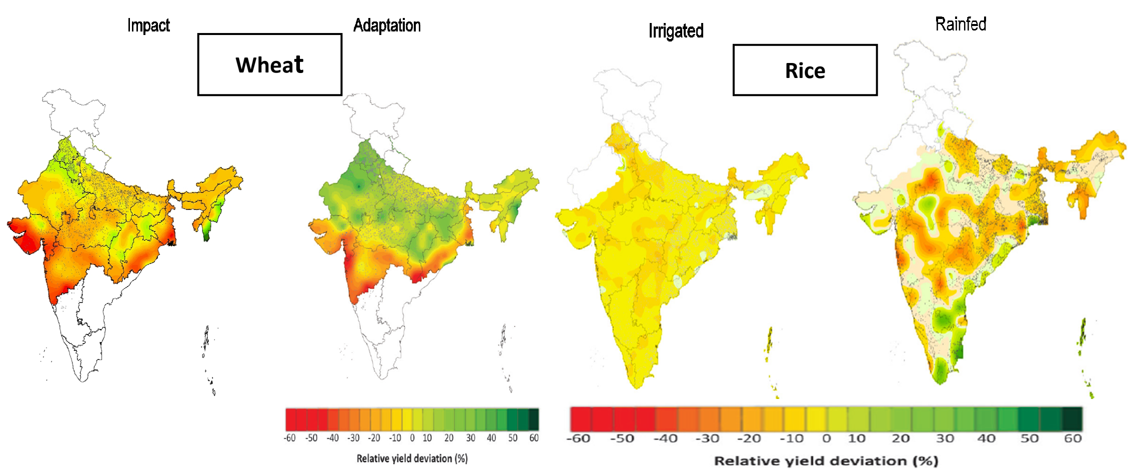


Fig4. Impacts on wheat and rice-2020 scenario

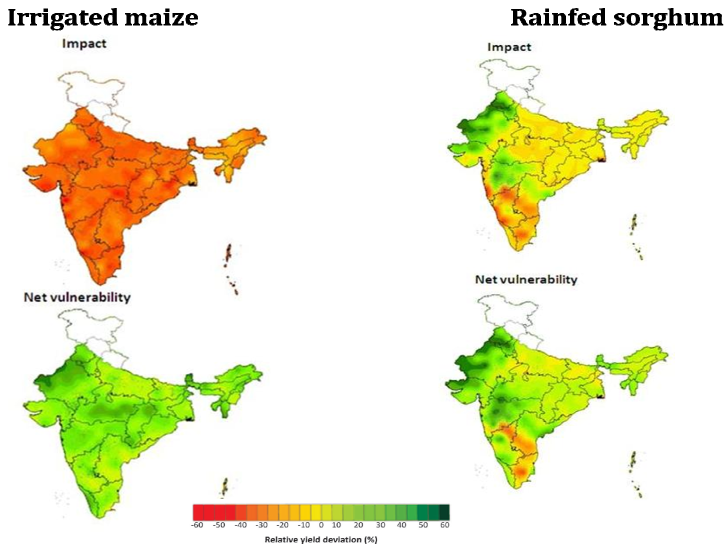


Fig 5.Climate change impacts and net vulnerability of Maize and Sorghum

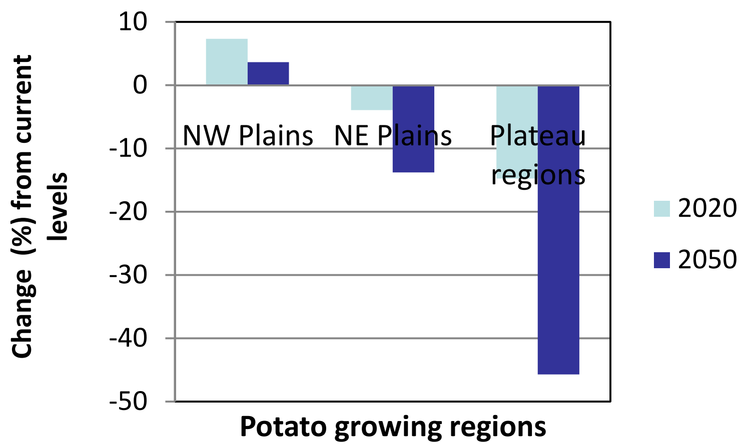


Fig 6. Impact of climate change on potato production in different regions of India

A significant decrease in average productivity of apples in Kullu and Simla districts of Himachal Pradesh have been reported which is attributed mainly to inadequate chilling required for fruit setting and development. Reduction in cumulative chill units of coldest months may have caused shift of apple belt to higher elevations of Lahaul-Spitti and upper reaches of Kinnaur districts of Himachal Pradesh. However, results from simulation models suggest that climate change could benefit coconut crop. Coconut yields are likely to increase by 4, 10, and 20% by 2020, 2050 and 2080, respectively, in the western coastal areas of Kerala, Maharastra, Tamil Nadu and Karnataka. But the impact may be negative in east coast areas as they are already facing a much warmer atmospheric thermal regime than western coast.

Besides, the nutrient loss from soil through high rate of mineralization, CO_2 emissions from soil could be accelerated as a result of increase in temperature. Low carbon soils of mainly dryland areas of India are likely to emit more CO_2 compared to high or medium carbon temperate region soils. Simulation of water balance using

Global and Regional Climate Models revealed likely increase in annual as well as seasonal stream-flows of many Indian river basins pointing to the need for adoption of more effective runoff and soil loss control measures to sustain crop production across the country.

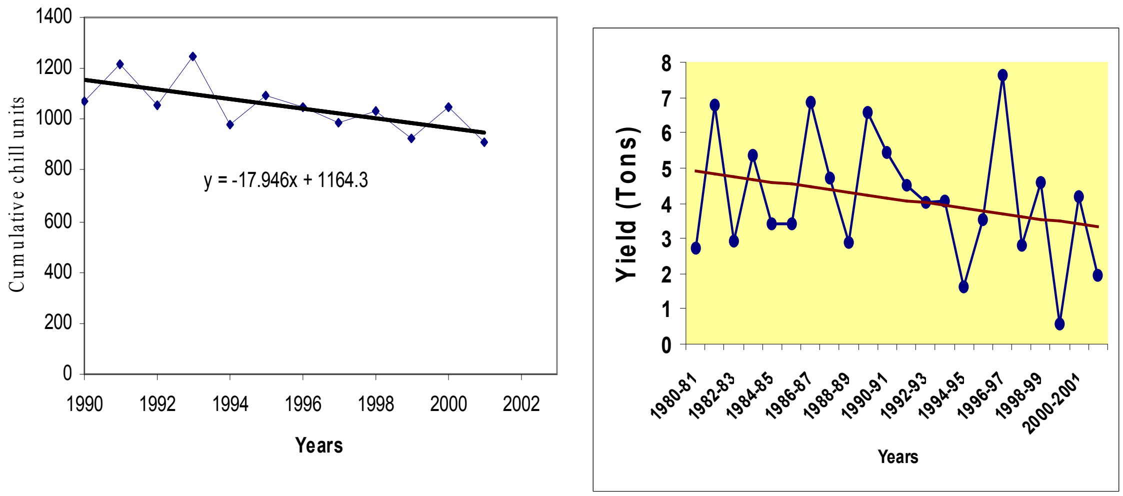


Fig 7. Shift in apple cultivation to higher elevations due to non fulfillment of chilling requirement

Agroforestry can play a significant role in mitigation through carbon sequestration. It can been observed Carbon sequestration potential of agro-forestry in Bundelkhand region is currently of the order of 22.42 Mg C ha^{-1} and is likely to increase up to 35.78 Mg C ha^{-1} at end of rotation period. In the middle Gangetic plains (Jaunpur, Pratapgarh, Azamgarh and Basti districts), it ranged from 18.5 to 21.80 Mg C ha^{-1} and after 24 years it is projected to increase in the range of 28-38 Mg C ha^{-1}. The annual C sequestration in coconut above ground biomass varied from 15 Mg CO2/ha/year to 35 Mg CO2/ha/year out of which 2-3 Mg CO2/ha/year stocked into stem. The carbon sequestration potential of arecanut plantations ranged from 5.14-10.94 Mg CO2/ha/year while that of cocoa plantation ranged from 2.02-3.89 Mg CO2/ha/year (Fig 8).

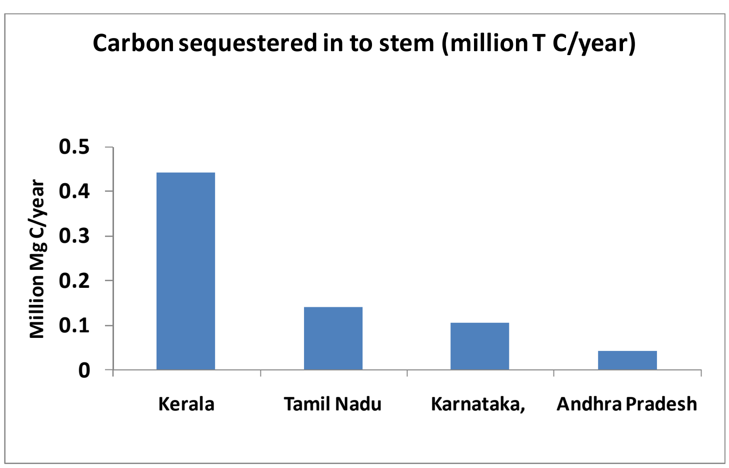


Fig 8. Mitigation options - Carbon sequestration potential of plantation crops and agroforestry

Crop-Pest Interactions

The change in climate may bring about changes in population dynamics, growth and distribution of insects and pests. Changes in rainfall, temperature and wind speed pattern may influence the migratory behaviour of the locusts. Most crops have C_3 photosynthesis (responsive to CO_2), while many weeds are C4 plants (non-responsive to CO_2). The climate change characterized by higher CO_2 concentration will favour crop growth over weeds. The impact of rising temperature and CO_2 are also likely to change insect pest dynamics. Dilution of critical nutrients in crop foliage may result in increased herbivory of insects. For example, Tobacco caterpillar (*Spodoptera litura*) consumed 39% more castor foliage under elevated CO_2 conditions than controlled treatments (Srinivasa Rao *et al.,* 2009).

Dairy sector

Global warming is likely to lead to a loss of 1.6 million tons in milk production by 2020 and 15 million tons by 2050. High producing crossbred cows and buffaloes will be affected more by climate change. Based on temerature-humdity index (THI), the estimated annual loss in milk production at the all-India level by 2020 is valued at Rs. 2661.62 crores at current prices. The economic losses were highest in UP followed by Tamil Nadu, Rajasthan and West Bengal. Stressful THI with 20 h or more daily THI-hrs (THI >84) for several weeks affects animal responses. Under climate change scenario, increased number of stressful days with a change in Tmax and Tmin and decline in availability of water will further impact animal productivity and health in Punjab, Rajasthan and Tamil Nadu (Upadhyay *et al*., 2009a; Annual Reports 2004 to 2010).

Increased heat stress associated with rising temperature may, however, caused distress to dairy animals and possibly impact milk production. A rise of 2 to 6 ^{0}C in temperature is expected to negatively impact growth, puberty and maturation of crossbred cattle and buffaloes. As of now, India loses 1.8 million tons of milk production annually due to climatic stresses in different parts of the country. The low producing indigenous cattle are found to have high level of tolerance to these adverse impacts than high yielding crossbred cattle. This needs to be explored by a systematic breeding programme emphasizing on increasing the productivity of indigenous breeds. Lactating cows and buffaloes have higher body temperature and are unable to maintain thermal balance. Body temperature of buffaloes and cows producing milk is 1.5- 2 ^{o}C higher than their normal temperature, therefore, more efficient cooling devices are required to reduce thermal load of lactating animals as current measures are becoming ineffective (Upadhyay *et al*., 2009b; Annual Reports 2004 to 2010).

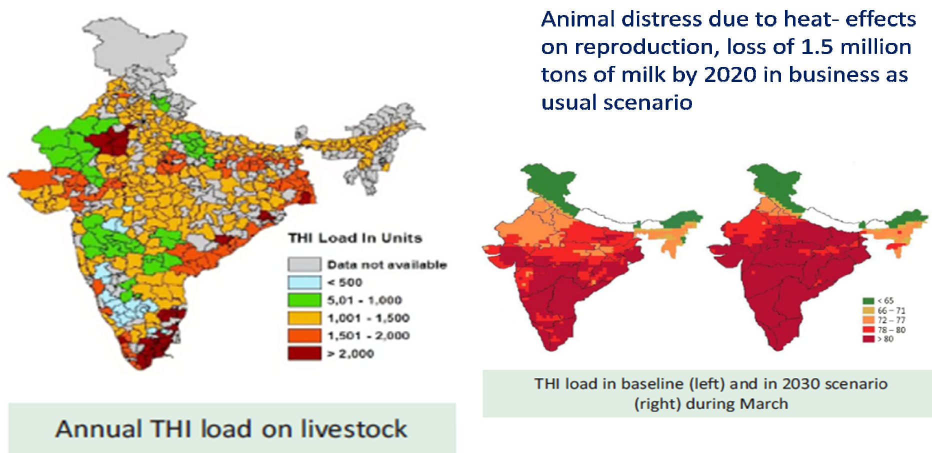


Fig 9. Annual Temperature Humidity Index load on cattle in India

Fishery Sector

Marine fisheries

A rise in temperature as small as 1°C could have important and rapid effects on the mortality of fish and their geographical distributions. Oil sardine fishery did not exist before 1976 in the northern latitudes and along the east coast of India as the resource was not available/and sea surface temperature (SST) were not congenial. With warming of sea surface, the oil sardine was able to find temperature of its preference especially in the northern latitudes and eastern longitudes, thereby, extending the distributional boundaries and establishing fisheries in larger coastal areas (Fig.10). (Vivekanandan *et al*., NPCC Annual Reports 2004 to 2010)

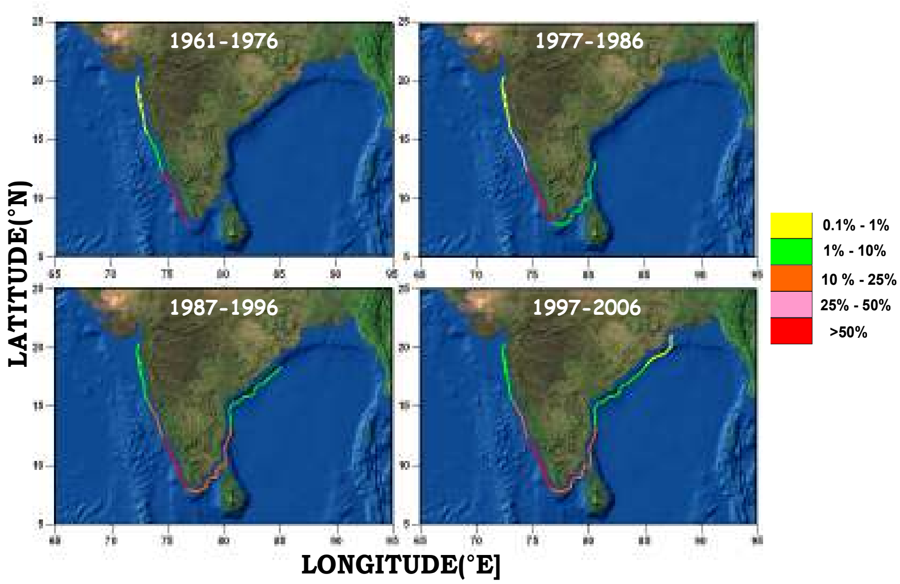
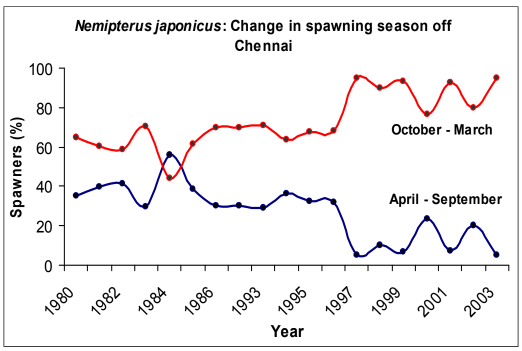


Fig 10. Extension of abundance of Oil sardine along Indian coast due to rise in sea surface temperature

The dominant demersal fish, the threadfin breams have responded to increase in SST by shifting the spawning season off Chennai. During past 30 years period, the spawning activity of *Nemipterus japonicus* reduced in summer months and shifted towards cooler months (Fig.11). A similar trend was observed in *Nemipterus mesoprion* too. Analysis of historical data showed that the Indian mackerel is able to adapt to rise in sea surface temperature by extending distribution towards northern latitudes, and by descending to deeper depths (Vivekanandan *et al*., 2009; Annual Reports 2004 to 2010)



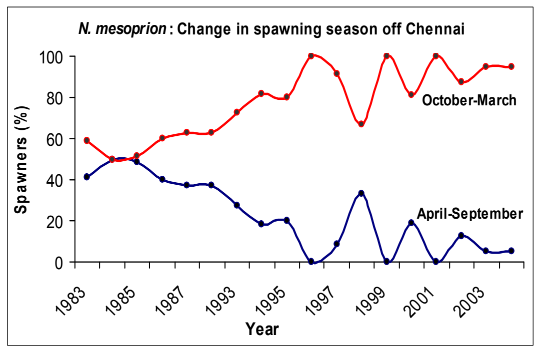


Fig 11. Change in spawning season of threadfin breams (N*emipterus Japonicas* **and N*. Mesoprion)*** **off Chennai**

Inland fisheries

In recent years, the phenomenon of Indian Major Carps maturing and spawning as early as March was observed in West Bengal with its breeding season extending from 110-120 days (Pre1980-85) to 160-170 days (2000-2005). As a result, it is now possible to breed them twice in a year at an interval ranging from 30-60 days. A prime factor influencing this trend is elevated temperature, which stimulates the endocrine glands and helps in the maturation of the gonads of Indian major carp. The average minimum and maximum temperature throughout the state has increased in the range of 0.1 to 0.9ºC (Das *et al*., 2009; Annual Reports 2004 to 2010).

Recent climatic patterns have brought about hydrological changes in the flow pattern of river Ganga. This has been one major factor resulting in erratic breeding and decline in fish spawn availability. As a result the total average fish landing in the Ganga river system declined from 85.21 tons during 1959 to 62.48 tons during 2004. In the middle and lower Ganga 60 genera of phytoplankton were recorded during 1959 and declined to 44 numbers by 1996. In case of Zooplankton during the same period, the number diminished from 38 to 26. A number of fish species, which were predominantly only available in the lower and middle Ganga in 1950s, are now recorded from the upper cold-water stretch up to Tehri (Das *et al*., 2009; Annual Reports 2004 to 2010)

Poultry Sector

In poultry sector, mortality due to heat stress, occurrs at about 34°C. It was significantly high in heavy meat type chickens (8.4%) as compared to light layer type (0.84%) and native type (0.32%) chickens. Increase in temperature from 31.6°C to 37.9°C decreased feed consumption by about 36% and egg production up to 7.5% in broiler breeders and up to 6.4% in commercial layers as compared to their standard egg production percentages. The critical body temperature at which the birds succumb to death was 45°C which was observed at the shed temperature of 42°C (Fig. 12). The naked neck birds performed significantly better than the normal birds with respect to thermo-tolerance, growth, feed efficiency and immunity in high temperatures as compared to normal broilers. The sperm viability and fertilizing ability, and live sperm counts were significantly reduced during high ambient temperature (Annual Reports 2004 to 2010)

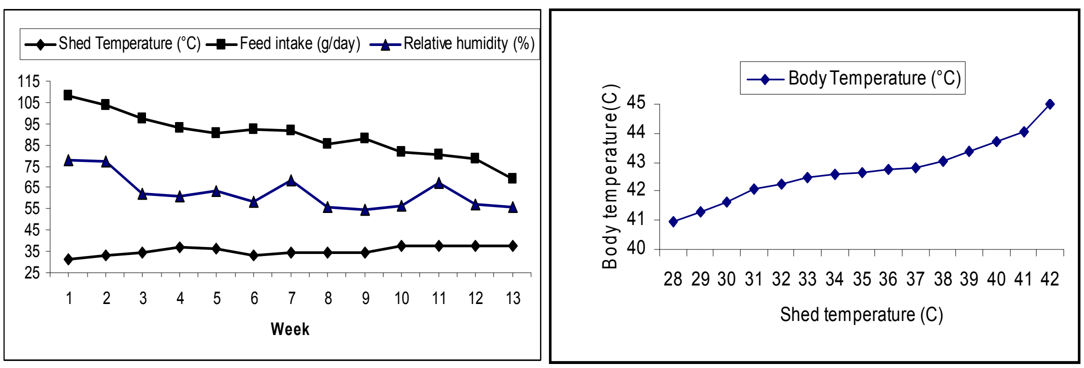


Fig 12. Influence of elevated ambient temperature on feed consumption.

Technology dissemination for empowering farmers:

The technology demonstration component of National Initiative on Climate Resilient Agriculture (NICRA) deals with demonstrating an integrated package of proven technologies for adaptation of the crop and livestock production systems to climate variability. This component is being 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 130 districts (see map) involving over one lakh farm families across the country (Fig. 13).

The selection of districts was based on analysis of climatic constraints of villages based on long term data, assessment of the natural resources status of the village, identification of major production systems, and study of existing institutional structures and identification of gaps through focused group discussion with the community to finalize the interventions.

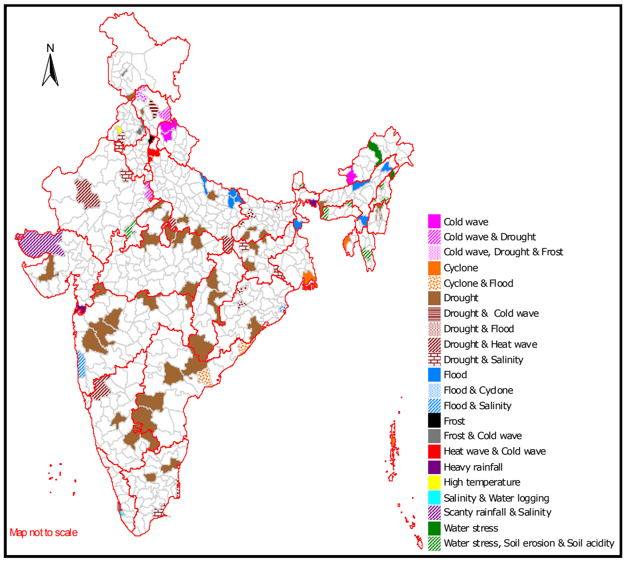


Fig 13. The location of 130 districts being covered in NICRA.

Rationale for Technology Demonstration Component (TDC)

Over the years, a plethora of technologies tailor made to suit different situations has been developed. 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 took a fresh look at these technologies to demonstrate them from the climate resilience perspective, as current efforts underway for developing climate resilient technologies may take some time before getting ready for implementation. The following points captured 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

With the following objectives:

- 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

The interventions covered under this component are broadly classified into four modules, *viz*: Natural resources, Crop Production, Livestock and Fisheries, and Institutional Interventions.

The Process

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 Station of the SAUs. After a careful study of the gaps, specific interventions from each of the modules were selected and an integrated package from all modules was formulated. The majority of the farmers were covered with one or more of the interventions in order to demonstrate a discernable effect. The project was launched in each village after giving 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.

The unique features of the project are that a baseline for all the project sites were established through a systematic benchmark survey, emphasis was on natural resource management interventions to build the communities' capacity to cope with climate variability through need based investment and establishment of a network of automatic weather stations across 100 KVKs as well as custom hiring centers in each project village for promoting mechanization on small farms and friendly setting up of Village Climate Risk Management Committees (VCRMC) – grassroots peoples' institutions to take need based decisions at the village level.

The project has already made a visible impact in helping the farmers in the vulnerable districts to cope up with the vagaries of weather.

Small weather station in project village to raise weather literacy

Improved implements at village custom hiring

VCRMC meeting in progress

Adaptation/mitigation strategies

A comprehensive strategy of utilization of existing knowledge, strengthening R&D in key areas and evolving a policy frame work that builds on risk management and providing incentives to sustainable use of natural resources will be required for successful adaptation to climate by the farm sector. The goal of this strategy is to minimize as risks associated with farming and enable farms to cope with these risks (Singh *et al.*, 2009).

The main adaptation strategies include development of new genotypes; intensifying search for genes for stress tolerance across plant and animal kingdom; intensifying research efforts on marker aided selection and transgenics development for biotic and abiotic stress management; development of heat and drought tolerant genotypes; attempt conversion of C3 plants to C4 plants; development of new land use systems; evolving new agronomy for climate change scenarios; explore opportunities for restoration of soil health; use multipurpose adapted livestock species and breeds; development of spatially differentiated operational contingency plans for weather related risks, supply management through market and non-market interventions in the event of adverse supply changes; enhancement research on applications of short, medium and long range weather forecasts for reducing production risks; development of knowledge based decision support systems for translating weather information into operational weather management sources; development of pest and disease forewarning systems covering range of parameters for contingency planning; conducting an integrated study of 'climate change triangle' and 'disease triangle', especially in relation to viruses and their vectors. Development of a compendium of indigenous traditional knowledge and explore opportunities for its utilization forms an important part of this strategy.

While adaptation measures are important, it also important to focus simultaneously on mitigation measures so that we contribute to a reduction in the pace of global climate change (Venkateswarlu and Arun Shanker, 2009). The important mitigation options include efficient water and nutrient management options to enhance use efficiency; evaluate carbon sequestration potential of different land use systems including opportunities offered by conservation agriculture and agro-forestry; identify cost effective opportunities for reducing methane emission in ruminants by modification of diet, and in rice paddies by water and nutrient management. Renewed focus is needed on nitrogen fertilizer use efficiency with added dimension of nitrous oxide mitigation. However, there is a need to assess the socio-economic implications of proposed mitigating options before developing a policy frame work.

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CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE

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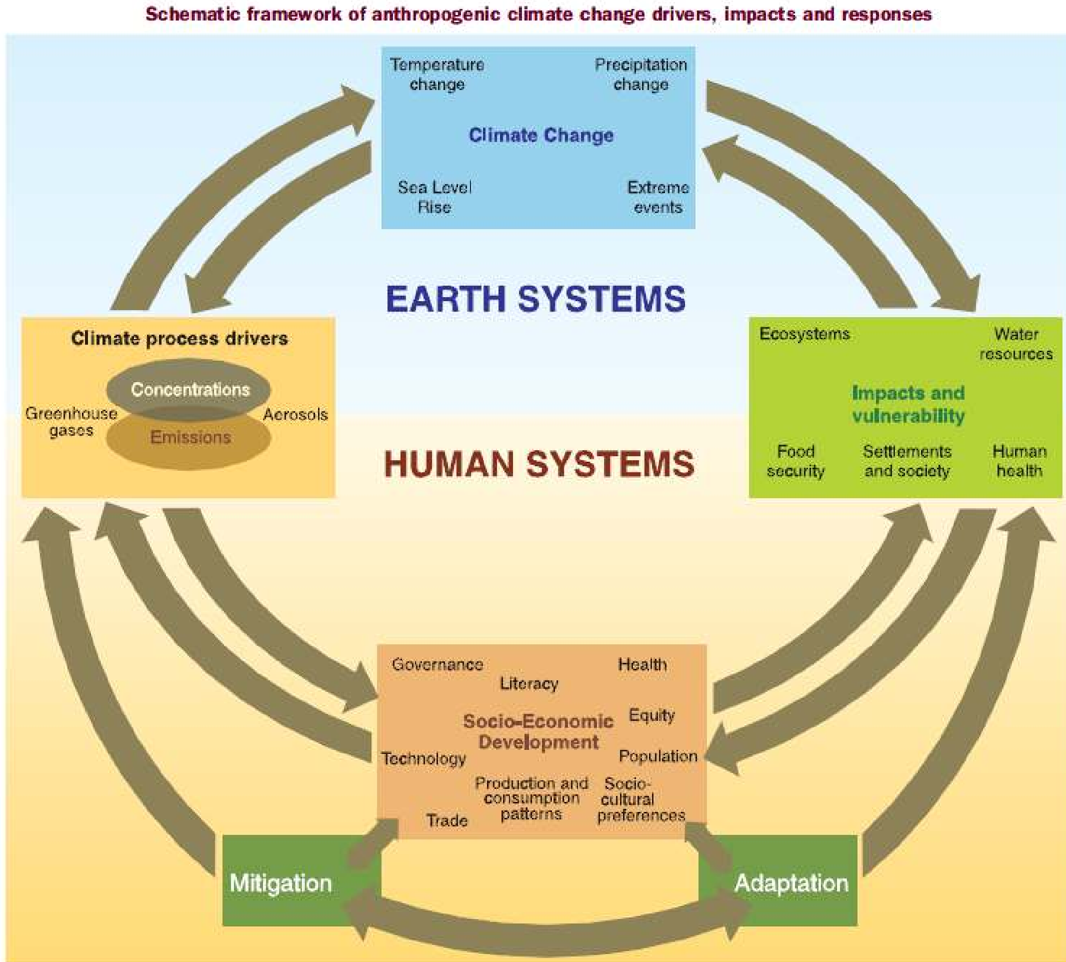
Agriculture is the sector most vulnerable to climate change due to its high dependence on climate and weather. Climate change is now a fact recognised globally. India, still an agrarian country with 70 % of the working population depends on agricultural activities for their livelihood. The ever increasing population and the food security increasing the pressure on Indian agriculture besides climate variability and change. Variability in onset of South west Monsoon and the distribution of rainfall in the kharif season are the key factors for crop production of the country. Temperature is the other factor effecting the rabi crops. The major cause to climate change has been ascribed to the increased levels of greenhouse gases like carbon dioxide (CO2), methane (CH4), nitrous oxides (NO2), chlorofluorocarbons (CFCs) beyond their natural levels due to the uncontrolled human activities such as burning of fossil fuels, increased use of refrigerants, and enhanced agricultural activities. The Inter-Governmental Panel on Climate Change has projected that the global mean surface temperature will rise by 1.4-5.8ºC by 2100 due to increase in carbon dioxide concentration in the atmosphere. Further, the projection of increase in extreme event frequencies further creating a chaos to the Indian agriculture. This paper mainly deals with the current level of climate change and the Impacts on Indian agriculture, some adaptation and mitigation strategies and vulnerability.

Introduction

Climate change (CC) refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC ,2007). The climate change is majorly ascribed to the increase in anthropogenic gases in atmosphere. The following picture shows how the anthropogenic gases drive the climate change in clockwise direction to derive climatic changes and impacts from socio-economic information and emissions With increased understanding of these linkages, it is now possible to assess the linkages also counterclockwise, i.e. to evaluate possible development pathways and global emissions constraints that would reduce the risk of future impacts that society may wish to avoid.

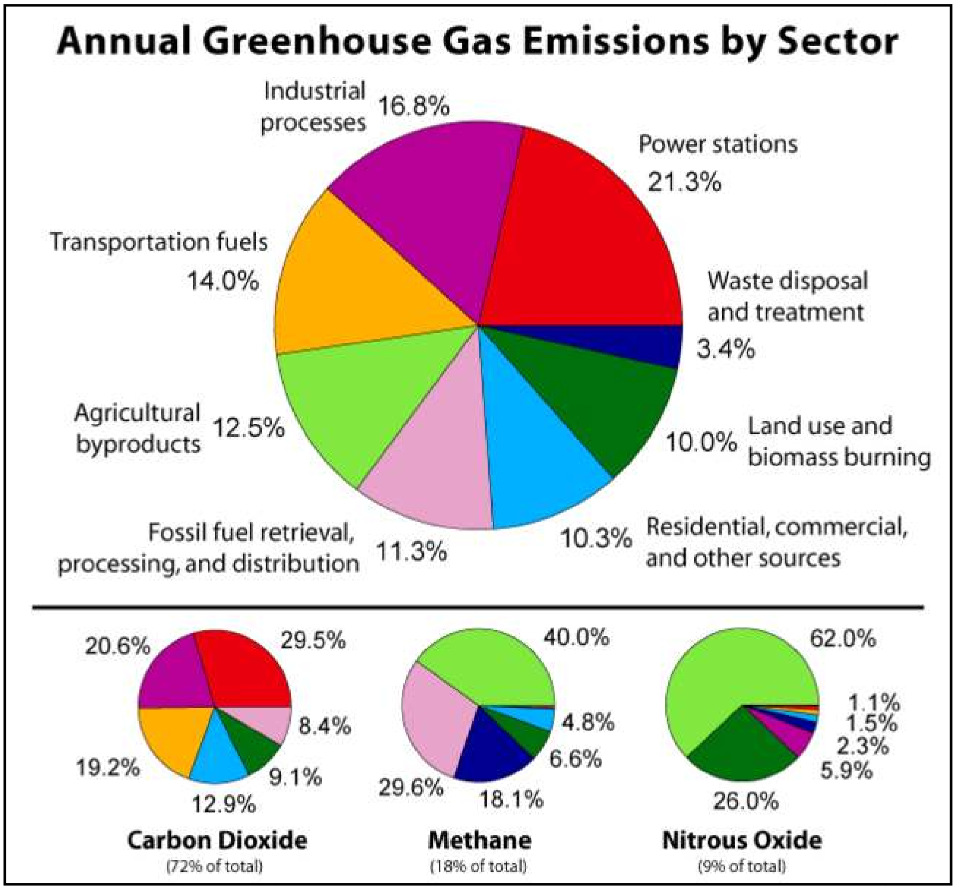


source: IPCC (2007)

Green House Gas (GHG)

Since the beginning of the Industrial Revolution, the burning of fossil fuels has contributed to the increase in carbon dioxide in the atmosphere from 280 ppm to 394 ppm, despite the uptake of a large portion of the emissions through various natural "sinks" involved in the carbon cycle.

The CO2 contribution from various sources namely burning of fossil fuels, deforestation etc. accounts for 76.6 percent of the total green house gas emissions over the globe. 44 percent of the entire GHG emissions over the globe are from the Industry and Energy sectors (Fig.)



Source: http://en.wikipedia.org/wiki/Greenhouse_gas

The IPCC (AR4), 2007 noted that "changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system", and concluded that "increases in anthropogenic greenhouse gas concentrations is very likely to have caused most of the increases in global average temperatures since the mid-20th century". In AR4, "most of" is defined as more than 50%.

Gas	Preindustrial level	Current level	Increase since 1750	Radiative forcing (W/m^2)
Carbon dioxide	280 ppm	394 ppm	114 ppm	1.46
Methane	700 ppb	1745 ppb	1045 ppb	0.48
Nitrous oxide	270 ppb	314 ppb	44 ppb	0.15
CFC-12	0	533 ppt	533 ppt	0.17

Global Temperatures

The Intergovernmental Panel for Climate Change (IPCC, 2007) reported that the temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans. These activities accelerated the processes of climate change and increased the mean global temperatures by 0.6°C during the past 100 years, a phenomenon known as global warming. Global average sea level has risen since 1961 at an average rate of 1.8 (1.3 to 2.3) mm/yr and since 1993 at 3.1 (2.4 to 3.8) mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and polar ice sheets. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 percent

(2.1 to 3.3) per decade, with larger decreases in summer 7.4 percent (5.0 to 9.8) per decade. Mountain glaciers and snow cover on average have declined in both hemispheres (Fig.).

The year 2011 tied with 1997 as the 11th warmest year since records began in 1880. The annually-averaged temperature over global land and ocean surfaces was 0.51°C (0.92°F) above the 20th century average of 13.9°C (57.0°F). This marks the 35th consecutive year (since 1976) that the yearly global temperature was above the 20th century average. The warmest years on record were 2010 and 2005, which were 0.64°C (1.15°F) above average. Including 2011, all eleven years in the 21st century so far (2001–2011) rank among the 13 warmest in the 132-year period of record. Only one year during the 20th century, 1998, was warmer than 2011**. (http://www.ncdc.noaa.gov/sotc/global/2011/13)**

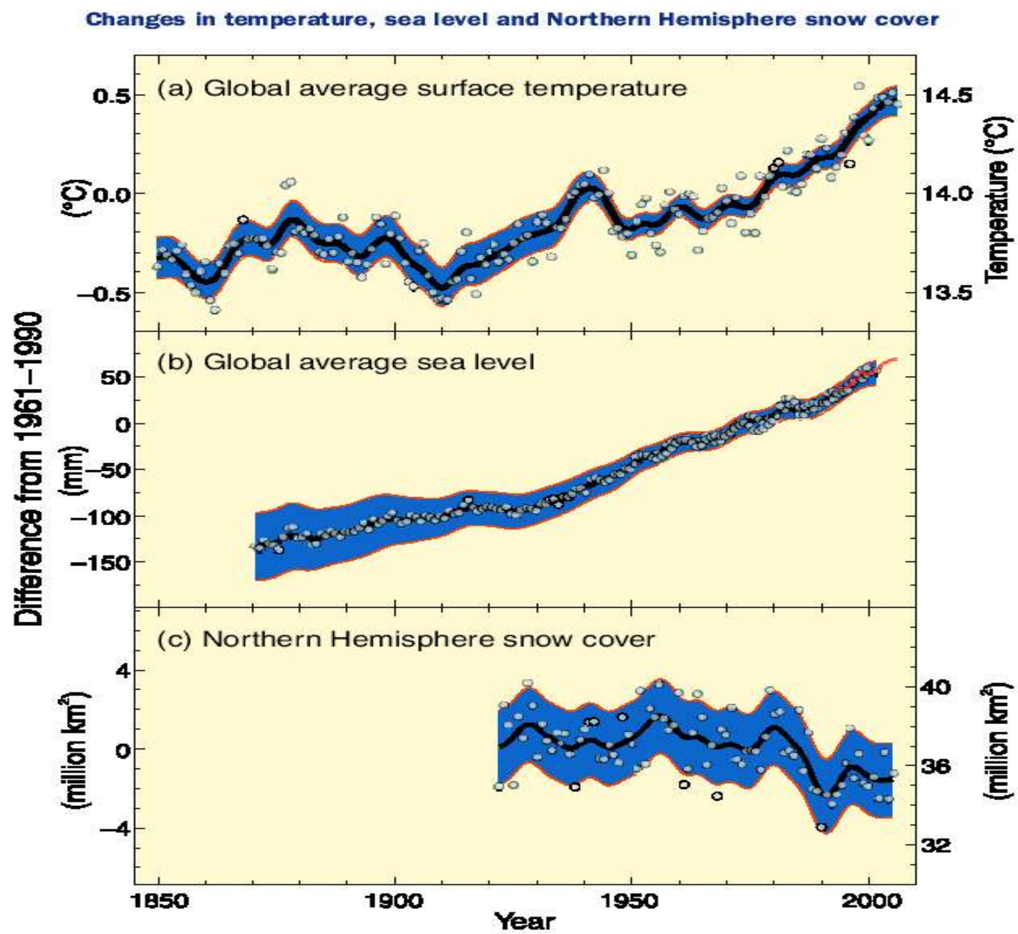


Fig. : Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. (IPCC,2007)

Over the past 50 years it was noticed that cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level has increased worldwide (IPCC, 2007).

Indian Scenario

Estimates of GHG emissions from the Indian agriculture sector arise from enteric fermentation in livestock, manure management, rice paddy cultivation, agricultural soils and on field burning of crop residue (Fig.). GHG emissions from livestock is estimated at 212.10 million tons of CO2 eq (10.1 million tons of CH4). This constituted 63.4% of the total GHG emissions (CO2 eq) from agriculture sector in India. The estimates cover all livestock, namely, cattle, buffalo, sheep, goats, poultry, donkeys, camels, horses and others. Manure management emitted 2.44 million tons of CO2 eq. where as in rice cultivation the estimated emissions are 69.87 million tons of CO2 eq or 3.27 million tons of CH4. The emissions cover all forms of water management practiced in the country for rice cultivation, namely, irrigated, rainfed, deep water and upland rice. The upland rice are zero emitters and irrigated continuously flooded fields and deep water rice emit maximum methane per unit area.

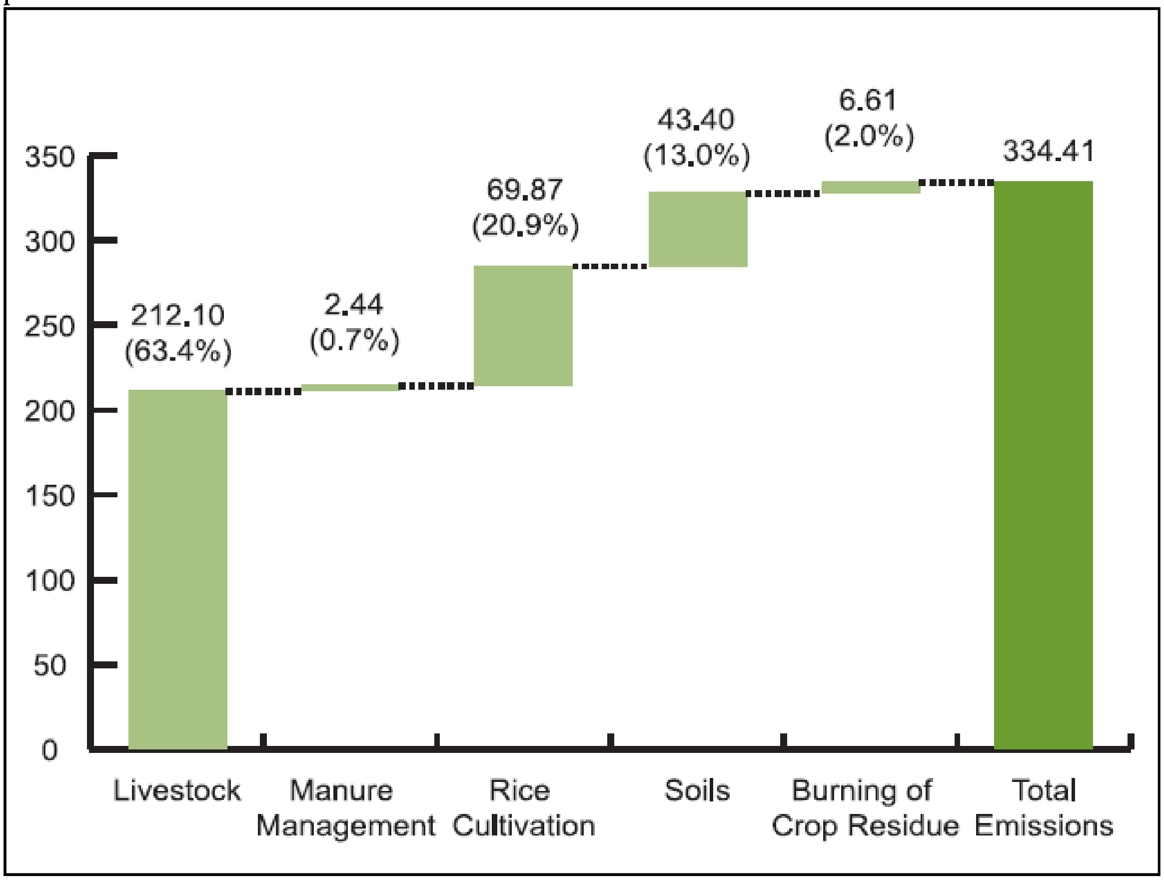


Fig: GHG emissions from Agriculture Sector (million tons of CO2 eq) (INCAA, 2007)

Temperature trends

In India, Rupa Kumar et al (2002). observed the warming trends were during all the four seasons with higher rate of temperature increase during winter and post-monsoon seasons compared to that of annual. (Table.)

TABLE.: TRENDS IN MEAN SURFACE AIR TEMPERATURES OVER INDIA DURING 1901-2000

Season	Trends (°C / Decade)
Annual	0.03*
Winter	0.04*
Pre-monsoon	0.02*
Monsoon	0.01
Post-Monsoon	0.05

* Significant at 95% and more (Source: Rupa Kumar et al., 2002)

Evaluation of trends in minimum and maximum temperatures for the entire country and also for the six homogenous regions in the country showed a decreasing minimum temperature trend during summer monsoon and an increasing trend during the winter season where as an increasing trend in both the seasons for maximum temperature was noticed which may have influence on rainfed agricultural production system in kharif and wheat production in rabi. Analysis of observed spatial patterns of maximum temperature indicate more than 45oC in central India, 35-40oC along west coast, about 25o C in Himachal Pradesh in North India (NATCOM Report, 2004). Arora et al (2005) reported that annual mean temperature, mean maximum and minimum temperature have increased at the rate of 0.42, 0.92 and 0.09 o C/100yr respectively.

The global average temperature for the last 100 years increased by 0.82°C (1901 to 2007) whereas in India, the analysis of data for the period 1901 to 2007 suggest that the annual mean temperature increased by 0.51°C (Krishna kumar,2009). It is observed that the increase in temperature was around 0.20°C per decade indicating greater warming in the recent decades.

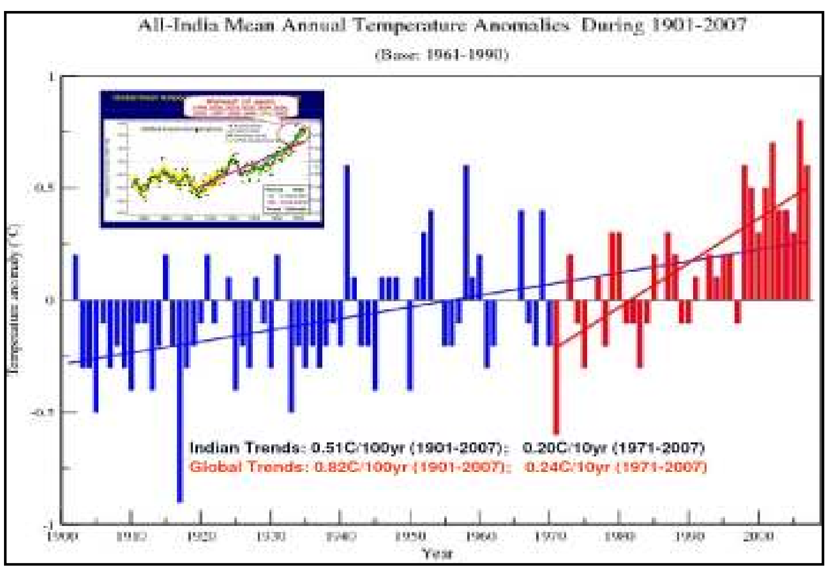


Fig. : Variation of All-India mean annual temperature during 1901-2007

The long-term trends in temperature were assessed with the minimum and maximum temperature data for 47 stations across the country for more than 50 years (DARE report 2008-09). Overall, 55 to 80% stations located across the country showed increasing trends in average annual temperature (fig.). About 75, 60 and 54% of the stations in south, east and central India, respectively, showed increasing trend in maximum temperature, whereas only 8 and 13% of the stations in central and west India, respectively, showed decreasing trend. Similarly 80, 78 and 75% of the stations in east, north and south, respectively, showed increasing trends in minimum temperature.

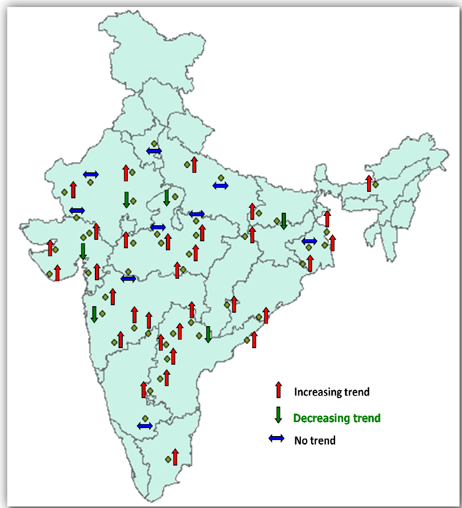


Fig.: Long-term (> 50 years) mean annual temperature (^{o}C) trends at 47 locations in India

Rainfall

No long-term trend in all-India mean Monsoon Rainfall was observed since 1871. Epochs of above/below normal monsoon activity with a periodicity of approximately 3 decades was observed. The current below normal epoch is still continuing (Fig.). Some changes are taking place in the monsoon rainfall character i.e. increase in the frequency and intensity of heavy rainfall events at the expense of low rainfall events were observed. Substantial decline in monsoon depressions and increase in low-pressure systems also observed

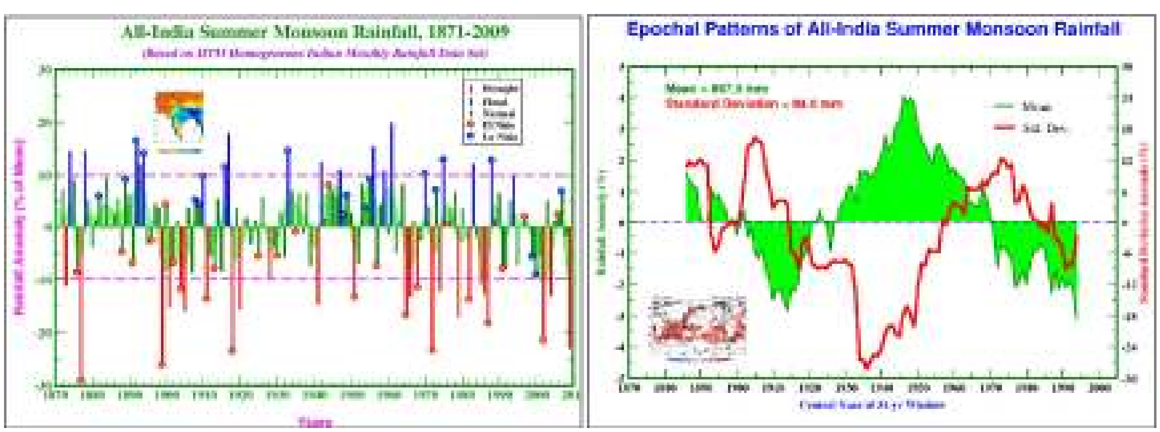


Fig. Long term trends in All India Summer Monsoon Rainfall (Krishna Kumar, 2009)

However at regional level, variations in rainfall patterns have been observed. Analysis of long-term rainfall data of over 800 stations across India show pockets of deficit rainfall over eastern Madhya Pradesh, Chhattisgarh and Northeast region in Central and Eastern India (Rao *et al*, 2007) especially around Jharkhand to Chhattisgarh. In contrast, increasing trends (+ 10 to 12%) in rainfall are observed along the west coast, northern Andhra Pradesh and parts of NW India (Note Action Plan on Climate Change 2008). However, there are indications of decadal shifts in monthly rainfall patterns in southern peninsular region.

Extreme Weather Events

A perception that is strongly felt is that during the recent decade, the extreme weather events (heat waves, cold waves, cyclonic activity) have increased. Number of depressions and cyclones were decreased but Intensity of cyclones increased. The cyclone that hit Orissa State (India) in October 1999 affected 12.9 million people and resulted in the loss of 1.6 million houses, nearly 2 million hectares of crops and 40,000 livestock. Human loss of 1,000 people who died in India during an intense heat wave in May 2002, and the 1,400 deaths in the heat wave in 2003. Continuous floods in different parts of Andhra Pradesh during 2005, 06 , 07 and 2009 after continuous deficit rainfall led to significant economic losses.
Though the number of droughts or floods per decade do not show any marked change, the intensities of these events have shown a significant increase.

Studies taken up at CRIDA showed that an increasing trend in frequency of occurrence of warm nights / nights with high minimum temperature was observed in north eastern states, West Bengal, Eastern Bihar, north & eastern Rajasthan, Haryana, Punjab, Uttarakhand, Himachal Pradesh, southern Jammu & Kashmir, western Gujarat, southern Andhra Pradesh, Karnataka and northern Tamil Nadu states. whereas cold nights showed declining in north Indian regions comprising north Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, western Uttar Pradesh, north & eastern Rajasthan, north west Madhya Pradesh and eastern India comprising West Bengal, eastern Jharkhand, Bihar, north eastern states, south and west Gujarat, west Maharashtra, coastal Andhra Pradesh, southern Karnataka, north western Tamil Nadu and northern Kerala(Fig.).

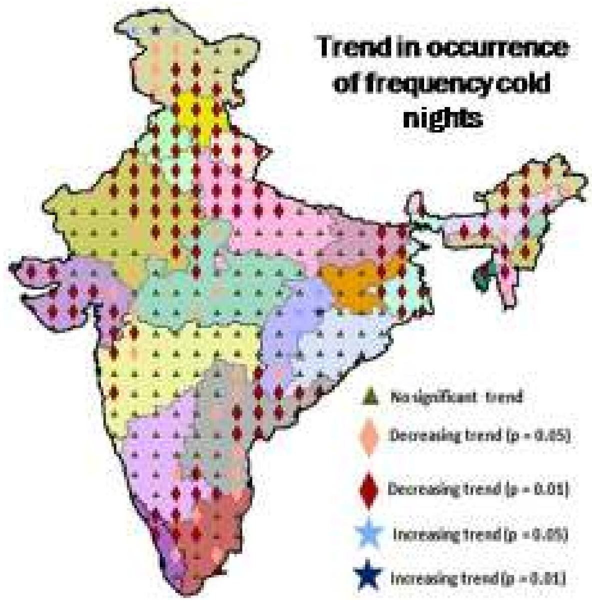


FIG: TREND IN OCCURRENCE OF FREQUENCY COLD NIGHTS

PROJECTED CLIMATE CHANGE FOR INDIA

The global atmosphere-ocean coupled models provide good representations of the planetary scale features, but their application to regional studies is limited by their coarse resolution (~300 km). Developing high resolution models on a global scale is not only very expensive besides time consuming for climate change simulations, but also suffers from errors due to inadequate representation of high-resolution climate processes worldwide. Instead, regional climate models (RCMs) can provide an opportunity to dynamically downscale global model simulations to superimpose the regional detail of a given regions.

High-resolution simulation on climate change has been carried out for India based using the second-generation Hadley Centre regional climate model (HadRM2). HadRM2 is a high-resolution climate model that covers a limited area of the globe (5,000 km x 5,000 km) with a horizontal resolution of 50 km x 50 km. Studies on Indian scenarios have conducted by the Indian Institute of Tropical Meteorology towards year 2030 (Krishna Kumar, 2010) on the basis of PRECIS (Providing Regional Climates for Impact Studies) runs, to assess the spatial patterns of seasonal rainfall over India (Fig.).

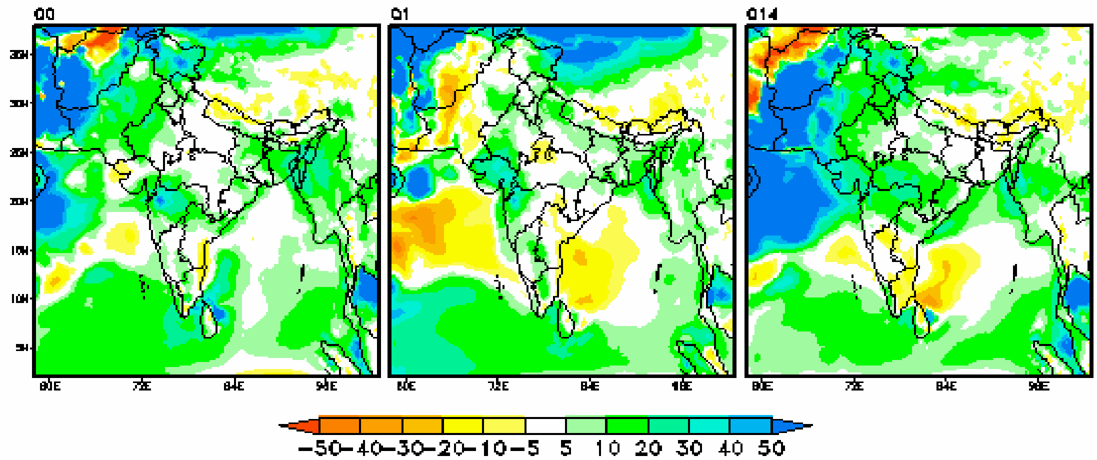


Fig.: Percentage change in the summer monsoon precipitation by three PRECIS runs towards 2030s with respect to 1970s.

Projected changes in 2030s:

- Coupled model simulations from IPCC AR4 show large uncertainty in simulating Indian summer monsoon rainfall, however a MME of 10 selected models give reasonably good representation of monsoon though with a dry bias at IITM, Pune (Krishna Kumar, 2010).
- Multi Model Ensemble (MME) projects around 10% increase in the Indian monsoon rainfall over central and peninsular India in
- 2030s. The expected change in the rainfall is within the current monsoon variability and there are large
- model to model differences making these projected changes to be lesser confident.
- MME projects 1.5-2oC warming in the annual mean temperature over the Indian landmass while winter
- (Jan-Feb) and spring (Mar-Apr-May) seasons show higher warming.
- High resolution regional climate model 'PRECIS' shows good skill in representing smaller scale features of monsoon.
- The projections of PRECIS in 2030s indicate 3-7% increase in all-India summer monsoon rainfall.
- The annual mean surface air temperature may rise from 1.7°C to 2°C by 2030s as indicated by the three simulations
- The regional climate model simulations indicate that the cyclonic disturbances over Indian Oceans during summer monsoon are likely to be more intense and the systems may form slightly to the south of normal locations.
- The ensemble mean changes in the monsoon rainfall are in the range of 2 to 12% while the annual temperature changes are of the order of 1.4 to 1.9o C, however the individual simulations show large differences.

Impacts of Climate Change on Agriculture

Climate Change associated with global warming would have profound influence on regional climate conditions and would impact the future performance on agriculture and allied sectors in many ways. The likely impacts on these systems are briefly given below.

AGRICULTURE

With rapid increase in population and urbanization, the availability of arable land dwindled considerably from 0.48 ha in 1950 to 0.15 ha in 2005 and is likely to further reduce to 0.08 ha by 2020 (Mall *et al*, 2006). Under the climate change scenario, the impacts on agricultural production in India are likely to be manifolds and the magnitude may vary greatly by the region. Some of the expected impacts are:

- The agricultural crops in eastern region in the country are predicted to be most affected by increased air temperature.
- Major shifts in cropping pattern are expected to take place and the areas under *rabi* crops are likely to be reduced and the cropping zones may move northwards to suitable cooler climate regions.
- Reduction in crop yields is more likely in the rainfed areas due to changes in rainfall pattern during monsoon season and increased crop water demands.
- There would be an increase in extreme weather events (heat and cold waves, high rainfall events) adversely affecting agricultural productivity.
- Although, increased levels of Co_2 may increase net primary productivity of plants, the changes in temperature associated with the above phenomena may nullify the benefit.
- Potential yields of major cereals crops especially wheat is likely to be reduced due to likely increase in minimum temperatures during the reproductive period.
- The yield levels of some of the major pulses like pigeonpea in *kharif* and chickpea in *rabi* sorghum are to be decreased.

Experimental studies under Network project on Climate change (NPCC) reveals that

- Reduction in yield of rice, mustard & chickpea @ 3-5 % per ^{0}C increase as compared to 5-8% reduction in yield of wheat, groundnut, green gram, soybean and potato when the temperatures were raised gradually (1 to 3 ^{0}C). Among the crops wheat showed highest degree of thermal sensitivity.
- The grain yield and biomass of wheat were reduced @ 10-12 and 8-10% per degree Celsius increase in atm. temp.

- Gradual rise in atmospheric temp. caused marked depletion in pollen germination of different rice cultivars, while lower temp. showed remarkable reduction in pollen germination of wheat cultivars

- Wheat and rice showed greater thermal sensitivity during reproductive and vegetative growth phase, while mustard and greengram registered greater thermal sensitivity during ripening growth phase (seed filling period).

OTC Studies

- The OTCs studies revealed that pulse crops in general are more responsive to elevated CO2 for both biomass and seed yield.
- The impact of elevated levels of CO2 in improving the harvest index in pulses indicates that elevated CO2 influencing the partitioning of assimilates towards economic yield
- Among the cereals Sorghum was found to be less responsive followed by Maize and Bajra.

Fisheries and Aquaculture

With increase in sea surface temperature (SST) and rise in sea level, the marine life would get affected considerably. Similarly, the inland aquaculture also would be affected due to changes in water body temperatures.

- Impacts of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish. Also the loss of infrastructure, fishing tools and housing will be enormous.

- Migration of different marine and inland species to favourable climate regions.

- In general temperature changes are likely to impact cool water species negatively, warm water species positively.

Mitigation Strategies

All the above projections indicate that the impacts of climate change would have considerable physical and socio-economic consequences on the country's linked resources and would have a strategic influence on future livelihood prospects of large percentage of the country's population. There is already considerable awareness on these issues and the country, at the highest level had initiated special drive on adaptation and mitigation strategies to face the challenges posed by the climate change. Briefly they are described below;

1. Improve inventories of emission of greenhouse gases using state-of-art emission equipments coupled with simulation models, and GIS for upscaling

2. Evaluate carbon sequestration potential of different land use systems including opportunities offered by conservation agriculture and agro-forestry
3. Critically evaluate the mitigation potential of biofuels; enhance this by their genetic improvement and use of engineered microbes

4. Identify cost-effective opportunities for reducing methane generation and emission in ruminants b y modification of diet, and in rice paddies by water and nutrient management. Renew focus on nitrogen fertilizer use efficiency with added dimension of nitrous oxides mitigation
5. Assess biophysical and socio-economic implications of mitigation of proposed GHG mitigating interventions before developing policy for their implementation

Policies

1. Mainstreaming adaptation in current policy considerations: Climate change impacts and adaptations should be considered in all major development planning activities.

2. Develop new infrastructure, policies and institutions to support the new land use arrangements identified by science and technology.

3. Enhance investment in water harvesting and conservation options; and promote small farm mechanization and efficient water use technologies.

4. Facilitate greater adoption of scientific and economic pricing policies, especially for water, land, energy, and other resources.

5. Explore international partnerships for joint food security.

6. Consider financial incentives and package for improved land management including resource conservation/ enhancement (water, carbon, energy), and fertilizer use efficiency.

7. Establish an inter-ministerial institutional mechanism for strategic follow-up action.

8. Consider incentives for industry and farming community for producing and using slow release fertilizers and Green House Gas inhibitors.

9. Explore CDM benefits for mitigation strategies for farmers and agriculture-based industry.

10. Explore international partnerships for collaborative research on adaptation of climate change r research.

11. Establish ‘Green Research Fund’ for strengthening research on adaptation, mitigation and impact assessment.

Epilogue

It has been noticed that climate change is a reality due to sharp increase in the concentration of green house gases since the industrial era. This has altered the climatic systems and has influenced the regional climate by way of increased frequency of extreme weather events and change in moisture and thermal regimes. The resultant impacts are expected to influence various sectors, *viz*., water resources, agriculture, forestry, natural ecosystems, fisheries and aquaculture and energy. The impact assessment studies due to projected climatic changes in the next 100 years provide directions and clues to develop adaptation and mitigation strategies in coping up with the expected changes in future. Perhaps, this review article may pave way in identifying suitable solutions for minimizing the risk and stabilize the agricultural production in meeting the future food requirements. More details on the impacts, adaptation and management strategies to meet the future climate change situations are discussed in detail in the chapters that follow in this publication.

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RAINWATER MANAGEMENT AS AN ADAPTATION STRATEGY TO CLIMATE CHANGE

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Rainfall is a basic resource for all the forms of water in semi arid tropics of India. Though the annual average rainfall of the country is 1200 mm, it varies in both space and time affecting the availability of water for different sectors. India uses 80% of the available water in agriculture keeping the remaining 20% for drinking, industry and energy sectors. The growing population puts tremendous pressure on the water resources. The annual per capita water availability has decreased from 5000 m3 in 1950 to 1300 m3 in 2010 and projected to decrease further to below 1000 m3 by 2025 (MOWR,2011). Added to this, the country may face climate change in future predicting more frequent floods, droughts, extreme events of rainfall etc. with increased temperature (IPCC, 2007). The food grain production in India is calculated by irrigated and rainfed areas by 60% and 40% respectively. Most of the pulse and oil seeds production (80%) comes from rainfed areas. Rainfed areas are suffer from severe land degradation and poor socio economic base of farmers.

Several management options are available at the farm scale to increase rainfall use
efficiency. Some of these are management of crop residues to improve infiltration and reduce sediment levels, construction of farm ponds for collection of excess rainfall flowing from the farm area, crop rotations and soil amendments (Freebairn *et al.,* 1986). Several researchers have shown that on-farm runoff collection into dugout farm ponds and supplemental irrigation can increase and stabilize the crop production (Krishna *et al.,* 1987). There is abundant scope and opportunity for harvesting excess runoff in the rainfed region in different states of the country (Wani, et al., 2003, Sharma et al, 2009) Among several interventions, farm ponds is the most important one in the integrated water management practices and other natural resource management. Farm ponds would help the farmers for on farm water management by using stored water for tackling the drought or dryspells during the season.

Planning of Farm Pond

Farm pond

Farm Pond is a dug out structure with definite shape and size having proper inlet and outlet structures for collecting the surface runoff flowing from the farm area. It is one of the most important rain water harvesting structure constructed at the lowest portion of the farm area. The stored water must be used for irrigation only. Inadvertently, some people use the farm ponds as ground water recharge structures which is not correct as per the definition. For recharging the ground water, the structures require high capacity and are generally located in the soils having high infiltration rates and are called percolation tanks. Percolation tank is meant for only recharge purpose and not for irrigation. Such structures conceptually differ in their hydrology and physical location. A farm pond must be located within a farm drawing the maximum runoff possible in a given rainfall event. A percolation pond can be dug out in any area where the land is not utilized for agriculture.

Farm ponds have a significant role in rainfed regions where annual rainfall is more than or equal to 500 mm. If average annual rainfall (AAR) varies between 500 to 750 mm, the farmponds with capacity of 250 to 500 m3 can be constructed. If AAR is more than 750 mm, the farm ponds with capacity more than 500 m3 can be planned particularly in black soil regions without lining. It was observed from the field experience and if present rainfall pattern changes; atleast two to three rainfall events producing considerable runoff are possible in a season making farm ponds an attractive proposition. Farm ponds conserve the natural resources like soil and nutrients apart from water and acts as flood control structure by reducing peak flows in the watersheds or given area of catchment. Depending on the source of water and their location; farm ponds are grouped into four

Types:
1) Excavated or Dug out ponds
2) Surface ponds
3) Spring or creek fed ponds and
4) Off stream storage ponds.

Soil type

India has 30% alfisols, 35% vertisols and 35% of other soils including alluvial, laterite, etc., in rainfed areas (Virmani, 1991). The distribution of different soils of India is given in. For construction of farm pond, the soils must have low hydraulic conductivity with minimum seepage and percolation so that water can be retained for more time in a farm pond. Soils with a low infiltration rate are most suitable for construction of pond. The black soils have good potential for rain water harvesting without lining as the seepage losses are minimum. The seepage losses are more in sandy soils and their mixed textures and they require lining for storing water for more time. The soils having outcrops and stones must be avoided for digging farm ponds. The soil profile depth must be investigated before digging of the pond. The soils having good depth of >1 m, free of stones, low Ph, Ec and ground water level may be choosen for site selection for farm pond. Peat soils have special problems, since they are usually very acidic in nature and need sufficient liming. Soils rich in limestone create special problems of precipitating phosphate and iron.

Soil depth

The depth of soil is important where rain water harvesting systems are proposed. Deep soils have the capacity to store harvested water for longer duration. Soils having more than 1m are ideal for construction of farm ponds. More the depth of soil, the depth of farm pond will be more and reduces the evaporation losses.

Topography

The topographic features of the farm catchment area may vary from place to place and proposed land for pond construction must have minimum earth excavation so that cost can be reduced with increased storage. Depending up on the capacity of the farm pond, the contour survey is conducted to determine the slope, drainage pattern within farm. However, for small catchments of 1-5 ha land, a reconnaissance is sufficient to identify the location for farm pond. The contour survey can be done by using dumpy level with staff or a total survey station which gives the digital map of the farm with contours. The farm pond must be located within farm itself looking into the slope and drainage flow pattern to the convenience of the farmer.

Drainage / Catchment area

The drainage/catchments area which produces surface runoff for storage in farm ponds is very important from hydrology point of view. The structure must get filled at least once in the season so that the farmers can use the water for critical irrigation during dry spells. The characteristics of a catchment that directly affect the runoff yield are the slope of the area, infiltration of the soil, vegetation, land use and shape of the catchment. These interrelated factors are variable and site-specific. If the drainage area is too small in relation to the pond size, the pond may not adequately fill, or the water level may drop too low during extended periods of hot, dry weather. The high intense rainfall events would cause soil erosion and the runoff carries the silt load into the farm pond. These problems can be solved through proper soil and water conservation treatments. In order to achieve the desired depth and capacity of a pond to be proposed, the inflow must be reasonably free of silt from an eroding catchment. The best protection is adequate erosion control through in situ moisture conservation or land management practices (Ridge and furrow, Broad bed furrow, Compartmental bunds, Contour bund and Graded bund etc). On the drainage contributing area. Land under permanent cover of trees or grasses are the most desirable drainage area. If such land is not available, treat the watershed with proper conservation practices to control erosion before constructing the pond. The catchments must be selected in such a way that, the drainage from farmsteads, feedlots, sewage lines, dumps, industrial and urban sites and other similar areas does not reach the pond.

Design of Farm Pond

Rainfall analysis

Rainfall is one of the most important and critical hydrological input parameter for the design of farm ponds. Its distribution varies both spatially and temporally in semi arid regions of the country. The quantity of surface runoff depends mainly on the rainfall characteristics like intensity, frequency and duration of its occurrence. The high intense rainfall exceeding infiltration capacity of soil can produce more runoff than the event with low intensity for longer duration. Apart from the physical characteristics of the catchment area contributing to produce surface runoff, the rainfall analysis is very critical for optimal economic design of farm pond. But long term data on rainfall intensity is seldom available in the country. A case of seasonal rainfall analysis is presented in this bullettin for the design of farm ponds.

Design rainfall

It is defined as the total amount of rain during the cropping season at or above which the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress for crop. If the actual rainfall exceeds the design rainfall, there will be surplus runoff which may cause damage to the structures. The design rainfall is calculated from the probability analysis. It is assigned some probability level of occurrence or exceedance. Suppose the probability of 67% is given to rainfall, it indicates that the seasonal rainfall may occurre or exceed 2 years out of 3 and therefore, the crop water requirements would also be met two years out of three in a crop season. More the probability of the rainfall, it is more reliable for getting assured runoff into the farm ponds.

Probability analysis

A simple graphical method can be used for probability analysis and frequency of occurrence of annual or seasonal rainfall for the design of ponds. There are several analytical methods by selecting a suitable probability distribution function. Weibulls distribution is commonly used for its simplicity and easy to adaptation for such fieldsituations. The first step is to get the seasonal rainfall (June to September) for the cropping season from the area of concern. It is important to obtain long term data for at least 20 years for the probability analysis. Short term data for 5 to 10 years may not be sufficient to represent the realistic rainfall pattern in the region. For the collected seasonal rainfall, each value has to be given ranks based on their amounts arranged in descending order. The occurrence of probability for each of the ranked observation can be calculated from the below equation (Critchley and Siegert, 1991) for the period N=10 to 100.

$$\mathbf{P}\ (\%) = \frac{\boldsymbol{m}-\mathbf{0.375}}{\mathbf{N+0.25}} \times \mathbf{100} \qquad \text{---(1)}$$

Where,

P = probability in % of the observation of the rank m

m = rank of the observation

N = total number of observations used.

Steps in probability analysis

1) Annual and seasonal rainfall for a period of 20-30 years may be collected from nearby weather station of either govt (or) research station or IMD for selected area.

2) All the above data may be entered into MS excel sheet.

3) Arrange the annual/ seasonal rainfall data in descending order and rank them, having maximum rainfall as 1 and the minimum value with maximum rank.

4) If two rainfall events are equal consecutively, the same rank must be given to both the quantities.

5) Calculate the probability of each rainfall by using the equation 1.

6) Plot the probability vs rainfall on normal probability paper.

7) Determine the rainfall for 50%, 67% and 75% from the plotting curve.

An example for probability analysis of annual and seasonal rainfall for 30 years at Gunegal Research Farm near Ibrahimpatnam of CRIDA representing Southern Telengana is given below. Thirty years (1981-2010) annual and seasonal rainfall at GRF are given in Table 1. From the above calculations, it is observed that the annual rainfall analysis gives more rainfall than the seasonal rainfall at all probabilities. Generally, farm ponds are more likely to be filled during seasonal rainfall than during other periods in a year. Therefore, annual rainfall analysis may give over estimated designs of farm pond than seasonal rainfall. Therefore, seasonal design rainfall is considered for further calculations.

Table.1. Annual and seasonal rainfall at Gunegal Research Farm (1981-2010)

Year	Annual Rainfall, mm	Year	Annual Rainfall, mm
1981	762	1996	590.6
1982	1022.5	1997	710.1
1983	850.5	1998	977.7
1984	534.2	1999	476.3
1985	553.5	2000	523.6
1986	602.3	2001	625.2
1987	911.9	2002	426.6
1988	570.1	2003	869
1989	769.5	2004	764.5
1990	1001.9	2005	1154.6
1991	883.2	2006	741.5
1992	507.4	2007	880.8
1993	584	2008	763.8
1994	790.5	2009	743.2
1995	1019.7	2010	780.8

Year	Seasonal rainfall, mm	Year	Seasonal rainfall, mm
1981	555.4	1996	341.3
1982	621.9	1997	439.1
1983	621.7	1998	731.6
1984	395.9	1999	370.8
1985	399.6	2000	459.9
1986	377.7	2001	490.3
1987	453.7	2002	241.3
1988	485.5	2003	651.9
1989	710.9	2004	381.5
1990	549.8	2005	683.6
1991	676.1	2006	515
1992	249.9	2007	716
1993	349.2	2008	431.8
1994	338.5	2009	496.2
1995	578.9	2010	550.8

On normal probability paper, the plot of annual/seasonal rainfall against corresponding probabilities is drawn as shown in Fig 1(a,b). The finally fitted curve would show the probability of occurrence or exceedance of rainfall value of a specific magnitude. It means that a seasonal rainfall of 500mm with probability of 50% may exceed or equal once in two years of period. With 67% probability, 425mm rainfall may exceed or equal twice in three years period. Similarly, it is three times in 4 years for 75% probability of 375mm seasonal rainfall as seen from the plotted graph (Fig 1(b)). On average, in case of annual rainfall, 760mm, 650mm and 600mm can be expected for 50, 67, and 75% probability respectively Fig 1(a).

Table 2. Rank and Probabilities of annual and seasonal rainfall at GRF

Year	Annual rainfall, mm	m	p (%)		Year	Seasonal rainfall, mm	m	p(%)
2005	1154.6	1	2.1		1998	731.6	1	2.1
1982	1022.5	2	5.4		2007	716	2	5.4
1995	1019.7	3	8.7		1989	710.9	3	8.7
1990	1001.9	4	12.0		2005	683.6	4	12.0
1998	977.7	5	15.3		1991	676.1	5	15.3
1987	911.9	6	18.6		2003	651.9	6	18.6
1991	883.2	7	21.9		1982	621.9	7	21.9
2007	880.8	8	25.2		1983	621.7	8	25.2
2003	869	9	28.5		1995	578.9	9	28.5
1983	850.5	10	31.8		1981	555.4	10	31.8
1994	790.5	11	35.1		2010	550.8	11	35.1
2010	780.8	12	38.4		1990	549.8	12	38.4
1989	769.5	13	41.7		2006	515	13	41.7
2004	764.5	14	45.0		2009	496.2	14	45.0
2008	763.8	15	48.3		2001	490.3	15	48.3
1981	762	16	51.7		1988	485.5	16	51.7
2009	743.2	17	55.0		2000	459.9	17	55.0
2006	741.5	18	58.3		1987	453.7	18	58.3
1997	710.1	19	61.6		1997	439.1	19	61.6
2001	625.2	20	64.9		2008	431.8	20	64.9
1986	602.3	21	68.2		1985	399.6	21	68.2
1996	590.6	22	71.5		1984	395.9	22	71.5
1993	584	23	74.8		2004	381.5	23	74.8
1988	570.1	24	78.1		1986	377.7	24	78.1
1985	553.5	25	81.4		1999	370.8	25	81.4
1984	534.2	26	84.7		1993	349.2	26	84.7
2000	523.6	27	88.0		1996	341.3	27	88.0
1992	507.4	28	91.3		1994	338.5	28	91.3
1999	476.3	29	94.6		1992	249.9	29	94.6
2002	426.6	30	97.9		2002	241.3	30	97.9

The return period T (in years) can easily be determined once the exceedance probability P (%) is known.

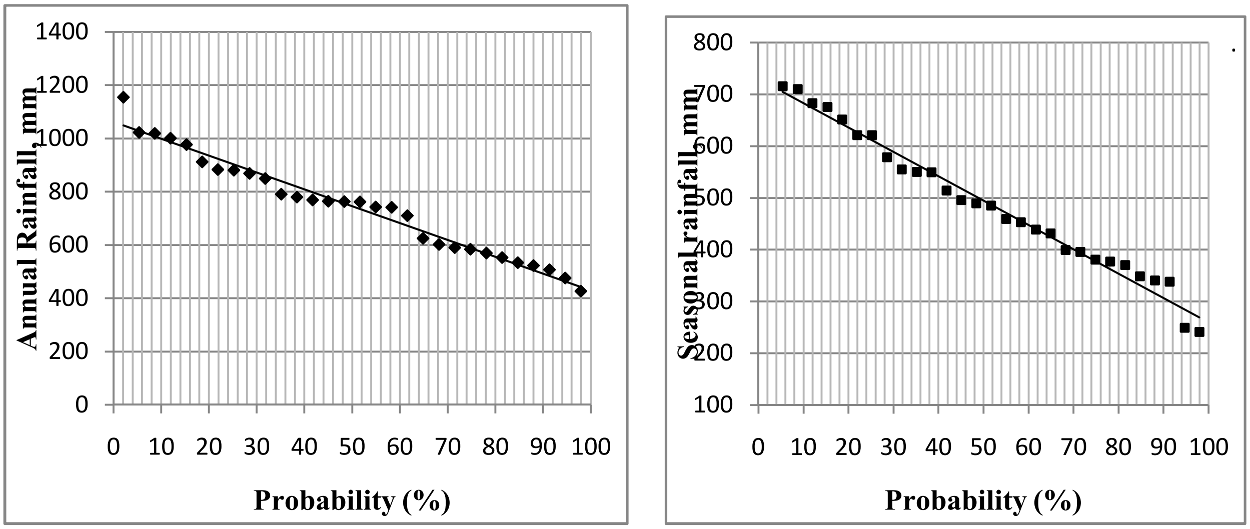
$$\mathbf{T} = \frac{\mathbf{100}}{\mathbf{P}} \qquad \text{------------------(2)}$$

From the above example, the return period for annual and seasonal rainfall can be calculated as below:

$$T_{50} = \frac{100}{50} = 2 \text{ years}$$

$$T_{67} = \frac{100}{67} = 1.5 \text{ years}$$

$$T_{75} = \frac{100}{75} = 1.3 \text{ years}$$



(a) Annual **(b) Seasonal**

Figure 1 (a,b). Probability plotting for an observed series of annual and seasonal rainfall at GRF

Surface runoff / Water yield

The surface runoff is generated in the catchment area after fulfilling the soil infiltration, interception and local depressions. It depends on the soil physical characteristics, land use characteristics, antecedent soil moisture, topography, shape and size of the catchment besides rainfall characteristics of intensity, frequency and duration.

Rainfall-Runoff relationship

There are several methods to estimate runoff. However, SCS curve number (USDA, 1967) is the most popular for the field engineers of soil and water conservation. It requires minimum data set of daily rainfall data , details of land use and its distribution, hydrologic groups of soils based on infiltration rate of the catchment area and antecedent moisture condition (AMC) of the watershed based on the previous 5 days consecutive total rainfall preceding the rainfall considered.

Catchment and Cultivable Area ratio

The water harvesting systems consist of catchment (collection) and a cultivable (concentration) area. The relationship between the two, in terms of size, determines by what factor the rainfall will be multiplied. For an appropriate design of a system, it is recommended to determine the ratio between catchment (Aca) and cultivable

area (Acu) based on information available on runoff coefficients and efficiency factor for the selected
Location. The calculation of (Aca): (Acu) ratio is primarily useful for rain water harvesting
systems where crops are intended to be grown and it can be related by the equation 2
(Critchley and Siegert, 1991) as given below:

$$\frac{\textbf{Crop water requirement - Design rainfall}}{\textbf{Design rainfall} \times \textbf{Runoff coefficient} \times \textbf{Efficiency factor}} = \frac{\textbf{Catchment Area}}{\textbf{Cultivable Area}} \quad \textbf{------ (3)}$$

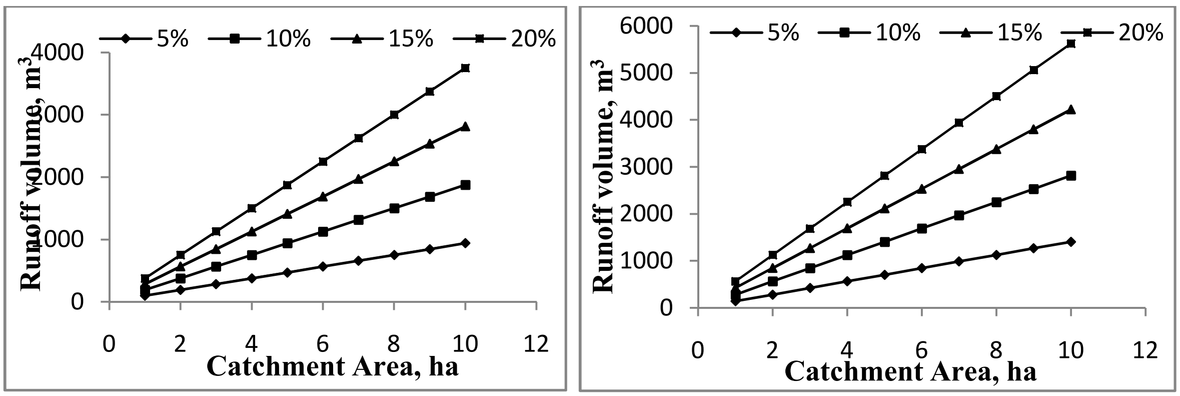
Crop water requirement
Crop water requirement depends on the type of crop and the climate of the location where
it is grown. It can be estimated from the climate data by using CROPWAT (FAO, 2011)
model.

Design rainfall
The design rainfall has to be calculated as suggested in section rainfall analysis. A conservative design would be based on a higher probability in order to make the system more reliable and thus to meet the crop water requirement more frequently.

Runoff coefficient
Runoff coefficient is the ratio of rainfall to runoff which flows along the ground. Degree ofslope, soil type, vegetative cover, antecedent soil moisture, rainfall intensity, frequency and duration of the rainfall are the major factors which influence the runoff coefficient. The coefficient usually ranges between 10 to 50% (Critchley and Siegert, 1991). A reasonable runoff coefficient must be selected based on the experience and physical characteristics of the catchment. Larger catchments will have low runoff coefficients with varying slopes. Black soils with mini catchments of 1 to 5 ha will have on an average the runoff coefficient of 10 to 20 % with mild to medium slopes (1-10%) (Adhikari et al, 2009). Higher runoff coefficients may be taken for slopes >10%. However, the red soils with high infiltration rates have runoff coefficients varying from 5 to 15% for the mild to medium slopes (1to 10%) and the catchment area varying from 1 to 14 ha for the design of farm ponds in semi arid regions. However, the runoff co efficients are site specific and they must be obtained from the research organizations nearby the area.

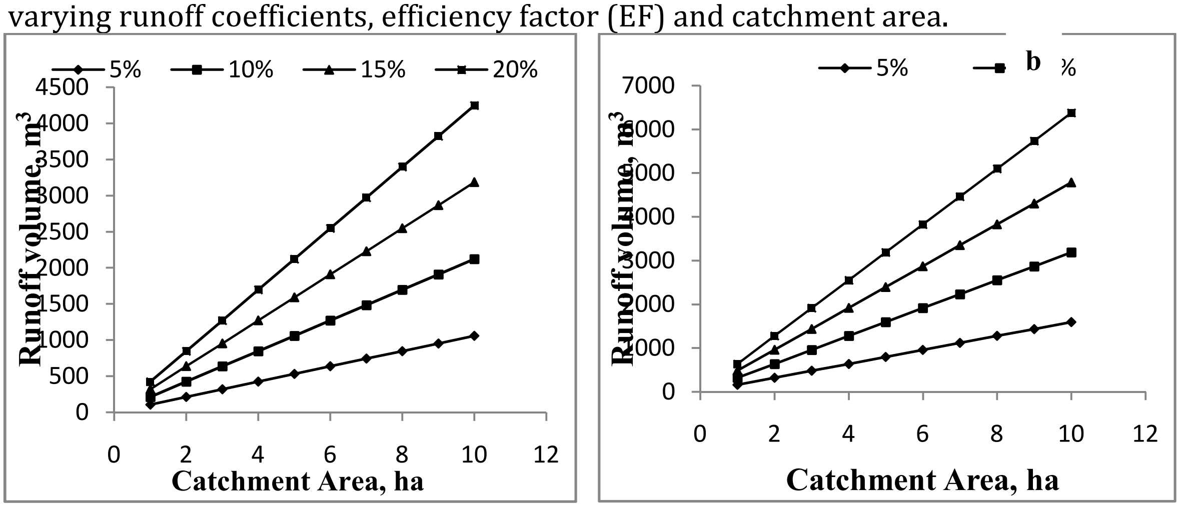
Efficiency factor
This factor takes into account the inefficiency of uneven distribution of the water with in the field as well as losses due to infiltration, surface depressions, evaporation and deep percolation. Where the cultivated area is levelled and smooth, the efficiency is higher. Micro catchment systems have higher efficiency as water is usually less deeply ponded. Selection of the factor is left to the discretion of the designer based on his experience and of the actual technique selected. Normally the

factor ranges between 0.5 to 0.75. A factor of 0.5 is selected for larger catchments and 0.75 is taken for micro catchments. The factor decreases with increasing catchment area (Aca). The ratios of catchment to cultivable area for southern Telengana region are calculated for different crops with design seasonal rainfall at probability of 75% with different runoff coefficients varying from 5 to 20% and efficiency factor of 0.5 for alfisols. The design rainfall of 375 mm at 75% probability was used in calculating the Aca : Acu. Based on the above information for different irrigation strategies with farm ponds, the cultivable area (Acu) for different crops can be estimated. For unlined farm ponds, the collected runoff volumes have to be multiplied with a factor of 1.5 for accounting water losses through seepage and evaporation. For linned farm ponds, the volume may be multiplied by the factor of 1.05 to account for only evaporation losses. These volumes have to be considered for the design of farm ponds in a selected catchments.



EF= 0.5 **EF= 0.75**

Fig 2(a). Expected runoff volume at design seasonal rainfall of 375mm (75% probability) for varying runoff coefficients, efficiency factor (EF) and catchment area.



EF= 0.5 **EF= 0.75**

Fig 2(b). Expected runoff volume at design seasonal rainfall 425mm (67% probability) for varying runoff coefficients, efficiency factor (EF) and catchment area.

Pond Design

A well designed pond is a valuable asset for integrated farming system with minimum maintenance cost. Proper construction of a pond must be preceded by proper planning and design. To design a pond, careful study is required with respect to the hydrology of the catchment, rainfall–runoff relationship, and requirement of water, expected seepage and evaporation losses. The main consideration in design is to provide enough water for agricultural operations at minimum cost. The analysis of these parameters will guide to decide the dimension of the ponds. Dimensions in designing a pond are the size, shape of the pond, side slopes and the water control structures (inlet, silt trap and outlet). The design of a excavated or dugout pond include the determination of specifications for the following: (a) Pond capacity, (b) Shape of pond, (c) Dimensions (depth, top & bottom widths and side slopes), (d) Inlet channels and (e) Emergency spillway or Outlet.

Pond Capacity

The capacity of the dugout pond depends on purpose for which water is needed and by the amount of inflow that can be expected in a given period. The seasonal water yield can be estimated using past historical weather data. The capacity of the pond depends upon the catchment size and factors affecting its water yield. On a conservative estimate, a dependable minimum value of 20% of the seasonal rainfall can be expected to go as runoff in case of black soils and 10% in case of red soils with mild to medium slopes. The pond should be of sufficient capacity to meet the demand of the crops or integrated farming system for which it is constructed. Generally, one or two supplemental irrigations with 50mm or less are planned for irrigating crops from such ponds. Barring summer months, the evaporation rate is fairly constant during the period of storage in the semi-arid regions. However, the seepage rate varies widely due to the variations in the sub-soil strata. A suitable provision should be made for the loss in storage capacity due to silting which is generally kept as 5-10 per cent. In sandy or light texture soils having high infiltration rate (>10cm/hr) will have a water loss of 50-60% in which seepage is predominant (40-50%). In such soils, the pond capacity must be designed for actual requirement of water for irrigation plus the seepage (40-50%) and evaporation losses (5%).

Shape of Pond

Excavated farm ponds may normally be of three shapes, viz; (a) square, (b) rectangular, and c) inverted cone. However, as curved shape offers difficulties in construction, either square or rectangular ponds are normally adopted. Inverted cone ponds with circular cross section are theoretically cheaper, but difficult to construct and manage. Lining of such ponds would require more material for the same capacity of square or rectangular farm ponds. Therefore, the lining of inverted cone farm ponds is costlier.

Dimensions of farm pond

The selection of dimensions for excavated pond depends on the required capacity, soil type, purpose and type of machine available for pond construction. The size of a pond should be relative to the size of the catchment area contributing surface runoff to the site. Ponds with too little catchment will have difficulty in filling up and remaining full during drought conditions. Ponds with too much watershed require expensive water control structures and are difficult to manage. Therefore, determination of optimum dimensions based on hydrological considerations is very important to keep the area loss to an extent of 10 to 12% in a farm catchment.

Depth and side slope of farm ponds

The depth of pond is generally determined by soil depth, kind of material excavated and type of equipment used. The selected pond depth should have a depth equal to or greater than the minimum required for the specific location as depth of pond is most important dimension among the three dimensions. In semi arid regions, the evaporation losses can be reduced by deepening the pond depth for the same volume of water stored as lesser is the area occupied by the pond. However, with increased depth, the seepage losses also increase. Seepage loss can be controlled by application of lining through LDPE/HDPE/Silpaulin plastic film. Water Technology Centre for eastern region reported that, when pond construction is done with labour, any increase in depth beyond 3.5 to 4.0 m becomes uneconomical. It also becomes uneconomical and difficult for lifting devices operated with human and animal power. Hence, a depth of 2.5 to 3.5 m may be suitable in general for the ponds.

The side slope of the pond are decided based on their angle of repose of the material being excavated and this angle of repose varies with type of soil. For the most cases, the side slopes of 1: 1 to 1.5:1 are recommended for practical purpose. Based on practical experience it is recommended that, selected side slopes are generally no steeper than the natural angle of repose of material. The recommended side slopes for different soil are given in Table 3.

Table 3. Suitable side slopes for different soils

Soil type	Slope (horizontal:vertical)
Clay	1:1 to 2:1
Clay loam	1.5:1to 2:1
Sandy loam	2:1to 2.5:1
Sandy	3:1

(Source: FAO, 2011)

The standing of water in a farm pond for a longer duration, may require relatively flatter side slopes to avoid slippage due to saturation. The area of the top and bottom for rectangular, square and inverted cone can be calculated from their dimensions in case of rectangular or square and diameter in case of inverted cone as per. Once the volume, depth and side slope are known, the dimensions of different shape of farm ponds can be calculated using the prismoidal formula.

$$V = \frac{A+4B+C}{6} \times D \qquad \text{------ (4)}$$

Where,

V = volume of excavation (m3)

A = area of excavation at the ground surface (m3)

B = area of excavation at the mid- depth point (D/2) (m3)

C = area of the excavation at the bottom of pond (m3); and

D = average depth of the pond (m).

From the equation (4) the bottom dimensions for rectangular is derived as given below:

$$X = (0.5/C)\left[\sqrt{Z^2D^2(1+C)^2 - 4C\{(4/3)\,Z^2D^2 - V/D\}} - ZD(1+C)\right] \qquad \text{---------- (5)}$$

Where, X, and Y are two sides of the dugout pond (rectangular) at the bottom and C= Y/X.

For a square section, C=1, i.e. X=Y, the equation (5) can be simplified as follows:

$$X = \sqrt{Z^2D^2 - (4/3\ Z^2D^2 - V/D\}} - ZD \qquad \text{---- (6)}$$

Construction of Farm Pond

After the site selection and pond dimensions decided, the pond site should be cleared of all stone and woody vegetation. Before construction of farm pond, proper layout should be made for proper construction. Stakes are used to mark the limits of the excavation and spoil placement areas and the depth of the cut from the ground surface to the pond bottom should be indicated on the stakes. Excavation and the placement of the dugout material are the principal items of work required in the construction of pond. Generally, the equipments used for pond construction are tractor pulled wheeled scrappers, draglines and bulldozers. The use of a bulldozer for excavation is usually limited to relatively small ponds due to its inefficiency in transporting the material. In semi arid regions any type of equipment can be used but in high rainfall areas where a ground water table exists in shallow depth, the dragline excavator is most commonly used equipment. The excavated material should be placed as near to the pond and that can be used for making the berm on the pond. After excavating of the earth, compaction of the sub grade and banks should be done thoroughly for proper establishment of the structure.

Earth moving machinery for excavation

The selected site should be free from vegetation, bushes and other obstacles and it should be levelled so that demarcation line of the pond area can be drawn. The design dimensions of proposed pond can be drawn with the help of rope and lines for demarcation can be done with lime powder or making small cuts with spade so that the demarcation lines are visible for equipment operator to enabling to excavate soil form the pond area. Initially digging of pond must be started at the central portion of layout to a designed depth indicated on stakes. There are two types of earth moving machinery like JCB with bucket volume of 0.1 m3 with short boom and Tata-Hitachi Volvo 200 model with bucket capacity of 1m3 with long boom of 4m. When the soil from the bottom of pond is completely removed, put the rope connecting to the corner of bottom area and outer top corner; give the required or desired slope at one corner of pond by cutting the soil. It is often suggested that shaping the pond must be done with cutting rather than filling of soil and this will facilitate better preparation of the sub grade, which is very important for stable pond boundary. The excavation soil should be compacted for its regular shape of trapezoidal bund with bottom width at least 1.5 to 2.5m and top width 0.5m and height of bund as 0.5m. The side slopes may be kept as 1:1. The bunds after compaction to the dimensions may be well grassed for its stability.

Operation and Maintenance of Pond

Proper maintenance of the pond can ensure good life and service as it prevents expensive repair costs. A pond, no matter how well planned and built, must be adequately maintained if its intended purpose are to be realized throughout its expected life. Lack of operation and maintenance has caused severe damage of ponds, and inlet, outlet channels. The pond should be inspected periodically. Care should be taken when heavy rains occur for the damages if any in farm pond. Initially damage may be small, but if neglected it may increase until repair becomes impractical. Any rills on the side slopes of the pond may be filled and any washes are in the inlet spillway must be immediately filled with suitable material with thorough compaction. Care should be taken to keep the water in the pond as clean and unpolluted as possible. Trampling by livestock, particularly dogs and wild life must be prevented.

Fencing

Fencing must be erected around the farm pond to prevent the entry of wildlife, stray dog etc. Fencing provides the protection from the damage and pollution by livestock. In farm field, cost effective vegetative hedges by using Henna, shallow rooted fruit trees, glyricidia etc., may be planned as protection to farm pond. Also, the barbed wire fencing with stones can also be preferred so as to reduce the cost of fencing.

Lining of Farm Pond

Lining of farm pond to control seepage and percolation losses would be helpful in supplemental irrigation at crop critical stages, livestock rearing and domestic water supply. Lining is required in farm pond to control seepage from the wetted surface area. Seepage losses are predominant in case of light texture soils where sand percentile is more as compared to clay and silt particles. Particularly, the farm ponds constructed in red soils require lining for long storage of water in the structures. Black cotton or vertislos or laterite soils do not require lining as the seepage losses are minimum because of more clay content.

It is found that water losses through seepage varies from 1.21 to 10.54 cumecs/million sqm from heavy clay loam to porous gravelly soils in the earthen ponds, are the major constraints to its failure. In other words we can say that the drop in depth per day (cm) of ponded water via seepage and evaporation is 10.36 to 90.65 cm from heavy clay to porous gravelly soils. Several material options are available for lining of farm ponds. The locally available material such as bricks and stones are used for hard surface lining of farm ponds. Such linings are constructed by using cement concrete and mortar. Asphaltic materials, paddy husk with cow dung. cement with soil mixture, flay ash mixture, bentonile have been tried to control seepage in farm ponds and their effectiveness are studied at different locations of the country bricks, stones etc.

Advantages of pond lining with plastic film

- Reduction in water losses through percolation and seepage to the maximum extent (95%).
- Availability of water for a longer period of time.
- Lining with plastic film has benefits in porous soils where water retention in pond and water harvesting tanks is minimal (Red soils).
- Prevents the lower area from the problem of water logging and prevents upward intrusion of salts in to stored water.
- Judicious utilization of stored water for the purpose of storage of drinking water, for fish culture and to provide supplementary irrigation during crop critical stages.
- Economical and effective method of storing water.

Method of laying Polyethylene films in farm ponds

For Laying of Polyethylene films minimum of 500 micron film are best suited for lasting of film and the following procedure are taken into consideration:

- Choose the film as per BIS/ISI mark
- Make the sides of the farm pond clean and smooth by removing vegetation and rills if any on the surface. A herbicide or weedicide may be applied on surface in advances so that there won't be any vegetation or root mass
- Make the trench of dimension 15 x 15 cm at the bottom along the sides for holding the plastic film firmly while laying
- Use minimum of 500 micron sheet or 300-350 gsm cross reinforced silpaulin
- Calculate the film requirement for dugout pond.
- Plastic films manufactured in to panels of standard widths. Therefore convert the film into a single sheet as a desired either mechanically by heat-sealing machine like Hot Air fusion welding machine or manually (by overlapping 15 cm of the edge of two sheet and scrubbed lightly using emery paper or sand paper (120 grade) using bitumen/ Synthetic Rubber adhesive No-998 made by fevicol so that it fit exactly to fit in to the pond.
- Monitor the film in sun light for searching/puncture hole if any, and seal the hole with bitumen/adhesive or by heat – sealing procedure.

- The ends of the film at the surface have to be firmly buried in a trench at the bank of the pond to avoid sagging in the pond with proper anchoring of the sheet in a trench and filling with soil.
- Care should be taken to avoid the wrinkles and film must be pulled at the corner.

Cost economics of construction of farm pond

Generally, the farm ponds are constructed with proper side slopes and inlet, silt trap and outlet structures to a recommended depth of 3 m. Presently, such structures are being done by using manual labour in the scheme of MNREGS implemented throughout the country by Govt. of India. But, they do not meet the design dimensions as required for meeting the crop water requirements and other uses. Therefore, it is recommended to use machinery articularly in hard soils where digging and earth removal becomes difficult by the human labour. Even in loose soils, the machinery is advisable for digging purpose and labor can be employed for making the side bunds and compacting soil. The earth moving machinery is available in the market with different bucket and boom sizes for digging purpose. The size of bucket varies from 0.1 to 1 m3 capacity with boom lengths varying from 2 to 4 m. A 4 m boom and 1 m3 bucket capcity machine can remove the earth quickly and make the pond with capacity of 500 m3 within 8 hrs of operation with proper side slopes and transport of the earth for bunding on the sides. The hiring charges with hagh capacity bucket machinery (TATA HITACHI V200 model) ranges from Rs1600-1700 in the market at present rates, which includes transport of the earth. On an average, the cost of digging becomes Rs26/ m3 of soil in constructing farm pond. For the machinery like JCB, it takes more time atleast 2.5 times more than the bigger machine. Therefore, digging of farm pond must be done on cluster approach identifying the group of farmers for implementing the scheme in watersheds or Govt. schemes in rainfed areas. The details are given in Table4.

Table 4. Construction cost of the different capacities of the lined farm ponds by using machinery

S. No.	Work component	Square	Square	Square	Inverted cone	Inverted cone
1	Dimensions of the pond Top dimensions Bottom dimensions , m×m	20 x 20 11x 11	27.5x27.5 17 x 17	17 x 17 8 x 8	14 dia 5 dia	20 dia 11 dia
2	Depth of pond , m.	3	3.5	3	3	3
3	Side slopes, Z:1	1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1
4	Capacity of the pond, m^3	741	1765	489	229	582
5	Cost for excavation of the soil, Rs.	19266	45890	12714	5954	15132
7	Surface area for lining, m^2	457	849	334	181	358
8	Required dimensions of the	24 x 24	32 x 32	21 x 21	18 x 18	24 x 24

	plastic sheet, m×m					
9	Lining with 500 micron Plastic sheet, Rs.	57,600	1,02,400	44,100	32,400	57,600
10	Construction cost of inlet requirements and spillway, Rs.	10,000	15,000	10,000	10,000	10,000
11	Labour cost for anchoring the lining plastic sheet including trenching, Rs.	11,520	20,480	8,820	6,480	11,520
12	Total cost, Rs.	98,386	1,83,770	75,364	54,834	94,252
13	Cost per unit volume of stored water, Rs./m^3	133	104	154	239	162

The unit cost of expenditure for creating storage of 1m3 of water decreases as the capacity of farm pond increases. The lining requirement is more in case of inverted cone farm ponds as the dimensions of the film are more for covering the pond surface area as it comes in square dimensions. In other dimensions of farm ponds with regular shape of square and rectangular, the lining requirement is less and easy to do the lining than the inverted cones.

Efficient utilization of runoff water

The field experiment was conducted in semi arid alfisols in southern telangana region by designing both raingun and sprinkler irrigation systems operated by 3hp diesel monoblock pumpset as shown in Fig 3.

Fig 3. Supplemental irrigation through raingun and sprinkler in rainfed crops

Supplemental irrigation:

The collected runoff in farm pond was used for supplemental irrigation in critical stages through spinkler irrigation systems. Supplemental irrigation was given in critical stages of peg initiation (30 DAS), pod formation and filling in ground nut (45 DAS) and pod setting (30 and 45 DAS) in Okra. The water productivity was calculated for both the crops in different treatments accounting for effective rainfall. The treatment supplemental irrigation with tank silt gave the maximum water productivity (WP) in groundnut and Okra during the three years as compared to rainfed. The water productivity recorded in the treatment of SI+ TS were 6.10, 6.67 and 23.77 t ha^{-1} mm^{-1} in 2008, 2009 and 2010 respectively for groundnut Table 5. In the treatment SI+NTS, the water productivity in groundnut obtained was 4.49, 5.96 and 20.31 t ha^{-1} mm^{-1} during respective years of experiment. The WP in groundnut in RF + TS was 3.37, 5.48 and 23.91 t ha^{-1} mm^{-1} during 2008, 2009 and 2010 respectively. In RF, the WP in groundnut was 2.66, 5.05 and 20.93 t ha^{-1} mm^{-1} in the three years respectively.

Table 5. Water productivity (kg ha^{-1} mm^{-1}) with (TS) and without (NTS) tank silt application in ground nut (ICGV91114) and Okra (Arka Anamica) in supplemental irrigation (SI) and rainfed (RF)

Crop	Year	SI		RF	
		TS	NTS	TS	NTS
Groundnut	2008	6.1	4.49	3.37	2.66
	2009	6.67	5.96	5.48	5.05
	2010	23.77	20.31	23.91	20.93
Okra	2008	13.08	12.61	7.93	4.76
	2009	11.96	9.96	9.11	5.76
	2010	29.15	24.14	28.05	21.41

In Okra, SI+TS treatment, the WP was 13.08,11.96 and 29.15 t ha^{-1} mm^{-1}; SI+NTS: 12.61,9.96 and 24.14 t ha^{-1} mm^{-1}; RF+TS: 7.93,9.11 and 28.05 t ha^{-1} mm^{-1}; RF+NTS: 4.76,5.76 and 21.41 t ha^{-1} mm^{-1} during the years 2008,2009 and 2010 respectively. It was observed that the WP was maximum in the year 2010 because of well distributed rainfall as well as correct timing of sowing in the second week of June due to early set in of monsoon as compared to preceding years of 2008 and 2009. The water productivity against the climate change in alfisols can be achieved by integrated rain water management through farm ponds with supplemental irrigation and application of soil amendments.

There is considerable evidence that runoff water could be used to optimize the production on semi arid Alfisols. On Alfisols, the potential for delivering excess rain water to runoff storage structure is extremely good since even improved system of farming results in the loss 15-35% of the seasonal rainfall as runoff. In rainfed alfisols, the combined use of supplemental irrigation and application of soil amendments such as tank silt can contribute significantly towards greater productivity with less uncertainty.

Conclusion:

The impact of climate change on rainfed alfisols creates problems in local and country level as alfisols are the predominant soil in India. The runoff producing in rainfed alfisol from extreme events due to climate change can be effectively collected and used as supplemental irrigation in critical stages of crop growth period which would improve the water productivity in rainfed alfisols. The soil water content in alfisols can be increased through application of soil amendments such as tank silt and organic materials by atleast 2 to 3%.

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DROUGHT MANAGEMENT MEASURES FOR CLIMATE RESILIENCE IN FIELD CROPS

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1.0 Introduction

Impacts of shifts in climatic pattern become more prominent when one considers the climatic spectrum of the dryland and arid regions (Ramakrishna, et al., 2000) as these marginal areas provide early signals of the impacts of climate variability and change (Sinha et. al., 1998). The rainfed regions encompassing the arid, semi-arid and dry sub-humid regions (covering regions less than 1150 to 1200 mm) are more prone to climatic variability as in these eco-systems drought is a regular part of the natural cycles affecting productivity and leading to desertification.

Drought is a perennial feature in some States of India. Sixteen percent of the country's total area is drought prone and approximately 50 million people are annually affected by droughts. In fact, persistent drought with less than average rainfall over a long period of time gives rise to serious environmental problems. Drought due to monsoon failure is a natural phenomenon and has always been occurring in all parts of the world. In India, about 29% of the total geographical area is considered as drought prone, experiencing every second or third year a drought. In the past 200 years (1800–1996), there were 40 drought years, of which 5 were severe (> 39.5% area affected) and 5 phenomenal (> 47% area affected). In other words, on an average, every fifth year was a drought year, every 20th year was a severe drought year and every 40th year was severe devastating drought year. The Indian Meteorological Department (IMD) officially acknowledged that the year 2002 and 2009 are "all–India drought years" since 1987. The aggregate rainfall during 2002's monsoon season (1st June to 30th September) was 20% less than the long period average (LPA) of 912.5 mm for the same period while 29% of the area in the country experienced drought condition.

Drought Differs from other Disasters

Drought seldom results in structural damage in contrast to floods, earthquake and cyclones. Because of this, the quantification of impact and the provision of relief are far more difficult tasks for drought compared to other natural disasters. Therefore, drought preparedness is less costly than mitigation and relief measures.

1.1 Types of Drought

Many people consider drought to be largely a natural or physical event. But, in reality drought has both natural and social components. Drought has been classified into four types namely: meteorological, hydrological, agricultural and socio-economic.

Meteorological drought is often defined by a period of substantially diminished precipitation duration and / or amount. The commonly used definition of meteorological drought is an interval of time, generally in the order of months or years, during which the actual moisture supply at a given place consistently falls below the climatically appropriate moisture supply.

Agricultural drought occurs when there is inadequate soil moisture to meet the needs of a particular crop at a particular time. Agriculture is usually the first economic sector to be affected by drought. Agricultural drought usually occurs after or during meteorological drought, but before hydrological drought, can also affect livestock and agricultural operations.

Hydrological drought refers to deficiencies in surface and subsurface water supplies. It is measured in terms of stream flow, snow pack, surface and groundwater levels. There is usually a delay between rains and measurable water in streams, lakes and reservoirs. Therefore, hydrological measurements tend to lag other drought indicators.

Socio-economic drought occurs when physical water shortages start to affect the health, well- being, and quality of life of the people, or when the drought starts to affect the supply and demand of economic goods and services.

1.2 Impact of Drought

Effect of drought is more severe than the other natural disasters and is often due to improper management of available water. Though, the country receives substantial / normal amount of rainwater through monsoon rains, often, part of it is lost creating scarcity of water leading to drought. Thus, each drought year is unique in climatic characteristic and its impact can be felt only after it happened. Droughts have multiple effects on agricultural production during the subsequent years too, due to:

- Non-availability of quality seeds for sowing of crops
- Inadequate draft power for carrying out agricultural operations as a result of either distress sale or loss of life of cattle
- Reduced use of precious inputs like fertilizers as the purchasing power of the farmers decline
- Non-availability of raw materials to agro-based industries, and
- Deforestation to meet the energy needs in domestic sector as agricultural wastes may not be available in required quantity

2.0 Contingency Planning for Extreme Weather Events

Agriculture experiences mostly three types of droughts viz., early, mid and late season depending upon the behavior of monsoon. Further, some specific recommendations are made for dry spells occurring during different stages of crop growth (**Table 1**).

2.1 Early Season Drought:The early season droughts occur due to delay in commencement of sowing rains. Sometimes, early rains may occur tempting the farmers to sow the crops followed by a long dry spell leading to withering of seedlings and poor crop establishment.
The management options to cope up with early season drought are:

- Raising a community nursery for cereal crops and transplant the seedlings with the onset of rainy season. Transplantation, however, is a labour intensive operation and water may not be available in some of the areas for raising a community nursery.

- Sowing of alternate crops / varieties depending upon the time of occurrence of sowing rains. The seeds may not be available to the farmers and government should provide seed through seed banks or alternative sources.

- If there is a poor germination and inadequate plant stand, it is better to re-sow the crop. If the dry spell after sowing is brief, gap filling is also advocated.

Table 1. Mitigation strategies during dry spells at different stages of crop growth

Crop stage	**Symptoms**	**Strategies**
Seedling	Germination of the crop (Plant stands): more than 75%	• Continue to grow the same crop with a precaution of *in situ* conservation of moisture through conservation furrows. • Adopt recommended package of practices.
	50 to 75% optimum population (gaps in rows and also in between rows).	• Sow the same crop of shorter duration variety in the gaps either within or in between rows.
	Less than 50% optimum population	• Sow suitable contingent crop as per the remaining effective growing season e.g. pearl millet in place of sorghum up to 1st week of July. • Sow castor up to the last week of July. • Greengram/cowpea afterwards.
Vegetative	-Drying of leaves	• Blade harrowing in rows during

	-Wilting of plant -Soil cracking in black soils	dry spell in coarse cereals, oilseed and pulse crops to create dust mulch and closing of cracks in black soils. • Supplemental irrigation of 5 cm. of rain water stored in farm pond during dry spell. AFTER RELIEF OF DRY SPELL • Spraying of 2% urea especially to pulses, castor and sunflower crop. • 10 kg N/ha (additional) application • Conservation furrows at 1.2 m distance after relief of dry spell.
FLOWERING	- Drying of flowers - Dropping of flowers - Wilting of plants	• Blade harrowing to create dust mulch in wide spaced crops like castor and sunflower. • 5 cm. of supplemental irrigation (if stored water is available in drought situation) • Spray urea@ 2% in pulses, oilseed and nutritive cereals during dry spell. • Additional 10 kg N/ha as a part of top dressing
Grain filling	- Wrinkled seeds - Dried pods/ cobs /spikes - Wilting of the crop - Excess leaf fall on the ground	• Supplemental irrigation from harvested rain water in the pond

Other options are:

- ❖ Growing short duration drought tolerant millets and intercropping with pulses, etc.
- ❖ Seed treatment: priming.
- ❖ Transplanting of seedlings of millets.
- ❖ Thinning.
- ❖ Mulching.
- ❖ Re-sowing, if drought occurs within 15 days after sowing.
- ❖ Growing crops for fodder alone.

2.2 Mid-Season Drought

Mid-season drought occurs in association with long gaps between two successive rainy events if the moisture stored in the soil falls short of water requirement of the crop during the dry period. At times, mid season drought may be associated with low and inadequate rainfall in the growing season that will not meet the crop water needs as per its phenological stage**.**

The management options to cope-up with the mid season drought are:

- Rain water harvesting for life saving irrigation and recycling when drought occurs
- Reducing crop density by thinning
- Weed control and mulching
- *In-situ* moisture conservation practices like conservation furrow
- Dust mulching, repeated harrowing
- Intercropping to minimize crop loss
- Contingency crop planning
- Defoliation of leaves at the bottom of the plant

2.3 Late Season Drought

If the crop encounters moisture stress during the reproductive stage due to early cessation of rainy season, there may be rise in temperature, hastening the process of crop maturity. The grain yield of crops is highly correlated with the water availability conditions during the reproductive stage of growth. Short duration high yielding varieties may escape late season droughts. Another possibility is to provide supplementary irrigation through rainwater harvesting and recycling. Organic mulches are found to be useful in improving crop yields during post-rainy season. When crops are grown late under rainfed conditions, terminal drought can be anticipated with greater certainty. Therefore, varieties that respond better to terminal droughts have to be preferred.

The management options to cope-up with the late season drought are:

- Rainwater harvesting and irrigating at critical stages like flowering/grain filling.
- Replacing paddy with less water requiring crops
- Intercropping to minimize risks
- Mulching at critical stages of crop growth
- Use of early harvesting and processing strategies
- Use of anti-transparent
- Thinning
- Defoliation: removal of leaves at the bottom
- Contour farming
- Strip Farming
- Deep ploughing

2.4 Short and Long Term Preventive and Corrective Measures

2.4.1 Preventive Measures

Short term

- Ploughing across the slope.
- Sowing across the slope.
- Introduction of less water requiring crops.
- Introduction of drought tolerant crop varieties.
- Urea treatment for dry fodder.
- Preventing deforestation.
- Roof water harvesting.

- Recycling of runoff water in farms.

Long -Term

- Tree based farming.
- Diversified farming.
- Change of cropping pattern.
- Revival of water harvesting structures.
- Construction of check dams/ farm ponds
- De-silting of tanks
- Watershed management Long Term

2.4.2 Corrective Measures

Short Term

- Soil and water conservation measures.
- Repair of existing water resources.
- Close monitoring of relief work.
- Taking up minor irrigation repair works.
- Loan and subsidy to needy people.
- Raising community nursery to supply seedlings.
- Production and supply of fodder.
- Efficient use of available irrigation water by drip and sprinkler irrigation techniques.

Long-Term

- Agroforestry.
- Horticulture development.
- Pasture and fodder development.
- Creation of water harvesting structures.
- Construction of check dams and percolation tanks.
- Drainage line treatment.
- Establishment of fodder and seed banks.
- Implementation of land use policy strictly.

3.0 Farming in Relation to Annual Rainfall

Depending on the range of rainfall (low to high), some farming strategies have been discussed for three types of rainfall situations.

Area Receiving Rainfall Less Than 500mm

- ♦ Linking arable farming with animal husbandry on high priority.
- ♦ Arable farming limited to millets and pulses and adoption of agroforestry, silvipastoral and hortipastoral systems.
- ♦ Growing drought – tolerant perennial tree species that provide fuel, fodder and food.
- ♦ Adopting arid – horticulture to augment farm income.

♦ Emphasizing efficient management of rangelands and common village grazing lands, adopting improved strains of grasses, reseeding techniques, and developing fodder banks.

Area Receiving Rainfall 500 To 750 Mm

- ♦ Emphasis on oilseed and legume based intercropping systems in not so favourable tracts.
- ♦ High value (fruits, medicinal, aromatic bushes, dyes and bio-pesticides) and high-tech agriculture (drip irrigation, processing, extraction and value added products).
- ♦ Utilization of marginal and shallow lands through alternate land use system with agriculture-forests-pasture system with a range of options.
- ♦ Afforestation of highly degraded undulating lands.
- ♦ Watershed approach in farming systems perspective.

Area Receiving Rainfall More Than 750 Mm

- ♦ Aquaculture in high-rainfall, double-cropped regions with rationalization of area under rice.
- ♦ Intercropping systems and improved crop varieties of maize, soybean, groundnut and double cropping in deeper soil zones.
- ♦ Dryland horticulture and tree farming
- ♦ Integrated watershed management

4.0 Drought in Andhra Pradesh: A Case Study

Andhra Pradesh is the third most drought prone State of India after Rajasthan and Karnataka. Rayalseema and Southern parts of Telangana are considered as the chronic drought prone regions compared to coastal Andhra. CRIDA was given the task by the Planning Department, Government of Andhra Pradesh to develop Disaster Management Plan in respect of Drought. The mandals prone to Meteorological, Hydrological and Agricultural droughts were assessed and prioritized using bio-physical and socio-economic parameters. Drought severity index was worked out for all the mandals. Drought assessment focused on meteorological, hydrological and agricultural drought scenario generation on real time basis for all the mandals of Andhra Pradesh. Decision Support Software (DSS) was developed with nine different modules dealing with drought assessment, mitigation and risk transfer measures to reduce the time lag in collection, processing and transfer of data/information. Using the art of information technology, a unique attempt was made to bring the planners and implementers on a single platform. In drought mitigation, stress has been laid on contingency crop planning and alternate land uses for drought proofing. Groundwater, surface water and livestock management received due attention as drought preparedness is much cost-effective than relief measures. Risk transfer measures focused on developing a response plan by assigning roles and responsibilities to various departments including banks and insurance. Community-based participatory planning was introduced to improve the effectiveness and transparency in various relief measures related to livelihood, food, fodder and nutritional security.

Decision Support Software for Contingency Crop Planning:

Software has been developed to make contingency crop planning user-friendly. The details of the software used are presented in the user manual. Information generated on alternate crops by the Acharya NG Ranga Agricultural University was used for its development. The inputs to the software are: district, month and soil type and the output is a list of crops that matches the given set of conditions (**Fig. 2**). Double clicking on the option displays the detailed package of practices of a selected crop. There is an in-built mechanism in the software that will take into account the mandal and *karthi,* provided data is available.

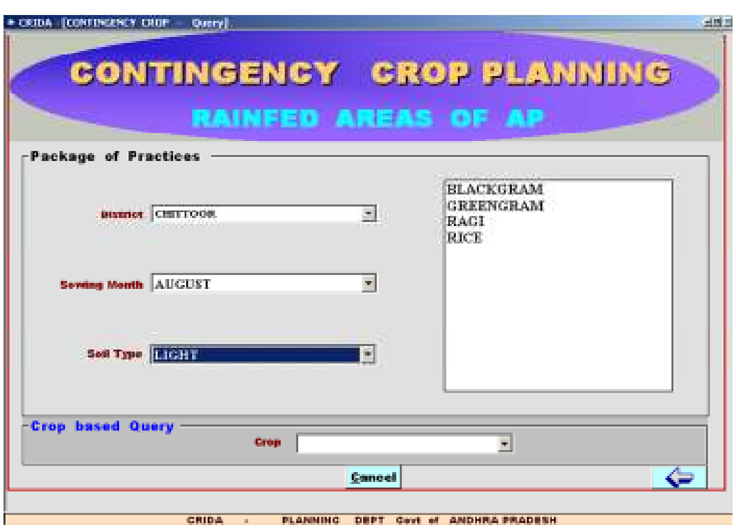

Fig. 2 Contingency crop planning (window frame)

5.0 Conclusions

Changing climatic scenario calls for effective contingency planning and a bottom–up approach with scientific blending. There is a need to work in a consortium mode as extreme weather events are going to be more and time for responding will be short. Preparedness for extreme weather events is cheaper when compared to mitigation or relief measures. There is a need of proactive approach rather than reactive as drought is recurring phenomenon. The information needed is available and the need of hour is the networking of R & D institutions and use of ICT will help in bridging this gap to a large extent.

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CDM CONCEPT:THEORY AND PRACTICE

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Introduction

Warming of the climate system is an established fact, which is evident from the increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. The warming trend in India over the past 100 years (1901 to 2007) was observed to be 0.51^0C with accelerated warming of 0.21^oC per every 10 years since 1970. Global green house gas (GHG) emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 where as the emissions of Carbon dioxide (CO2) have grown by about 80% between 1970 and 2004, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (IPCC 2007). With the current climate change mitigation policies global GHG emissions will continue to grow over the next few decades. A warming of about 0.2°C per decade is projected for a range of emissions scenarios for the next two decades. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected (IPCC 2007). Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of the high population depending on agriculture and excessive pressure on natural resources. The projected impacts are likely to further aggravate yield fluctuations of many crops with impact on food security and prices. Cereal productivity is projected to decrease by 10-40% by 2100 and greater loss is expected in *rabi*. There are already evidences of negative impacts on yield of wheat and paddy in parts of India due to increased temperature, increasing water stress and reduction in number of rainy days. Water requirement of crops is also likely to go up with projected warming and extreme events are likely to increase. In view of the widespread influence of climate change, there is a need to reduce the emissions of green house gases which are the main drivers of climate change.

Climate change, Kyoto protocol and Clean Development Mechanism

In response to the concerns of increasing concentrations of GHGs, as early as 1992, more than 150 nations came together to sign the United Nations Framework Convention on Climate Change (UNFCCC) at The Earth Summit in Rio. A part of the agreement is that the developed nations would reduce the GHG emissions to 1990 levels by the year 2000. This led to the establishment of a protocol in 1997 at Kyoto, Japan that would be binding for the developed nations, which is popularly called as the Kyoto Protocol. The Kyoto Protocol was adopted in December 1997. The Protocol creates legally binding obligations for 38 industrialized countries, including 11 countries in Central and Eastern Europe, to reduce their emissions of GHGs to an average of approximately 5.2 percent below their 1990 levels as an average over the period 2008-2012. The targets cover the six main greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride. The Protocol also allows these countries the option of deciding which of the six gases will form a part of their national emissions reduction strategy. After more than four years of debate, governments finally in 2001 agreed to a comprehensive rulebook—the Marrakech Accords—on how to implement the Kyoto Protocol.

The Protocol established three mechanisms designed to help industrialized countries (Annex I Parties) to reduce the costs of meeting their emissions targets by achieving emission reductions at lower costs in other countries than they could domestically.

• International Emission Trading permits countries to transfer parts of their 'allowed emissions' ("assigned amount units").

• Joint Implementation (JI) allows countries to claim credit for emission reductions that arise from investment in other industrialized countries, which result in a transfer of equivalent "emission reduction units" between the countries.

• The Clean Development Mechanism (CDM) allows emission reduction projects that assist in creating sustainable development in developing countries to generate "certified emission reductions" for use by the investor.

The mechanisms give countries and private sector companies the opportunity to reduce emissions anywhere in the world—wherever the cost is lowest—and they can then count these reductions towards their own targets. It is envisaged that through emission reduction projects, these mechanisms could stimulate international investment and provide the essential resources for cleaner economic growth in all parts of the world. The CDM, in particular, aims to assist developing countries in achieving sustainable development by promoting environmentally friendly investment from industrialized country governments and businesses. The funding channeled through the CDM should assist developing countries in reaching some of their economic, social, environmental, and sustainable development objectives, such as cleaner air and water, improved land use, accompanied by social benefits such as rural development, employment, and poverty alleviation and reduced dependence on imported fossil fuels.

Emissions of GHGs from agriculture in India

Agriculture sector is one of the main sources of GHG emissions throughout the world and in India as well. In India, agriculture contributed about 17% of the CO_2 equivalent emissions for the base year 2007 (INCCA 2010). Details of GHG emissions from agriculture are given below:

a) CH_4: The agriculture sector dominates the total national CH_4 emissions, within which emissions due to enteric fermentation (63%) and rice cultivation (21%) were the largest. Methane emissions from various categories of animals range from 28 to 43 g CH_4 / animal. The methane emission coefficient for continuously flooded rice fields is about 17 g/ m^2. Burning of crop residue is a significant net source of CH_4 in addition to other trace gases.

b) N_2O: Agriculture sector accounted for 71 percent of total N_2O emission from India in 2007. Emissions from soils are the largest source of N_2O emissions in India followed by manure management. Emissions of N_2O results from anthropogenic nitrogen input through direct and indirect pathways, including the volatilization losses from synthetic fertilizer and animal manure application, leaching and run-off from applied nitrogen to aquatic systems.

c) CO_2**:** CO_2 emissions from agriculture are due to the consumption of diesel for various farm operations and due to the use of electricity for pumping of groundwater. Land use conversion from forests to agriculture due to shifting cultivation and on-sit*e* burning results in CO_2 emissions.

Mitigation options in agriculture

Agriculture can help mitigate climate change by reducing GHG emissions and also by sequestering CO_2 from the atmosphere.

- In irrigated rice cultivation, management practices such as water management, nutrient management, selection of suitable variety, spacing, stand establishment, crop sequence were found to reduce methane emissions by 7 to 68%. Mid season drainage also found to reduce the emissions of methane substantially in lowland paddy. Application of nitrification inhibitors, matching nitrogen supply with crop demand, tighten N flow cycles, use advanced fertilization techniques, optimum tillage, irrigation and drainage, etc. found to reduce the N_2O losses up to 80% (Adhya, 2008).
- Conservation agriculture practices such as reduced tillage, retention of crop residues on the surface, application of optimum quantum of nutrients and suitable crop rotation contributes to reduction of CO_2 emissions and contributes towards carbon sequestration. Application of organic manures, fertilizers and integrated nutrient management practices improves the crop growth and also sequesters substantial quantities of soil carbon. The potential of carbon sequestration due to adoption of recommended package of practices on agricultural soils is about 6 to 7 Tg C/y. In addition, the potential of soil inorganic carbon sequestration estimated at 21.8 to 25.6 Tg C/y (Lal, 2004).
- Restoration of degraded lands by establishing suitable vegetative cover not only arrest further erosion from these soils but also increases carbon sequestration through enhanced biomass recycling. Trees should be integrated with arable cropping where ever possible and emphasis needs to be given to horticulture and short rotation forestry to meet the demands of the economy. Large scale tree planting can be integrated in to the employment guarantee program by which it can be made as a community led development initiative. Degraded forest lands which are under joint forest management (JFM) and community forest management (CFM) can also be brought under this kind of community initiative and this can be linked to the CDM of UNFCCC where the community will get the benefit of the afforestation activity and also the benefits of the tree produce.
- Organic agriculture reduces soil erosion, restores organic carbon content, reduces nitrogen fertilizer use and energy requirement. Organic agriculture reduces the usage of nitrogen fertilizers substantially and thus emissions and contributes to carbon sequestration.
- There is significant scope to reduce the emissions by using energy efficient pumps for irrigation, reducing the number of tillage operations and adoption of energy efficient devices in agricultural operations.

- Improved management of livestock feed, and research on dietary supplements, balanced nutrition, feed mixtures needs to be further investigated.

Agriculture and CDM

Large number of CDM projects developed so far relates to energy sector and industrial processes with high global warming potential. Landfill gas and HFCs (Hydro Chloro Flouro Carbon) together account for much of the CERs (Certified Emission Reductions) in the CDM pipeline. In agriculture sector, the number of projects registered was 87 (6.08 %). However, majority of these projects are related to manure management in large-scale livestock/ animal production units and not related to core agriculture activities of small sized holdings. Similarly the number of projects in Afforestation/Refforestation (A/R) sector is only five out of 1430, representing less than 1% percent. Projects related to agriculture and afforestation and reforestation will ensure greater participation of farmers/ communities in the emission reduction activities resulting in sustainable development benefits. Properly designed CDM projects in these two sectors can provide useful additional revenue to rural communities, which will be independent of existing streams of revenue from the forestry plantations besides contributing to the emission reduction or carbon sequestration.

Potential CDM projects related to agriculture

The prerequisites for a CDM project is that they should be project based and the proposed activity should have an approved methodology. Two kinds of activities are possible in agriculture in the first commitment period. They are energy efficiency projects and carbon sequestration projects. Activities which reduce the green house gas emissions through improving energy efficiency can be taken up in CDM. In sink projects, only afforestation and reforestation related activities are allowed, and the maximum use of CERs from A&R projects should be less than 1% of the 1990 emissions of the Annex 1 party during the first commitment period of the Kyoto protocol. Soil carbon sequestration is eligible only as a part of land use change and afforestation and reforestation activities, during the first commitment period of Kyoto Protocol. Other sinks related activities like revegetation, forest management, cropland management and grazing land management are not allowed under the CDM but only as joint implementation projects in Annex-I countries. Hence clean development projects exclusively on soil carbon sequestration in arable lands are not forthcoming during the first commitment period. However few CDM projects are under implementation in afforestation and reforestation sector which considers soil carbon pool.

a) Energy efficiency (Emission reductions).

Substantial quantities of energy are being consumed in various agricultural operations and also at the household level. Activities which can reduce emissions by introducing energy efficiency measures are eligible in CDM. Some of the possible activities could be, reducing the number of tillage operations in agriculture, installing capacitors to agricultural pump sets, using pump sets operated by solar energy for water lifting, replacing the incandescent lights with the compact fluorescent lights in the houses, farms, streets, installing energy efficient equipment, etc. All these interventions have supporting methodologies which can be used for the CDM project preparation. Some of the methodologies that can be used for energy efficiency in rural sector are as follows:

Table 1 Approved methodologies related to energy efficiency which can be used for agricultural/ household related interventions

S. No	Methodology	Possible interventions
1	AMSIIJ (Demand side activities for efficient lighting technologies)	Replacement of incandescent bulbs by using CFL lamps only residential purpose
2	AMSIIC (Demand side activities for specific technologies.)	Replacement of incandescent bulbs by using CFL lamps only. Residential street lights commercial areas refrigerators pump sets
3	AMSIIG (Energy efficiency measures in Thermal applications of Non – Renewable Biomass.)	Replacement of Three stone fires by using Thermal efficiency tested Improved cook stoves.

b) Carbon sequestration

Agroforestry systems like agri-silvi-culture, silvipasture and agri-horticulture offer both adaptation and mitigation opportunities. Agroforestry systems buffer farmers against climate variability by modifying the microclimate. Agroforestry systems are better land use systems for arresting land degradation and also improves the productivity of degraded lands and can sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. The extent of carbon sequestration by these systems is given below.

Table 2 Carbon storage (Mg/ha/ year) in different agri silvicultural and silvi pasture systems

Location	System	Carbon sequestration (Mg/ha/year)
a) Agrisilviculture systems		
Raipur (Swami & Puri, 2005)	Gmelina based system	2.96*
Chandigarh (Mittal & Singh, 1989)	Leucaena based system	0.87
Coimbatore (Viswanath et al.	Casuarina based	1.45

2004)	system	
b) Silvipasture systems		
Karnal (Kaur et al. 2002)	Prosopis based system	2.36
	Acacia based system	1.29
	Dalbergia sissoo system	1.68
Himalayan foot hills (Narain et al. 1998)	Eucalyptus based system	3.41
	Leucaena based system	3.60
Jhansi (Rai et al. 2000)	Leucaena based system	1.82
	Terminalia based system	1.11
	Neem based system	0.80
	Albizia procera system	2.01
	Dalbergia sissoo system	2.90

*Includes soil carbon storage of 0.42 Mg/ha/year (up to 60 cm depth)

Sole tree plantations produce large quantities of biomass in a short period and they provide fodder, timber, pulpwood and props for commercial use. The carbon sequestered by these systems is presented in Table: 3.

Table 3 Carbon storage (Mg/ha/ year) in different sole tree plantations

Location	**System**	**Carbon sequestration (Mg/ha/year)**
Hyderabad (Rao et al. 2000)	Leucaena based system	5.65
Raipur (Swami & Puri, 2005)	Gmelina based system	5.74*
Tripura (Negi et al. 1990)	Teak based system	3.02

	Gmelina based system	3.69
Dehradun (Dhyani et al. 1996)	Eucalyptus based system	5.54

* Including soil carbon storage 2.16 Mg/ha/year

There are many approved methodologies in CDM which supports agroforestry interventions. Many of these methodologies were developed in the last 2 years and supports introduction of trees in various landscapes which performs various roles. Some of the approved methodologies for A/R are given below:

Table 4 Approved small scale methodologies in afforestation and reforestation sector

S No	Methodology	Applicability
1	AR-AMS001 (Simplified baseline and monitoring methodologies for small-scale /afforestation and reforestation project activities under CDM implemented on grasslands or croplands)	Agro forestry systems, short rotation intensive forestry systems, silvipasture
2	AR-AMS002 (Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under CDM implemented on settlements)	Agroforestry systems, silvipasture, horticultural crops, energy crops
3	AR-AMS004 (Simplified baseline and monitoring methodologies for small-scale agro forestry afforestation and reforestation project activities under CDM	Agroforestry systems
4	AR-AMS005 (Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under CDM implemented on lands having low inherent potential to support biomass)	Estbalishment of trees on sand dunes, contaminated or mine spoils lands highly alkaline or saline soils.
5	AR-AMS006 (Simplified baseline and monitoring methodologies for small-scale silvipastoral afforestation and reforestation project activities under CDM)	Tree systems on degraded lands/ grasslands, subject to grazing activities.

One of the above methodologies can be used for preparaing CDM project depending on the category of the land and also the kind of tree systems.

Conclusions

The contribution of the agricultural sector towards the reduction in GHG emissions and sequestration depends largely on the farmers' adoption of environmentally friendly land use and management practices. Adoption of these practices in a wider scale largely depends on, to what extent farmers are compensated for the additional global benefits and payments for the environmental services besides the on-farm benefits such as increased crop yields. The quantum of benefits from the carbon sequestration services depends on the extent of reductions of GHGs/ sequestration achieved, the extent of allocation of land for the mitigation activity, the market price of the CERs and the project arrangement between the farmers and the proponents of the CDM project and the demand for the CERs in the international market. The quantum of carbon sequestered under rainfed situations and also the small scale nature of holdings associated with rainfed agriculture, the returns from the sequestration activity may not be attractive at the current carbon prices but the associated benefits in terms of the balanced nutrition, reduced erosion, better crop growth and performance, stabilised and enhanced yields and better soil quality under rainfed situations will be remarkable.

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MANAGING SUSTAINABLE HORTICULTURAL PRODUCTION IN A CHANGING CLIMATE SCENARIO

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Abstract:

Climate change cause Abiotic stress in the living system which otherwise referred to as the negative impact of non-living factors on the living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of variation to adversely affect the population performance or individual physiology of the organism. Abiotic stress factors, or stressors, are naturally occurring factors such as low or high rainfall, extremes in temperature, intense sunlight or wind that may cause harm to the plants and animals in the area affected. Abiotic stress is essentially unavoidable. Abiotic stress affects organisms dependent on environmental factors. Abiotic stress is the most harmful factor concerning the growth and productivity of horticultural crops. Drought or flood is unpredictable condition or event for unspecified period or duration. Drought is a frequent occurrence 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 annuals with in the perennial fruit tree rows, suitable grass and legume species for horti-pastural systems and root stocks are discussed. Integrated horticultural management practices to combat climate change related events and more so drought and possible remedial measures are discussed in the present paper.

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.

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.

For semi-arid climatic environment 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 & 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 & 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.

Suitable Fruit Varieties for Semi Arid Tropical Regions

CROPS	**CULTIVARS**
FRUITS:	
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.
Papaya	Coorg Honey Dew, Pusa Delicious, Pusa Majsty, Pusa Dwarf,Taiwan 786
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 & Singh, 2002.

Suitable Vegetables Varieties for Semi Arid Tropical Regions

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 & Singh, 2002.

Microcatchment or farm pond water harvesting system:

Heavy rains resulting in the heavy down pours is a common event resulting in runoff even in dry land regions. About 15-30% runoff water could be capitalized for water harvesting and runoff recycling (Reddy *et al.,*2002). Efficient utilization of harvested water requires an elaborate consideration in selection of site, runoff inducement, storage, seepage, evaporation losses, water lifting and conveyance devices and their efficiencies. A farm pond of 150m^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.

<u>Microsite Improvement:</u>

It is preferable to plant the fruit trees with the onset of monsoon in well prepared and well filled pits at suitable distances. Most of the above fruit species respond well in closed spacing except tamarind, aonla, jamun and mango which prefer wider spacing. The pits should be of one cubic metre dimension, filled with equal quantities of tank silt, well decomposed compost or Farm yard Manure and the good soil from the site, two kg single super phosphate, two kg neem cake or castor cake and 50 g of BHC dust. Before filling the pit, dried leaves may be burnt in the pit to kill any inoculum 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:

Fertilizer schedule for fruit plants (N, P_2 0_5 & K_2 0 in g / plant)

	1-3 years	4 - 6 years	7 – 10 years	> 10 years
Guava	50-25-75	100-40-75	200-80-150	300-120-150
Pomegranate	300-250-250	500-300-300	700-400-400	900-500-500
Custard apple	100-100-100	150-150-150	250-250-250	350-300-300
Ber	200-200-200	300-300-300	400-300-300	500-400-400
Mango	350-150-150	700-300-300	1000-2000-5000	1000-2000-5000
Aonla	100-75-100	200-150-200	300-800-1000	400-1000-1200

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 5-10 years of the plantation, it is remunerative to encourage intercropping with suitable annual crops like groundnut, cowpea and greengram or fodder crops. This will help in meeting the initial expenditure on the plantation besides adding fertility to the soil and generating more employment.

Table: Grass Species suitable in fruit crops under horti - pastural cropping systems

Region/Grass	**Rainfall(mm)**	**Soil type**	**Dry forage yield (t/ha)**	**Crude proteien content(%)**
Semi arid				
Sehima nervosum	600-1000	Mixed red and	3.5	5-8

		black		
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: Legume species suitable as intercrops in different orchards

Region / Legume	**Soil preference**	**Dry forage yield (t/ha)**
Semi-arid (600-1000mmrainfall)		
Desmodium intertum	Versatile	3.8
Desmodium uncinatum	Versatile	3.0
Glycine wightii	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(<600mmrainfall)		
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, tamirnd, wood apple, cashenut, custard apple, karonda mahua, few local indigenous plants like kair (*Capparis deciduas*), khejri (*Prosopis cineraria*), drumstick (*Moringa oleifera*), lasora (*Cordia dichotoma*), khirni (*Manilkara hexandra*) have xerophytic characteristics and can be cultivated under moisture stress situations.

Table: 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: Rootstock Reaction

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

Integrated horticultural management practices:

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:

I. 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 Sesham (*Dalbergi sissoi*), Jamun *(Syzygium cuminii*), Jackfruit (*Artocarpus heterophyllus*), *Cassia* siamia, *Acacia tortilis, 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.

II. Profile modification:

In marginal land normally tree growth is restricted, hence planting distance need to be reduced by 20-30 percent 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.

III. 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.

IV. 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. It's application improves the moisture retention capacity of soil. It also increases nitrogen and organic matter content of soil.

V. 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 lo be carried out in the same or following year. This practice shall encourage better plant establishment, besides cheaper for adaptation.

VI. 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.

TABLE: **Mango Based Cropping Models (REDDY *ET AL.*, 1998)**

Main crop (p/ha)	Filler crop (p/ha)	(p/ha)
Mango 100	Ber 100	-
Mango 100	Guava 100	-
Mango 100	Fig 100	Karonda 200
Mango 100	Fig 100	Karonda 400

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 workout suitable combinations under various drought districts so that root and aerial competition could be minimized.

VII. 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 vigour. Use of inorganic mulches is expensive and it does not incorporate organic matter content in the soil.

VIII. 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 percent slope with54 sq.m. 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.

IX. 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. tubewell 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.

X. Top Working/Frame working:

Seedling plants of ber *{Zizyphus spp)* is 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

Suggestions:

1. Sincere research efforts should be continued in order to select out promising fruits/genotypes having tolerance to abiotic stress (moisture stress/salt tolerance).
2. Efforts should be made for establishment of model nurseries for the local supply of quality planting material.
3. Information should be made available on fruit based cropping models (multi storied) for different drought prone districts.
4. With high management system and adoption of high-density orcharding, there is every possibility of outbreak of few biotic stress (disease/pest), hence, the research information on IPM for fruit based farming system should be made available.
5. Demonstration orchards maintained in the drought prone districts under technically competent persons would be self-guiding to the growers.
6. Most of the fruit trees require high investment and growers don't get income for several years depending upon juvenility of fruit crops. Therefore, to sustain the cost of orchard establishment and management proper agri-horti, horti- horti involving seasonal vegetables and perennial fruit cropping systems should be identified and promoted in the frequently drought prone dryland regions.

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CONSERVATION AGRICULTURE FOR PRODUCTIVITY ENHANCEMENT AND MITIGATING GHG EMISSIONS

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India is endowed with a rich and vast diversity of natural resources, particularly soil, water, weather, multipurpose trees and bio-diversity. To realize the potential of production system on a sustained basis, efficient management of the natural resources is very crucial. With the advent of high-yielding crop varieties and intensive cultivation, the food grain production has increased from 51 million tones (mt) in 1950-51 to a record figure of 210 mt during 2007-2008. This impressive achievement has pulled the country in to self-sufficiency for food demand. With adoption of intensive agriculture to meet the varied growing demands for food, fuel, fiver, feed, fertilizer and products in the recent year, the natural resources are however, put under intense strain resulting in fast degradation and lowering of their production efficiency.

Land degradation is a major threat to our food and environmental security. There is 150 m ha degrades land constituting 45.5% of total geographical area. The area suffering due to water and wind erosion is 109.7 and 11.7 m ha respectively. The area under waterlogging, salinization/alkalization and other problems are 9.0,9.2 and 10.3 m ha respectively. The widespread erosion tin the hilly catchments area is resulting in excessive siltation of multipurpose reservoirs and other water-bodies to the country at rates higher than their designed capacity.

A major factor responsible for the degradation of the natural resources is soil erosion, The accelerated soil erosion has irreversible destroyed some 430 m ha of land area covering 30% of the present cultivated area in different countries of world. In general soil erosion is more severe in mountainous than undulating areas. Their rate of natural erosion for the world is of the order of 1.5 to 7.0 t/ha/year for the mountainous region and 0.1-7 t/ha/year for the undulation plains. If the global warming trends (caused by increases in atmospheric, Co2,expected to reach 600 ppm by 2070,continues, global erosion rate may increase considerably., Erosion by water is most serious degradation problem in the Indian context. It has been estimated that soil erosion was taking place at an average rate of 16.35t/ha /year totaling 5,334 mt/year,nearly 29% of the total eroded soil was parentally loss to the sea and nearly 10% was deposited in reservoirs, resulting in the reduction of their storage capacity by 1-2% annually. The remaining 61% of the eroded soil was transferred from one place to another. The annual water erosion rate values ranged from <5 t/ha/year to more than 80 t/ha/year.

Conservation agriculture (CA) is concept for resource saving agricultural crop production that strives to achieve acceptable profits together with high and sustainable production levels. While concurrently conserving the environment, CA is based o enhancing natural biological processes above and below ground. Intervention viz., 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 to disrupt the biological processes.

What is conservation Agriculture

Conservation Agriculture (CA) refers to the system of raising crops without tilling the soil while retaining the crop residues on the soil surface. It has the potential to emerge as an effective strategy to the increasing concerns of serious and widespread natural resources degradation and environmental pollution, which accompanied the adoption and promotion of green revolution technologies, since the early seventies,

Over the past 2-3 decades globally, CA has emerged as a way of transition to the sustainability of intensive production systems. It permits management of water and soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation like erosion, compaction, aggregate breakdown etc,

The key features which characterize CA include:

a) Minimum soil disturbance by adopting no-tillage and minimum traffic for agricultural operations,

b) Leave and manage the crop residues on the soil surface, and

c) Adopt spatial and temporal crop sequencing/crop rotation to derive maximum benefits from inputs and minimize adverse environmental impacts.

Conservation agriculture permits management of soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation e.g. erosion, compaction, aggregate breakdown, loss in organic matter, leaching of nutrients etc. Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment, an example of a win win situation. In the conventional systems, while soil tillage is a necessary requirement to produce a crop, tillage does not form a part of this strategy in CA. In the conventional system involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and burning of crop residues causing pollution, green house gases emission and loss of valuable plant nutrients. When the crop residues are retained on soil surface in combination with no tillage, it initiates processes that lead to improved soil quality and overall resource enhancement.

Benefits of CA have been demonstrated through its large-scale adoption in many socioeconomic and agro-ecological situations in different countries the world over.

Benefits to Farmers

These include:

- Reduced cultivation cost through savings in labour, time and farm power.
- Improved and stable yields with reduced use of inputs (fertilizers, pesticides).
- In case of mechanised farmers, longer life and minimum repair of tractors and less

- water, power and much lower fuel consumption.
- Benefits of CA come about over a period of time and in some cases, might appear less
- profitable in the initial years.

Benefits to Natural Resources

These include:

- Reduced soil degradation through reduced impact of rainfall causing structural
- breakdown, reduced erosion and runoff.
- Gradual decomposition of surface residues leading to increased organic matter and
- biological activity resulting in improved capacity of soils to retain and regulate water
  and nutrient availability and supply.

- Improved biological activity and diversity in the soil including natural predators and competitors.
- Reduced pollution of surface and ground water from chemicals and pesticides, resulting from improved inputs use efficiency.
- Savings in non-renewable energy use and increased carbon sequestration.

Conservation Agriculture Global Scenario

According to current estimates globally, CA systems are being adopted in some 96 million ha, largely in the rainfed areas and that the area under CA is increasing rapidly. USA has been the pioneer country in adopting CA systems and currently more than 18 million ha land is under such system. The spread of CA in US has been the result of a combination of public pressure to fight erosion, a strong tillage and conservation related research and education backup and public incentives to adopt reduced tillage systems. Other countries where CA practices have now been widely adopted for many years include Australia, Argentina, Brazil and Canada. In many countries of Latin America CA systems are fast catching up. Some states of Brazil have adopted an official policy to promote CA. In Costa Rica a separate Department of Conservation Agriculture has been set up. A redeeming features about CA systems in many of these countries is that these have come more as farmers' or community led initiatives rather than a result of the usual research extension system efforts. Farmers practising CA in many countries in South America are highly organized into local, regional and national farmers' organizations, which are supported by institutions from both south and north America. Spread of CA systems is relatively less in Europe as compared to countries mentioned above. While extensive research over the past two decades in Europe has demonstrated the potential benefits of CA yet the evolution of practice its has been slower in EU countries vis-a-vis. other parts of the world possibly due to inadequate institutional support. France and Spain are the two countries where CA was being followed in about one million ha of area under annual crops. In Europe a European Conservation Agriculture Federation, ECAF, a regional lobby group has been founded. This body unites national associations in UK, France, Germany, Italy, Portugal and Spain. Conservation agriculture is being adopted to varying degrees in countries of southeast Asia viz. Japan, Malaysia, Indonesia, Korea, the Philippines, Taiwan, Sri Lanka and Thailand. Central Asia is another area prospective of CA. In South Asia CA systems would need to reflect the unique elements of intensively cultivated irrigated cropping systems with contrasting edaphic needs, rainfed systems with monsoonic climate features, etc. Concerted efforts of Rice-Wheat Consortium for the Indo-Gangetic Plains (IGP) a CG initiative and the national research system of the countries of the region (Bangladesh, India, Nepal and Pakistan) over the past decade or so are now leading to increasing adoption of CA technologies chiefly for sowing wheat crop. According to recent assessments in more than one million ha area wheat was planted using a no-till seed drill in the region. Experiences from Pakistan (Punjab, Sindh and Baluchistan provinces) showed that with zero-tillage technology farmers were able to save on land preparation costs by about Rs. 2500 per ha and reduce diesel consumption by 50 to 60 litres per ha. Zero tillage allows timely sowing of wheat, enables uniform drilling of seed, improves fertilizers use efficiency, saves water and increases yield up to 20 percent. The number of zero tillage drills in Pakistan increased from just 13 in 1998-99 to more than 5000 in 2003-2004. Farmers have also adopted bed planting of wheat, cotton and rice. Wheat straw chopper has also been adapted to overcome planting problems in wheat crop residue. Bed and furrow planting of cotton is finding favour with the farmers due to savings in irrigation water and related benefits of improved use-efficiency of applied fertilizers, reduced soil crusting, etc. There is widespread use of laser land leveller which helps in curtailing irrigation, reduces labour requirement, enhances cultivated area and improves overall productivity. In 2003-04 around 225 laser land levellers were being used.

Conservation Agriculture in Rainfed Semi-arid and Arid Regions

Rainfed semi-arid and arid regions are characterized by variable and unpredictable rainfall, structurally unstable soils and low overall productivity. Results of most research station studies show that zero/ reduced tillage system without crop residues left on the soil surface have no particular advantage because much of the rainfall is lost as runoff due to rapid surface sealing nature of soils. It would therefore appear that no tillage alone in the absence of soil cover is unlikely to become a favored practice. However, overall productivity and residue availability being low and demand of limited residues for livestock feed being high also poses a major limitation for residue use as soil cover in the arid and semi-arid regions. In the semi-arid regions there is wide variability in rainfall and its distribution and nature of soils. It would appear that there is need to identify situations where availability of even moderate amount of residues can be combined with reduced tillage to enhance soil quality and efficient use of rainwater. There appears no doubt that managing zero-tillage system requires a higher level of management vis-a-vis conventional crop production systems. Also there exists sufficient knowledge to show that benefits of CA mainly consist of reversing the process of degradation and that its advantage in terms of crop productivity may accrue only gradually.

CA or no-till farming has spread mostly in the rainfed agriculture allover the world. However, in India its success is more in irrigated belt of the Indo-Gangetic plains. Considering the severe problems of land degradation due to runoff induced soil erosion, rainfed areas particularly in arid and semi-arid regions requires the practice of CA more than the irrigated areas to ensure a sustainable production.

Unlike the homogenous growing environment of the IGP, the production systems in arid and semi-arid regions are quite heterogeneous and diverse in terms of land and ware management and cropping systems. These include the core rainfed areas which cover up to 60-70% of the net sown area and the irrigated production systems in the remaining 30-40% area. The rainfed cropping systems are mostly single cropped in the red soil areas while in the black soil regions; a second crop is taken on the residual moisture. In ***rabi*** black soils farmers keep lands fallow during ***kharif*** and grow ***rabi*** crop on conserved moisture. The rainfall ranges from >500 mm in arid to 1000 mm in dry sub-humid zones. Alfisols, vertisols, inceptisols and entisols are the major soil orders. Soils are slopy and highly degraded due to continued erosion by water and wind. Sealing, crusting, subsurface hard pans and cracking are the key constraints which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface is another important component of CA, but in rainfed areas due to its competing uses as fodder, little or no residues are available for surface application.

Experience from several experiments in the country showed that minimum or reduced tillage does not offer any advantage over conventional tillage in terms of grain yield without retention of surface residue. Leaving surface residue is key to control runoff, soil erosion and hard setting in rainfed areas which are the key problems. In view of the shortage of residues in rainfed areas, several alternatives strategies have emerged for generation of residues either through in situ cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulching. Agro forestry and alley cropping systems are other options where biomass generation can be integrated along with crop production. This indicates that the concept of CA has to be understood in a broader perspective in arid and semi-arid agriculture which include an array of practices like reduced tillage, land treatments for water conservation, on-farm and off-farm biomass generation and agro forestry. Here, conservation tillage with reduced retention on surface is more appropriate than zero tillage which is emphasized in irrigated agriculture.

Constraints in Adopting Conservation Agriculture Systems

Conservation agriculture poses a challenge both for the scientific community and the farmers to overcome the past mindset and explore the opportunities that CA offers for natural resources improvement. CA is now considered a route to sustainable agriculture. Spread of CA, therefore, will call for a greatly strengthened research and linked development efforts.

- Although significant successful efforts have been made in developing and promoting machinery for seeding wheat in no till system, successful adoption of CA systems will call for greatly accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crop and cropping sequences, permanent bed and furrow planting systems, harvesting operations to manage crop residues, etc.
- Conservation agriculture systems represent a major departure from the past ways of doing things. This implies that the whole range of practices including planting and

harvesting, water and nutrient management, diseases and pest control etc. need to be evolved, evaluated and matched in the context of new systems.

- Managing CA systems will be highly demanding in terms of knowledge base. This will call for greatly enhanced capacity of scientists to address problems from a systems perspective, be able to work in close partnerships with farmers and other stakeholders and strengthened knowledge and information sharing mechanisms.

How Long Does It Take to See Benefits

Usually the full benefits of CA take time and, in f act, the initial transition years may present problems that influence farmers to disadopt the technology. Weeds are often a major initial problem that required integrated weed management over time to get them under control. Soil physical and biological health also takes time to develop. Three to seven years may be needed for all the benefits to take hold. But in the meantime, farmer save on costs of production and time and usually get similar or better yields than with conventional systems. Farmers should be encouraged to continue this sustainable pract ice and correct problems as they arise.

Conclusions

Crop production in the next decade will have to produce more food from less land by making more efficient use of natural resources—and with minimal impact on the environment. Only by doing so can food production keep pace with demand, while land's productivity is preserved for future generations. This is a tall order for agricultural scientists, extension personnel, and farmers. Use of productive but more sustainable management practices described in this paper can help solve this problem. Crop and soil management systems that improve soil health parameters (physical, biological, and chemical) and reduce farmer costs are essential. Development of appropriate equipment to allow these systems to be successfully adopted by farmers is a prerequisite for success. Overcoming traditional mindsets about tillage by promoting farmer experimentation with this technology in a participatory way will help accelerate adoption. Encouraging donors to support this long-term, applied research with sustainable funding is also an urgent need.

ROLE OF CONSERVATION AGRICULTURAL PRACTICES TO MITIGATE ADVERSE EFFECTS OF CLIMATE CHANGE

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1. Introduction

India has predominantly agrarian economy. Of the total geographical area of 329 million ha, 142 million ha is devoted to agriculture (FAI, 1990). Out of an estimated net cultivated area of about 142.2 m ha, only about 55 m ha is under irrigation, while 87 m ha is unirrigated. The irrigated area produces about 56% of total food requirement of India. The remaining 44% of the total food production is supported by rainfed agriculture. Most of the essential commodities such as coarse cereals (90%), pulses (87%), and oil seeds (74%) are produced from the rainfed agriculture. These statistics emphasise the role that rainfed regions play in ensuring food for the ever-rising population. 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 m ha), Inceptisols (95.8 m ha), Vertisols (26.3 m ha), Aridisols (14.6), Mollisols (8.0 m ha), Ultisols (0.8 m ha), Alfisols (79.7 m ha), Oxisols (0.3 m ha) and non-classified soil (23.1 m ha). Rainfall wise, 15 m ha area falls in a rainfall zone of <500mm, 15 m ha under 500 to 750 mm, 42 m ha under 750 to 1150 mm and 25 m ha 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.

Out of the 328.7 m ha of land, it has been estimated that about 187.7 m ha (57.1%) of total geographical area is degraded. Of the total degraded area, water erosion has affected 148.9 m ha (45.3%), wind erosion 13.5 m ha (4.1%), chemical deterioration 13.8 m ha (4.2%), physical deterioration 11.6 m ha (3.5%). Another 18.2 m ha (5.5%) land which is constrained by ice caps, salt flats, arid mountains, and rock out crops is not fit for agriculture at all (Sehgal and Abrol, 1994). Moisture stress accompanied by other soil related constraints result 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 of organic matter and robbing away of its 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.

2. Soil degradation - major causes

The predominant reasons which degrade soil quality and deteriorate its productive capacity could be enumerated as: i) washing away 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 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) dismally 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 crop 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 some 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.

3. Effect of Climate on Agriculture in India – likely risk

According to Rao et al (2010), the major weather related risks in Agriculture could be as follows: Monsoons in India exhibits substantial inter-seasonal variations, associated with a variety of phenomena such as passage of monsoon disturbances associated with active phase and break monsoon periods whose periodicities vary from 3-5 and 10-15 days respectively. It is well noticed that summer monsoon rainfall in India varied from 604 to 1020 mm. The inter-seasonal variations in rainfall cause floods and droughts, which are the major climate risk factors in Indian Agriculture. The main unprecedented floods in India are mainly due to movement of cyclonic disturbances from Bay of Bengal and Arabian Sea on to the land masses during monsoon and post-monsoon seasons – and during break monsoon conditions in some parts of Uttar Pradesh and Bihar. The thunderstorms due to local weather conditions also damages agricultural crops in the form of flash floods. Beside floods, drought is a normal, repetitive feature of climate associated with deficiency of rainfall over extended period of time to different dryness levels describing its severity. During the period 1871 to 2009, there were 24 major drought years, defined as years with less than one standard deviation below the mean. Another important adverse effect of climate change could be unprecedented heat waves. Heat waves generally occur during summer season where the cropped land is mostly fallow, and therefore, their impact on agricultural crops is limited. However, these heat waves adversely affect orchards, livestock, poultry and rice nursery beds. The heat wave conditions during 2003 May in Andhra Pradesh and 2006 in Orissa are recent examples that have affected the economy to a greater extent. Also occurrence of heat waves in the northern parts during summer is common every year resulting in quite a good number of human deaths. Further, the water requirements of summer crops grown under irrigated conditions increase to a greater extent. Another adverse effect of climate change is cold waves which mostly occur in northern states. The Northern states of Punjab, Haryana, U.P., Bihar and Rajasthan experience cold wave and ground frost like conditions during winter months of December and January almost every year. The occurrence of these waves has significantly increased in the recent past due to reported climatic changes at local, regional and global scales. Site-specific short-term fluctuations in lower temperatures and the associated phenomena of chilling, frost, fogginess and impaired sunshine may sometimes play havoc in an otherwise fairly stable cropping/farming system of a region.

3.1 Influence of climate change on soil quality

Climate change is 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 becomes heavier, 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.

Not only does climate influence 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. Land use change can trigger organic matter decomposition, primarily via land drainage and cultivation. Restoration and recreation of peatlands can result in increased methane emissions initially as soils become anaerobic, whereas in the longer term they become a sink for carbon as organic mater accumulates. Climatic factors have an important role in peat formation and it is thus highly likely that a changing climate will have significant impacts on this resource.

3.2 Carbon build up and rising temperatures

In India, over two-thirds of the increase in atmospheric CO_2 during the past 20 years is due to fossil fuel burning. The rest 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 effect until year 2104. 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. The production of food more locally is also being promoted in an attempt to reduce food miles. 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 evapotranspiration, 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

3.3 Climatic change effect on soil fertility and erosion

No comprehensive study has yet been made of the impact of possible 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. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. In the Leningrad region of the USSR a one-third increase in rainfall (which is consistent with the GISS 2 x CO2 scenario) is estimated to lead to falls in soil productivity of more than 20 per cent. Large increases in fertilizer applications would be necessary to restore productivity levels. Decreases in rainfall, particularly during summer, could have a more dramatic effect, through the increased frequency of dry spells leading to increased proneness to wind erosion. Susceptibility to wind erosion depends in part on cohesiveness of the soil (which is affected by precipitation effectiveness) and wind velocity.

Nitrogen availability is important to 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.

3.4 Impact on biodiversity

Climate change is having a major impact on biodiversity and in turn biodiversity loss (in the form of carbon sequestration trees and plants) is a major driver of climate change. 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 feed back loop that intensifies climate change.

4. Conservation agriculture and its components

Conservation agriculture is 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 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).

Lal (1989) reported that the tillage system can be labeled as conservation tillage if it i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) cut short the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments. In order to ensure the above criteria in agriculture, there is a need to follow a range of cultural practices such as i) using crop residue as mulch, ii) adoption of non-inversions or no-tillage systems, iii) promotion of crop rotations by including cover crops, buffer strips, agroforestry, etc., iv) enhancement of infiltration capacity of soil through rotation with deep rooted perennials and modification of the root zone; v) enhancement in surface roughness of soil without jumping into fine tilth, vi) improvement in biological activity of soil fauna through soil surface management and vii) reducing cropping intensity to conserve soil and water resources and building up of soil fertility. The effects of conservation tillage on various soil properties, organic matter status, soil nutrient status and environmental quality have comprehensively reviewed by Blevins and Frye (1993), Lal (1989), Unger and McCalla (1980) and Unger (1990). From the various reviews, it is understood that no single tillage system is suitable for all soils and climatic conditions. The predominant advantages of the conservation tillage have been found in terms of soil erosion control, water conservation, less use of fossil fuels specifically for preparation of seed bed, reduced labour requirements, more timeliness of operations or greater flexibility in planting and harvesting operations that may facilitate double cropping, more intensive use of slopping lands and minimized risk of environmental pollution. Some of the discouraging and undesirable effects of conservation tillage has been reported as: (1) Increase in use of herbicides and consequently increased cost, (2) problems and difficulties in controlling of some of the infested weeds, (3) difficulty in managing poorly drained soils, (3) slower warming of temperate soils due to surface residue layer during winter and springs which delays germination and early growth. However, in tropics this negative aspect can become an asset in helping in maintaining relatively lower temperature and thereby enhancing germination. It also helps in preserving soil and water resources.

5. Importance and scope of conservation agricultural practices in rainfed areas

As discussed in the foregoing section, soil quality degradation is more prominent 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 through 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%). 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.

6. Conservation agriculture vis-à-vis soil quality

Various research reports have emphasized that conservation agricultural practices play an important role in preventing the soils from further degradation and in restoring back the dynamic attributes of soil quality. According to Doran and Parkin (1994) and Karlen *et al.*, (1997), soil quality is defined as the functional capacity of the soil. Seybold *et al.,* (1998) defined the soil quality as '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.' Quality with respect to soil can be viewed in two ways: (1) as inherent properties of a soil; and (2) as the dynamic nature of soils as influenced by climate, and human use and management. This view of soil quality requires a reference condition for each kind of soil with which changes in soil condition are compared and is currently the focal point for the term 'soil quality'. The soil quality as influenced by management practices can be measured quantitatively using physical, chemical and biological properties of soils as these properties interact in a complex way to give a soil its quality or capacity to function. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as 'indicators'. Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality and human and animal health. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. They provide signal about desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. Some of the important indicators which are given below can be influenced by appropriate soil management practices which in turn can help in moderating the ill effects of climate change (Table1).

Table 1: Predominant soil quality indicators and associated processes and functions which can moderate the ill effects of climate change

Soil quality indicators	Soil processes and functions
i) Physical indicators	
A. Mechanical	
Texture	Crusting, gaseous diffusion, infiltration
Bulk density	Compaction, root growth, infiltration
Aggregation	Erosion, crusting, infiltration, gaseous diffusion
Pore size distribution and continuity	Water retention and transmission, root growth, and gaseous exchange
B. Hydrological	
Available water capacity	Drought stress, biomass production, soil organic matter content

Non-limiting water range	Drought, water imbalance, soil structure
Infiltration rate	Runoff, erosion, leaching
C. Rooting zone	
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna
ii) Chemical indictors	
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solubilization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
iii) Biological indicators	
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and other soil macro fauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organo-mineral complexes
Total soil organic carbon	Soil nutrient source and sink, biomass carbon, soil respiration and gaseous fluxes

Source: Lal (1994)

7. 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.

7.1 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.

7.2 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.

7.3 Aggregation is closely associated with biological activity and the level of organic matter in the soil. The gluey substances that bind components into aggregates are created largely by the various living organisms present in healthy soil. Therefore, aggregation is increased by practices that favor soil biota. Because the binding substances are themselves susceptible to microbial degradation, organic matter needs to be replenished to maintain aggregation. To conserve aggregates once they are formed, minimize the factors that degrade and destroy them.

7.4 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.

7.5 **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.

7.6 **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.

7.7 **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.

8. Some research experiences showing the effect of conservation management practices on soil quality improvement

There are several reports on the influence of conservation agricultural management practices comprising of tillage, residue recycling, application of organic manures, green manuring and integrated use of organic and inorganic sources of nutrients, soil water conservation treatments, integrated pest management, organic farming, etc., on soil quality. Improved soil quality parameters create additional muscle power to soil to combat the ill effects of climate change. Some of the results pertaining to the effect of conservation agricultural practices on soil quality are given below:

The studies conducted over a 9 year period in Alfisols at Bangalore with finger millet, revealed that the yields were similar with optimum N, P, K application and with 50% NPK applied through combined use of fertilizers + FYM applied @ 10 t ha^{-1}. Application of vermicompost in combination with inorganic fertilizer in 1:1 ratio in terms of N equivalence was found very effective in case of sunflower grown in Alfisol at Hyderabad (Neelaveni, 1998). Combined use of crop residues and inorganic fertilizer showed better performance than sole application of residue. Use of crop residue in soil poor in nitrogen (Bangalore) showed significant improvement in the fertility status and soil physical properties. Continuous addition of crop residues for five years enhanced maize grain yield by 25%. Organic matter status improved from 0.5% in the control plots to 0.9% in plots treated with maize residue at 4 t ha^{-1} year^{-1}. In Alfisols at Hyderabad, use of crop residues in pearl millet and cowpea not only enhanced the yields but also made appreciable improvements in stability of soil structure, soil aggregates and hydraulic conductivity.

Capitalisation of legume effect is one of the important strategies of tapping additional nitrogen through biological N fixation. There are many reports on this aspect (Singh and Das, 1984; Sharma and Das, 1992). The beneficial effect of preceding crops on the succeeding non-legume crops has been studied at many locations. When maize was grown after groundnut, a residual effect of equivalent to 15 kg N ha^{-1} was observed at ICRISAT (Reddy et al. 1982). Sole cowpea has been reported to exhibit a residual effect of the magnitude of 25-50 kg N ha^{-1} (Reddy et al. 1982). Based on a five year rotation of castor with sorghum + pigeon pea and green gram + pigeon pea in an Alfisol of Hyderabad, it was observed that green gram + pigeon pea intercrop (4:1) can leave a net positive balance of 97 kg ha^{-1} total N in soil (Das et al. 1990).

Results of a long-term study conducted on soil quality improvement revealed that the application of gliricidia loppings proved superior to sorghum stover and no residue treatments in maintaining higher soil quality index (SQI) values. Further, increasing N levels also helped in maintaining higher SQI. Among the 24 treatments, the highest SQI was obtained in conventional tillage (CT) + gliricidia loppings (GL) + 90 kg N ha^{-1} ($CTGLN_{90}$) (1.27) followed by $CTGLN_{60}$ (1.19) and minimum tillage (MT) + sorghum stover (SS) + 90 kg N ha^{-1} ($MTSSN_{90}$) (1.18), while the lowest was under minimum tillage + no residue (NR) + 30 kg N ha^{-1} ($MTNRN_{30}$) (0.90) followed by $MTNRN_{0}$ (0.94), indicating relatively less aggradative effects. The application of 90 kg N ha^{-1} under minimum tillage even without applying any residue ($MTNRN_{90}$) proved quite effective in maintaining soil quality index as high as 1.10. The key indicators, which contributed considerably towards SQI were, available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC). Among the various treatments, $CTGLN_{90}$ not only had the highest SQI, but was most promising from the viewpoint of sustainability, maintaining higher average yield levels under sorghum-castor rotation. From the view point of SYI, CT approach remained superior to MT. To maintain yield as well as soil quality in Alfisols, primary tillage along with organic residue and nitrogen application are needed (Sharma et al, 2005).

Another long-term experiment was conducted with two tillage (conventional (CT) and reduced (RT)) and five INM treatments (control, 40 kg N through urea, 4 t compost + 20 kg N, 2 t Gliricidia loppings + 20 kg N and 4 t compost + 2 t Gliricidia loppings) using sorghum and green gram as test crops. Tillage did not influence the soil quality index (SQI), while the conjunctive nutrient use treatments had a significant effect. The conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, while the sole inorganic treatment could aggrade only to the extent of 18.2 % over the control. Statistically, the overall superiority of the treatments in aggrading the soil quality was: 4 Mg compost + 2 Mg gliricidia loppings (T5) > 2 Mg Gliricidia loppings + 20 kg N through urea (T4) = 4 Mg compost + 20 kg N through urea (T3) > 40 kg N through urea (T2). The extent of percent contribution of the key indicators towards soil quality index (SQI) was: microbial biomass carbon (MBC) (28.5%), available nitrogen (28.6%), DTPA- Zn (25.3%), DTPA- Cu (8.6%), hydraulic conductivity (HC) (6.1%) and mean weight diameter (MWD) (2.9%) (Sharma et al., 2008).

Based on the network tillage experiment being carried out since 1999 at various centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA), it was observed that in arid (< 500 mm rainfall) region, low tillage was almost comparable to conventional tillage and the weed management was not so difficult, whereas, in semi arid (500 – 1000 mm) region, conventional tillage was found superior. It is a well-established fact that infiltration of rainfall depends on soil loosening and its receptiveness and thus requires more surface disturbance. Success of crops depends on rainfall infiltration and soil moisture holding in the profile.

For improving the carbon content in soil, apart from crop residues, the agro-forestry also becomes important. However, nothing comes free. The agro-forestry system comprising of perennial components depends on the sub-soil components. It has been observed that grasslands and tree system play an important role in improving soil properties such as bulk density, mean weight diameter, water stable aggregates and organic carbon. Apart from the above, other soil properties such as infiltration rate and hydraulic conductivity were also influenced due to agro forestry systems compared to agricultural systems.

8. Promotion of conservation farming- Steps

The following steps are needed to promote conservation farming in the future:

8.1 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.

8.2 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

8.3 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.

8.4 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.

8.5 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.

8.6 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.

8.7 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.

8.8 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.

8.9 Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.

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.

9. Research and management strategies to improve soil resilience towards climatic change

The following research, developmental and policy strategies are suggested to restore and maintain soil quality on long-term basis.

9.1 **Checking soil resource through effective soil and water conservation (SWC) measures**: It is well accepted connotation that 'Prevention is better than cure'. In order to protect the top soil, organic mater content contained in it and associated essential nutrients, it is of prime importance that there should be no migration of soil and water out of a given field. If this is controlled, the biggest robbery of clay-organic matter -nutrients is checked. This can be easily achieved, if the existing technology on soil and water conservation is appropriately applied on an extensive scale. The cost for in-situ and ex-situ practices of SWC has been the biggest concern in the past. There is a need to launch 'soil resource awareness program' among the farming community. Suitable incentives / support need to be given to the farming community by way of employment / food for work program, etc.

9.2 **Rejuvenation and reorientation of soil testing program in the country:** About more than 600 Soil testing labs situated in the country need to be reoriented, restructured and need to be given fresh mandate of assessing the soil quality in its totality including chemical, physical, biological soil quality indicators and water quality. The testing needs to be on intensive scale and recommendations are required to be made on individual farm history basis. Special focus is required on site specific nutrient management (SSNM). Soil Health Card system needs to be introduced. Soil fertility maps of intensive scale need to be prepared. District soil testing labs need to be renamed as 'District Soil Care Labs' and required to be well equipped with good equipments and qualified manpower for assessing important soil quality indicators including micronutrients. Fertilizer application needs to be based on soil tests and nutrient removal pattern of the cropping system in a site specific manner. This will help in correcting the deficiency of limiting nutrients. Keeping in mind the sluggish and inefficient activities of regional soil testing labs of the states, private sector can also be encouraged to take up Soil Care Programs with a reasonable costs using a principle of 'Soil Clinics, Diagnosis and Recommendation'.

9.3 **Promotion of management practices which enhance soil organic matter**: Management practices such as application of organic manures (composts, FYM, vermi-composts), legume-crop based green manuring, tree-leaf green manuring, residue recycling, sheep-goat penning, organic farming, conservation tillage, inclusion of legumes in crop rotation need to be encouraged (Sharma et al., 2002, 2004). Similar to inorganic fertilizer, subsidy provisions for organic manures can also be made so that growers should be motivated to take up these practices as components of integrated nutrient management (INM). As is being done in some of the countries such as USA, conservation tillage and land cover need to be promoted in India too for better carbon sequestration.

9.4 **Development and promotion of other bio-resources for enhancing microbial diversity and ensuring their availability**: In addition to organic manures, there is a huge potential to develop and promote bio-fertilizers and bio-pesticides in large scale. These can play an important role in enhancement of soil fertility and soil biological health. Use of toxic plant protection chemical can also be reduced. In addition to this, there is a need to focus on advance research for enhancing microbial diversity by identifying suitable gene pools

9.5 **Ensuring availability of balanced multi-nutrient fertilizers:** Fertilizer companies need to produce multi-nutrient fertilizers containing nutrients in a balanced proportion so that illiterate farmers can use these fertilizers without much hassle.

9.6 **Enhancing the input use efficiency through precision farming:** The present level of use efficiency of fertilizer nutrients, chemicals, water and other inputs is not very satisfactory. Hence, costly inputs go waste to a greater extent and result in monetary loss and environmental (soil and water) pollution. More focus is required to improve input use efficiency. The components required to be focused could be suitable machinery and other precision tools for placement of fertilizers, seeds and other chemical in appropriate soil moisture zone so that losses could be minimized and efficiency could be increased. This aspect has a great scope in rainfed agriculture. This will also help in increasing water use efficiency (WUE) too.

9.7 **Amelioration of problematic soils using suitable amendments and improving their quality to a desired level:** History has a record that poor soil quality or degraded soils have taken toll of even great civilizations. No country can afford to let its soils be remaining degraded by virtue of water logging, salinisation, alkalinity, erosion etc. Lots of efforts have already gone into the research process. There is a need to ameliorate the soils at extensive scale on regular basis. No matter, how much it costs.

9.8 **Land cover management:** Promotion of land cover management is must to protect the soil and to enhance organic matter in soil.

9.9 **Mass awareness about the importance of soil resource and its maintenance:** There is need to introduce the importance of soil resource and its care in the text books at school and college levels. The subject is dealt at present apparently along with geography. Farming communities too need to be made aware about soil, its erosion, degradation, benefits and losses occurred due to poor soil quality. This can be done through various action learning tools which explain the processes of soil degradation in a simple and understandable manner.

9.10 **Need to constitute a high power body such as National Authority on Land and Soil Resource Health or National Commission on Soil Resource Health:** State Soil and Water conservation departments restrict their activities only up to construction of small check dams, plugging of gullies etc in common lands. State Soil testing labs are almost sluggish in action, poorly equipped and are with under-qualified manpower. Mostly, no tests are done except for Organic C, P and K. State agricultural universities (SAU) only adopt few villages, and consequently, no extensive testing of soil health is done. ICAR institutions also take up few watersheds. Then, there will be no one to work for Soil Health Care program at extensive scale. Hence, a Central High Power Authority / Commission on soil Resource Health is needed to coordinate the program with States. It is beyond the capacity of research organizations to take up such giant and extensive task in addition to their regular research mandates.

Thus conservation agriculture can play an important role not only in improving the physical, chemical and biological soil quality parameters but also in mitigating the adverse impact of climate change. The principles of conservation agriculture need to be followed in holistic manner and the practices must continue on long term bases to see the explicit impact.

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IMPACT OF CLIMATE CHANGE ON CROPS

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Impact of climate change on agriculture will be one of the major deciding factors influencing the future food security of mankind on the earth. Agriculture is not only sensitive to climate change but at the same time is one of the major drivers for climate change. Understanding the weather changes over period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agricultural sector as a whole.

Relatively small changes in climate can have significant impacts on agricultural productivity. The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. The inter-annual variability of crop yields is particularly sensitive to changes in climatic variability. The inter-annual variations in temperature and precipitation were much higher than the predicted changes in temperature and precipitation. The crop losses may increase if the predicted climate change increases the climate variability. The tropics are more dependent on agriculture as 75% of world population lives in tropics and two thirds of these people main occupation is agriculture. With low levels of technology, wide range of pests, diseases and weeds, land degradation, unequal land distribution and rapid population growth, any impact on tropical agriculture will affect their livelihood.

India, being a large country, experiences wide fluctuations in climatic conditions with cold winters in the north, tropical climate in south, arid region in west, wet climate in the east, marine climate in coastline and dry continental climate in interior. A likely impact of climate change on agricultural productivity in India is causing a great concern to the scientists and planners as it can hinder their attempts for achieving household food security. Food grain requirements in the country (both human and cattle) would reach about 300 mt in 2020. The future agriculture sector is under enormous pressure to address the increasing demand for food, fibre and fuel as well as income, employment and other essential ecosystem services for the growing population from less affable natural resources such as diminishing availability of water and arable land and warmer atmosphere. Any measures to maximize the production or productivity to address these multiple demands placed on agriculture should have inbuilt mechanisms to reduce the greenhouse gas emissions as well as required to possess more potential to sequester the carbon or otherwise culminate into disastrous climatic conditions.

Temperature

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. Agriculture is expected to be affected by changes in temperature, precipitation and atmospheric carbon dioxide concentrations. The increasing concentration of greenhouse gases is predicted to increase average global temperatures gradually. The gradually increasing concentrations of greenhouse gases will lead to gradually increasing global temperatures and more precipitation. The global temperature increases, however, are not likely to be uniform across the planet. Most climate models agree that the temperature increases will be larger in the higher latitudes and that they will be greater at night than during the day. That is, global warming will increase average temperatures but it will also decrease the range of temperatures both through the day (diurnal cycle) and across latitudes. The mean atmospheric temperatures of the globe have been on the increase and the last 13 out of 15 years recorded the highest temperatures in the last 100 years. The frequency of occurrence of heat and cold waves is on the increase. Significant changes in daily maximum and minimum temperatures are observed.

The mean global temperature rose by 0.6°C over the past 100 years. The projections suggest that the global surface temperature may increase by 1.4 to 5.8° by the end of the Century if there is no let up in the release of GHG into the atmosphere. Warmest summers were observed in the last decade of the past Century and the warming phase continued in this decade also during 2002 and 2003 in Asian Sub-continent and Europe, which has witnessed heavy human causalities.

Exceeding crop-specific high temperature thresholds may result in a significantly higher risk of crop failure. The inter-annual variability of crop yields is particularly sensitive to changes in climatic variability. In regions where crop production is affected by water shortages, increases in the year-to-year variability of yields in addition to lower mean yields are predicted. It was estimated that a 0.5ºC increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 tonne per hectare. An increase in winter temperature by 0.5ºC would thereby translate into a 10 per cent reduction in wheat production in the high-yield states of Punjab, Haryana and UP. An estimated 2ºC increase in mean air temperature could decrease rice yield by about 0.75 tonne per hectare in high yield areas and by about 0.60 tonne per hectare in low coastal regions. Even with adaptation by farmers of their cropping patterns and inputs in response to climate change, the losses would remain significant. The loss in farm level net revenue is estimated to range between 9 and 25% for a temperature rise of 2.0ºC to 3.5ºC.

Precipitation

Climate model predictions of CO_2-induced global warming typically suggest that rising temperatures should be accompanied by increases in rainfall amounts and intensities, as well as enhanced variability. Both the number and intensity of heavy precipitation events are projected to increase in a warming world, according to the IPCC. Monsoon rainfall is an important socio-economic feature of India, and that climate models suggest that global averaged temperatures are projected to rise under all scenarios of future energy use, leading to "increased variability and strength of the Asian monsoon." Kripalani et al. report, "there is no clear evidence to suggest that the strength and variability of neither the Indian Monsoon Rainfall (IMR) nor the epochal changes are affected by the global warming." The analysis of observed data for the 131-year period (1871-2001) suggests no clear role of global warming in the variability of monsoon rainfall over India."

Earth's climate is determined by a conglomerate of cycles within cycles, all of which are essentially independent of the air's CO_2 concentration; and it demonstrates that the multi-century warm and cold periods of the planet's millennial-scale oscillation of temperature may have both wetter and drier periods embedded within them. Consequently, it can be appreciated that warmth alone is not a sufficient condition for the concomitant occurrence of the dryness associated with drought.

Water availability

Of the 1.5 billion hectares (ha) of cropland worldwide, only 18% (277 million hectare) is irrigated land; the remaining 82 percent is rainfed land. The importance of rainfed agriculture varies regionally, and is most significant in country like India where rainfed agriculture accounts for about 65% of the cropland and 70% of population main occupation. Under current water use practices, increases in population and changes in diet are projected to increase water consumption in food and fiber production by 70-90%. If demands for biomass energy increase, this may aggravate the problem. In addition, sectoral competition for water resources will intensify, further exacerbating the stress on developing country producers. Throughout the 20th century, global water use has increased in the agricultural, domestic and industrial sectors. Evaporation from reservoirs has increased at a slower rate. Projections indicate that both global water use and evaporation will continue to increase.

Climate model predictions of CO_2-induced global warming typically suggest that rising temperatures should be accompanied by increases in rainfall amounts and intensities, as well as enhanced variability. Both the number and intensity of heavy precipitation events are projected to increase in a warming world, according to the IPCC. More intense and longer droughts have been observed over wider areas since 1970's, particularly tropics and subtropics (IPCC, 2007). Increased drying linked with higher temperatures and decreased precipitation has contributed to changes in drought. Changes in sea surface temperatures (SST), wind pattern and decreased snow pack and snow cover have also been linked to droughts. Many regions across the world started witnessing increased occurrence of extreme weather events. There have been events of increased number of intense cyclonic events and increase in occurrence of high rainfall events, even though the quantum of rainfall had not shown large changes.

Impacts of GHGs

Rice, wheat, maize, sorghum, soybean and barley are the six major crops in the world and they are grown in 40% cropped area, 55% of non-meat calories and over 70% of animal feed (FAO, 2006). Since 1961, there is substantial increase in the yield of all the crops. The impact of warming was likely offset to some extent by fertilization effects of increased CO_2 levels. At the global scale, the historical temperature- yield relationships indicate that warming from 1981 to 2002 very likely offset some of the yield gains from technological advance, rising CO_2 and other non-climatic factors.

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 370 parts per million (ppm) today, a 30 percent 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 21^{st} 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. Voluminous scientific evidence shows that if CO_2 were to rise above its current ambient level of 370 parts per million, most plants would grow faster and larger because of more efficient photosynthesis and a reduction in water loss. There are two important reasons for this productivity boost at higher CO_2 levels. One is superior efficiency of photosynthesis and the other is a sharp reduction in water loss per unit of leaf area. By partially closing stomatal 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.

The mean response to a doubling of the CO_2 concentration from its current level of 360 ppm is a 32 percent improvement in plant productivity, with varied manifestations in different species. Cereal grains with C3 metabolism, including rice, wheat, barley, oats, and rye, show yield increases ranging from 25 to 64 percent, resulting from a rise in carbon fixation and reduction in photo-respiration. Food crops with C4 metabolism, including corn, sorghum, millet, and sugarcane, show yield increases ranging from 10 to 55 percent, resulting primarily from superior efficiency in water use. 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. When the dry mass production and yield increase of the world's ten most important crop species in response to elevated CO_2 was analyzed from different experiments, it was found that in some species the relative increase of total biomass and in others that of economic yield is greater.

Field crops under drought often experience two quite different but related and simultaneous stresses: soil water deficit and high temperature stresses. Elevated CO_2 increase growth, grain yield and canopy photosynthesis while reducing evapotranspiration. 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. Elevated atmospheric CO_2 concentration ameliorates, to various degrees, the negative impacts of soil water deficit and high temperature stresses.

Methane in the Earth's atmosphere is an important greenhouse gas with a global warming potential of 25 over a 100-year period. This means that a methane emission will have 25 times the impact on temperature of a carbon dioxide emission of the same mass over the following 100 years. Methane has a large effect for a brief period (a net lifetime of 8.4 years in the atmosphere), whereas carbon dioxide has a small effect for a long period (over 100 years). Because of this difference in effect and time period, the global warming potential of methane over a 20 year time period is 72. The Earth's methane concentration has increased by about 150% since 1750, and it accounts for 20% of the total radiative forcing from all of the long-lived and globally mixed greenhouse gases.

Methane is emitted from a variety of both human-related (anthropogenic) and natural sources. Human-related activities include fossil fuel production, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management. These activities release significant quantities of methane to the atmosphere. It is estimated that 60% of global methane emissions are related to human-related activities. Natural sources of methane include wetlands, gas hydrates, permafrost, termites, oceans, freshwater bodies, non-wetland soils, and other sources such as wildfires.

Soils emit N_2O through biological and non-biological pathways and the agricultural lands are most significant sources of this GHG. The quantity of N_2O emitted from agricultural land dependent on fertilizer application and subsequent microbial denitrification of the soil. Emissions of N_2O from soils are estimated to be as much as 16 percent of global budget of N_2O. Various agricultural soil management practices contribute to greenhouse gas emissions. Agricultural soil management practices such as irrigation, tillage or the fallowing of land can affect the efflux of these gases. Level of N_2O emissions may be dependent on the type of fertilizer used, amount and placement depth of fertilizer, soil moisture and temperature. Tilling tends to decrease N_2O emissions; no-till and herbicides may increase N_2O emissions.

In order to estimate how greenhouse gases will impact farming, we must examine the range of climate change predictions. We also must predict what farming will look like in the distant future. Climate change will occur slowly. The impacts we are concerned about will occur in the second half of the 21st century. It is consequently important to project what agriculture will look like in 50 to 100 years because it is this future system that will be affected. The answers to these basic questions about future agriculture will help determine what global warming will likely do to the agricultural sector.

Adaptation strategies

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. Seasonal precipitation distribution patterns and amounts could change due to climate change. With warmer temperatures, evapo-transpiration rates would raise, which would call for much greater efficiency of water use. Yields can be significantly enhanced by improved agricultural water management, in particular by increasing water availability through on-farm water management techniques such as water harvesting and supplemental irrigation, and by increasing the water uptake capacity of crops through measures such as conservation farming. In many circumstances, investments in improved water management in rainfed agriculture are catalytic, reducing barriers to the adoption.

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. The crop varieties with short duration and/or tolerance to high temperature, flooding, drought are recommended to fit in future predicted conditions with more frequent extreme events such as heat waves, droughts, and floods.

Increasing agricultural production in order to meet projected increases in demands can be accomplished by bringing new land into agricultural production, increasing the cropping intensity on existing agricultural lands and increasing yields on existing agricultural lands. Adoption of any one of these strategies will depend upon local availability of land and water resources, agro-ecological conditions and technologies used for crop production, as well as infrastructural and institutional development. Seventy-five percent of the projected growth in crop production in developing countries comes from yield growth and 16 percent from increases in cropping intensity.

Many under developed and developing countries are already vulnerable to weather shocks, having already weak economies, without significant investments in agriculture and limited institutional capacities to adapt, future climate changes will increase this vulnerability. Thus, increasing the resilience of agricultural systems is a key means of adapting to climate change as well as increasing food security. Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

ENERGY EFFICIENCY IN AGRICULTURE TO MINIMIZE GHG EMISSIONS

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Introduction:
The agriculture sector has at its core the production process for foodstuff (e.g., grains, fruits and vegetables, meat, fish, poultry, and milk), and non-food vegetable products of economic value (e.g., tobacco, jute, hemp). However, the sector also comprises or has close links with processes that take place before and after this core production process, such as fertilizer production, post-harvest processing, and transport of foodstuff. Defined broadly, the agriculture sector has as its primary goal the delivery of food on the table for the population or for export. Despite the relative importance of this sector to economic activity and employment in the Developing countries, agricultural energy use tends to be small compared to that in industry or transport.

Energy needs of Agriculture and its impact on emissions:
Agriculture requires energy at all stages of production. Energy is used by agricultural machinery (e.g., tractors and harvesters), irrigation systems and pumps, which may run on electricity, diesel, or other energy sources. Energy is also needed for processing and conserving agricultural products, transportation, and storage. In that respect, it is a critical factor in adding value in the agricultural sector. Indirect energy use occurs mainly through the production and application of mineral fertilizers and chemicals required to improve crop yields. In many cases, electricity and fuel use tends to be inefficient because of price subsidies, and thus mitigation options may offer a significant potential for improving efficiency and reducing GHG emissions from this sector.

Mitigation options available for energy conservation in agriculture sector:
Potential mitigation options for agricultural energy use are described below. While some of the options are not yet available for widespread implementation, or need more scientific and economic analysis before their applicability can be assessed, they are also presented since they might become feasible later on. The main near-term option likely to be of interest for GHG mitigation is efficiency improvement in irrigation. The use of various renewable sources of energy for agricultural applications (e.g., wind-driven pumps, solar drying, diesel engines powered with mostly gasified biomass) have been tested on a limited scale and may be of interest in some cases. (Agricultural residues may also be used for meeting energy demands outside the agriculture sector - e.g., for cogeneration in agro-processing industries.)

- **Reduce energy use for irrigation.**

Irrigating crops often requires considerable amounts of electricity or diesel fuel. Reducing energy consumption for irrigation while providing the desired service may be accomplished through use of more efficient pump sets and water-frugal farming methods. To improve the efficiency of irrigation pump sets, a number of technical measures are available. These include: use foot valves that have low-flow resistance; replace undersized pipes and reduce number of elbows and other fittings that cause frictional losses; use high-efficiency pumps; select pumps better matched to the required lift characteristics; use rigid PVC pipes for suction and delivery; operate pumps at the recommended RPM; select prime mover for the pump (i.e., electric motor or diesel engine) matched to the load; select an efficient diesel engine or motor for the application; schedule and perform recommended maintenance of the pump and the prime mover; and ensure efficient transmission of mechanical power from the prime mover to the pump.

- **Increase the efficiency of non-pumping farm machinery:**

Energy use for traction for cultivation, sowing, weeding, harvesting, and other operations can be reduced through use of more efficient equipment or by minimizing the need for traction through low-tillage agriculture.

- **Switch to lower-carbon energy sources:**

Options in this category include wind- and photovoltaic-powered pumps, enhanced solar drying, and use of biofuels instead of fossil fuels in various applications where heat is required.

- **Reduce input of chemical fertilizers:**

The two basic ways of reducing the input of chemical fertilizers are to target fertilizer application better and to substitute organic or microbial fertilizers for chemical fertilizers. Reduced demand for chemical fertilizer lowers energy use in the chemical industry. There have been limited studies in developing and transition countries on reducing the intensity of chemical fertilizer inputs through improved application or use of organic fertilizers so assessing the potential impact of this option is difficult.

- **Use conservation tillage systems:**

Conservation tillage practices store carbon in the soil through retention of vegetative matter (crop residue). Since most conservation tillage practices reduce the number of trips across a field needed to grow and gather a crop, total energy required to grow a crop is reduced.

- **Improve efficiency of post-harvest drying and storage:**

Various agricultural products are subjected to drying or cold storage before they are sent to market. The efficiency of these processes can generally be improved through use of better equipment and proper maintenance.

- **Reduce post-harvest food grain losses:**

Assuming that food needs are being met, use of storage methods impervious to pests and rodents can reduce the need for crop production, thereby saving the energy that would be used in that production.

Energy efficient Technologies presently using in agriculture:
1. Conservation Agriculture:

In the context of mitigation of GHG's, conservation tillage, defined, in general terms, as the reduction of soil tillage intensity in combination with the maintenance of crop residues on the soil surface, can play a decisive role. Nothing is more important to humanity than reliable food production, but the mechanization and intensification of traditional tillage based systems has exacerbated major environmental problems, because:

1. Conventional tillage is fossil-energy intensive process, which also accelerate s oxidation of soil organic matter
2. Conventional tillage buries residue, which is the surface soil's natural protection against erosion by wind and water
3. Tillage and traffic cause subsurface degradation, reducing soil biological activity and promoting root zone water logging, which converts crop nutrients into nitrous oxide and methane-both damaging the greenhouse gases.

Conservation tillage was originally developed to halt the soil erosion caused by traditional tillage based agriculture. The first conservation agriculture system identified soil tillage as a major problem, and replaces this with herbicide and other weed control measures. It 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. Conservation Agriculture is characterized by three principles which are linked to each other, namely:

- Continuous minimum mechanical soil disturbance.
- Permanent organic soil cover.
- Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops.

Advantages of Conservation Agriculture:

Conservation Agriculture, understood in this way, provides a number of advantages on global, regional, local and farm level:

- It provides a truly sustainable production system, not only conserving but also enhancing the natural resources and increasing the variety of soil biota, fauna and flora (including wild life) in agricultural production systems without sacrificing yields on high production levels. As CA depends on biological processes to work, it enhances the biodiversity in an agricultural production system on a micro- as well as macro level.

- No till fields act as a sink for CO_2 and conservation farming applied on a global scale could provide a major contribution to control air pollution in general and global warming in particular. Farmers applying this practice could eventually be rewarded with carbon credits.
- Soil tillage is among all farming operations the single most energy consuming and thus, in mechanized agriculture, air-polluting, operation. By not tilling the soil, farmers can save between 30 and 40% of time, labour and, in mechanized agriculture, fossil fuels as compared to conventional cropping.
- Soils under CA have very high water infiltration capacities reducing surface runoff and thus soil erosion significantly. This improves the quality of surface water reducing pollution from soil erosion, and enhances groundwater resources. In many areas it has been observed after some years of conservation farming that natural springs that had dried up many years ago, started to flow again. The potential effect of a massive adoption of conservation farming on global water balances is not yet fully recognized.
- Conservation agriculture is by no means a low output agriculture and allows yields comparable with modern intensive agriculture but in a sustainable way. Yields tend to increase over the years with yield variations decreasing.
- For the farmer, conservation farming is mostly attractive because it allows a reduction of the production costs, reduction of time and labour, particularly at times of peak demand such as land preparation and planting and in mechanized systems it reduces the costs of investment and maintenance of machinery in the long term.

Limitations of Conservation Agriculture:

The most important limitation in all areas where conservation agriculture is practiced is the initial lack of knowledge. There is no blueprint available for conservation agriculture, as all agro-ecosystems are different. A particularly important gap is the frequent dearth of information on locally adapted cover crops that produce high amounts of biomass under the prevailing conditions. The success or failure of conservation agriculture depends greatly on the flexibility and creativity of the practitioners and extension and research services of a region. Trial and error, both by official institutes and the farmers themselves, is often the only reliable source of information.

Conservation Agriculture Technologies and Machinery used:

Conservation Agriculture

Conservation agriculture Technologies	MACHINERY USED	**Potential Benefits**
Laser leveler	Land leveller, Laser land leveller	Cuts water use; fewer bunds and irrigation channels; better soil nutrient distribution; less leaching of nitrates into groundwater; more efficient tractor use (reduced diesel consumption); increased area

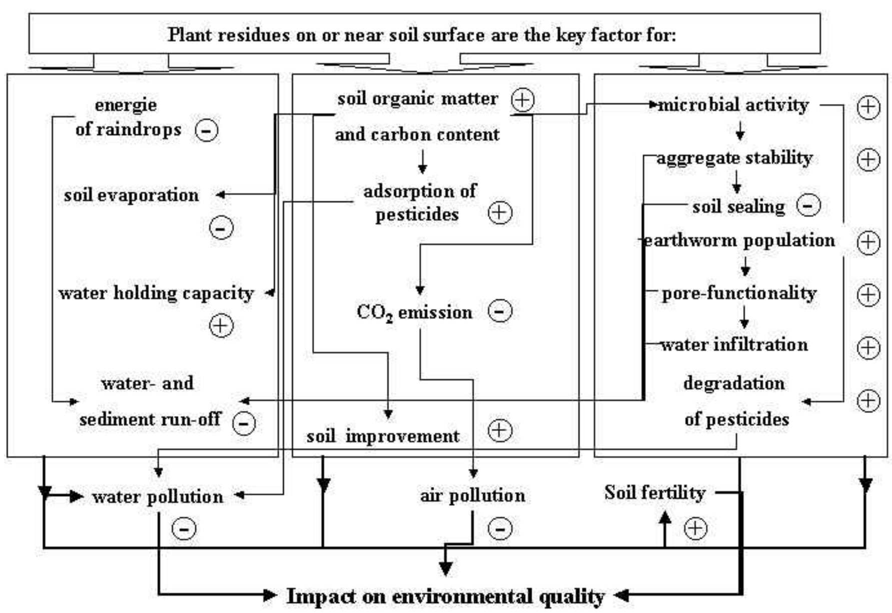
		for cultivation.
Zero-tillage	Zero till drill, Planter with double disc coulters	Less labor required; soil physical structure is maintained (reduced nutrient loss, soil health maintained); less water required; avoids large cracks in soil after dry periods; can keep previous crop's residue in field for mulch (if appropriate drill seeder is used for seeding); subsoil layer is not compacted by tractors (compacted subsoil impedes root growth).
Crop residue mulch	Heavy ripper, motorized rotary hand-held mower, Animal traction knife roller, Tractor mounted knife roller, Shredder, Combine harvester with straw chopper	Increases soil water-holding capacity, increases soil quality, reduces weed pressure, avoids burning.
Dry seeding	Rolling punch injection planter, Drill seeder	Less water required; less labor required (especially at peak transplanting time); post harvest condition of field is better for succeeding crop; deeper root growth (meaning better tolerance of dry conditions, better access to soil nutrients).
Drill seeder	Dibbler, Animal/Tractor drawn precision planter	Precise seeding (reduced seed rate); applies fertilizer and/or herbicide simultaneously with seed (increased input efficiency); seeds through previous crop's residue; incorporates previous crop's residue into soil (adds to soil fertility).
Green manure (*Sesbania*)	Knife Slasher, Straw chopper	Fast early growth suppresses weeds; after herbicide treatment, it acts as mulch (reduces evaporative water loss; adds soil organic matter plus nutrients—especially nitrogen—to the soil).
Crop diversifi	Bed planter,	Two to three crops grow

cation (raised seedbeds, intercropping)	Raised bed and furrow planter	simultaneously (e.g., rice, chickpea, pigeon pea, maize); increased income; increased nutritional security.

Effect of conservation agriculture on GHG emissions:

The importance of conservation tillage for a possible increase of soil organic carbon (SOC) is associated only with its effect on the reduction of biological oxidation and thus the mineralization rate of organic matter and soil carbon. In fact, a great number of studies shows that conservation tillage, and especially no-tillage, are able to increase the levels of SOC.However, there are other factors besides the reduced soil aeration and consequent oxidation of SOC that contribute to the soil's potential as a sink for organic carbon and for a reduction of the emission of GHG's. The below Figure shows the overall benefits and interactions of conservation tillage in combination with the maintenance of crop residue on or near the soil surface.

FIG: Conservation Tillage and its Impact to Environmental Quality



Especially under rain fed conditions where water availability is a limiting factor reduced

evaporation losses both at soil and seed bed preparation and through soil coverage during vegetation lead to higher water availability and thus to higher biomass production and crop yields. Higher yields result in a greater amount of crop residues left in the field, which consequently contributes to the SOC pool. Besides the immediate effect of conservation tillage on increased water availability a medium and long term effect through an increase of the soil's water holding capacity through more soil organic matter and a more favorable pore size distribution can be expected. Finally, the amount of irrigation water can be reduced resulting in a lower energy use for its transport.

Again, with regard to soil fertility soil organic matter acts as a key factor for improvement of biomass production and crop yields, especially on the SOC depleted intensively cultivated cropland with low stocking rates. Furthermore, improved soil fertility will allow to reduce mineral fertilizer input contributing thus to reduced energy use for its manufacturing and a reduced potential for the emission of nitrous oxides. In this context the inclusion of winter cover crops in crop rotations as a recommended management practice within the concept of Conservation Agriculture (Derpsch, 2001) can also be regarded as a strategy to not only prevent nutrient leaching and reduce fertilizer input but also to enhance SOC accumulation and to improve soil fertility and biomass production.

Potential of Conservation Agriculture to reduce CO_2 emissions and increase in Carbon Sequestration

The estimation of the potential for carbon sequestration through conservation tillage requires at least information on the potential land area, which could be submitted to this change in soil management, and the rate with which carbon is accumulated per unit of time and area as a consequence of this change. One of these few attempts has been made by Smith et al. (1998), indicating a carbon sequestration through no-tillage of around 0.4 t $ha^{-1}a^{-1}$. According to the same authors the maintenance of 2 or 10 t of straw may have an additional effect on carbon sequestration of around 0.2 or 0.7 t C $ha^{-1}a^{-1}$, respectively. Based on this information carbon sequestration and savings in fuel consumption per hectare by using conservation agriculture are given below:

- Carbon sequestration (reduced C emission) under no-tillage (NT): 0.77 t C ha-1a-1
- Carbon sequestration under reduced tillage (RT): 0.50 t C ha-1a-1
- Reduced fuel consumption under NT: 44.2 l ha-1a-1
- Reduced fuel consumption under RT: 20.0 l ha-1a-1

2. Biogas technology:

Biogas is a proven and widely used source of energy in Asia. There is now yet another wave of renewed interest in biogas due to the increasing concerns of climate change, indoor air pollution and increasing oil prices. Such concerns, particularly for climate change, open opportunities for the use of the Clean Development Mechanism (CDM) in the promotion of biogas. Biogas originates from bacteria during the process of bio-degradation of organic materials under anaerobic (without air) conditions.biogas is produced from different types of biogas plants like Ballon plants, Fixed dome type , Floating dome type depending up on raw material. Biogas is a mixture of gases mainly composed of:

Methane (CH_4): 40-70 % by volume

Carbon dioxide (CO_2): 30-60 % by volume

Hydrogen (H_2): 0-1 % by volume

Hydrogen sulfide (H_2S): 0-3 % by volume

The burning of dung and plant residue is a considerable waste of plant nutrients. Farmers in developing countries are in dire need of fertilizer for maintaining cropland productivity. Nonetheless, many small farmers continue to burn potentially valuable natural fertilizers, despite being unable to afford chemical fertilizers. The amount of technically available nitrogen, potassium and phosphorous in the form of organic materials is around eight times as high as the quantity of chemical fertilizers actually consumed in developing countries. Biogas technology is a suitable tool, especially for small farmers, for maximizing the use of scarce resources. After extraction of the energy content of dung and other organic waste material, the resulting sludge is still a good fertilizer, supporting soil quality as well as higher crop yields.

Benefits of Biogas Technology:

Well-functioning biogas systems can yield a range of benefits for users, the society and the environment in general:

- Production of energy (heat, light, electricity);
- Transformation of organic wastes into high-quality fertilizer;
- Improvement of hygienic conditions through reduction of pathogens, worm eggs and flies;
- Reduction of workload, mainly for women, in firewood collection and cooking;
- Positive environmental externalities through protection of soil, water, air and woody vegetation;
- Economic benefits through energy and fertilizer substitution, additional income sources and increasing yields of animal husbandry and agriculture;
- Other economic and eco-benefit through decentralized energy generation, import substitution and environmental protection.

Applications of Biogas technology:

Cooking: Biogas can be used for cooking in a specially designed burner. A biogas plant of 2 m^3 capacity is sufficient for providing cooking fuel to a family of four to five.

Lighting: Gas lamps can be fuelled by biogas. To power a 100-candle lamp (60 W), the biogas required is 0.13 m^3 per hour.

Power generation: Biogas can be used to operate a dual-fuel engine and can replace up to 75% of the diesel. At presently biogas power based irrigation pumps and sludge from biogas digester are using as power souces in agriculture. Still biogas based IC engines are not extensively using in Indian agriculture. However, the required high level of investment in capital and other limitations of biogas technology should also be thoroughly considered. But there is a lot of scope for deployment of these technologies in Indian agriculture.

Biogas Effect on GHG Emissions

Last but not least, biogas technology takes part in the global struggle against the greenhouse effect by reducing the release of CO2 from burning fossil fuels in two ways. First, biogas is a direct substitute for gas or coal for cooking, heating, electricity generation and lighting. Second, the reduction in the consumption of artificial fertiliser avoids carbon dioxide emissions that would otherwise come from the fertiliser-producing industries. By helping to counter deforestation and degradation caused by overusing ecosystems as sources of firewood and by melioration of soil conditions, biogas technology reduces CO_2 releases from these processes and sustains the capability of forests and woodlands to act as a carbon sink.

Methane, the main component of biogas is itself a greenhouse gas with a much higher "greenhouse potential" than CO_2. Converting methane to carbon dioxide through combustion is another contribution of biogas technology in the mitigation of global warming. However, this holds true only for the case that the material used for biogas generation would otherwise undergo anaerobic decomposition, thereby releasing methane into the atmosphere. Methane leaking from biogas plants without being burned does contribute to the greenhouse effect. Burning biogas also releases CO_2. Similar to the sustainable use of firewood, this returns carbon dioxide which has been assimilated from the atmosphere by growing plants. There is no net intake of carbon dioxide in the atmosphere from biogas burning, as is the case when burning fossil fuels.

3. Biofuels:

Adequate energy and power availability on Indian farms and in rural sector is essential to enhance agricultural productivity and agro-processing facilities. The availability of energy is closely linked to agricultural productivity and profitability. Indian farms had only 0.3 kW/ha power in 1971 with 45% of it available from animal power. Today it is close to 1.5 kW/ha with a diminished supply of animate power and increased dependence on fuels and electricity. The contribution of different power sources to the total power has changed with time. This change is mainly due to increased use of tractors, whose contribution increased from 7.5 % in 1971 to 47 % in 2005-06.
Presently about 3 million (2004-05) tractors and power tillers in India farms contribute about 65,000 MW of power. The share of stationary power in the overall agricultural power availability has increased from 32 % in 1971-72 to 41 Percent in 2003-04. Average level of farm mechanization as on now is about 25 percent and this level needs to be gradually increased to about 50 % in the next decade. Farm operations in India presently consume 37-62 % of total energy used in cultivation of different crops. The tractors and engines in the agricultural sector today consume about 10 % of the total diesel consumption in the country. A serious effort is required to quantify the energy and power requirements of agricultural sector with growth targets of 4 % annually, the emerging scenario points for doubling the energy availability during the next decade. Certain estimates indicate 1.4 MT increase in diesel consumption by the agricultural sector every five years. There is a requirement to make available different sources of alternate power for agricultural

needs. In this connection transport 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 material and have been proved to be good substitutes for oil. As such biofuels –ethanol and Biodiesel- are aining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy.

Biodiesel is made from virgin or used vegetable oils (both edible & non-edible) and animal fats through trans-esterification and is a diesel substitute and requires very little or no engine modifications up to 20% blend and minor modification for higher percentage blends. Since India cannot afford the use of edible vegetable oils as power source because of its increased human population, planners suggested the use of non-edible vegetable oils like Pongamia, Jatropha, etc for use as alternate fuels. As India comprises of 40 % wasteland, it may be appropriate to grow non-edible oil plants, which not only gives the oil but also enriches the environment by adding green forest cover for ecological balance. Small-scale biodiesel production units and oil expeller are available in the market for on farm application. The petroleum companies also buy jatropha and pongamia oils at predetermined cost from farmers.

Advantages of Biofuels:

- Ethanol and biodiesel being superior fuels from the environmental point of view
- Use of biofuels becomes compelling in view of the tightening of automotive vehicle emission standards and court interventions,
- The need to provide energy security, specially for the rural areas,
- The need to create employment, specially for the rural poor living in areas having high incidence of land degradation,
- Providing nutrients to soil, checking soil erosion and thus preventing land degradation,
- Addressing global concern relating to containing Carbon emissions,
- Reducing dependence on oil imports.
- Usability of biofuels in the present engines without requiring any major modification
- The production of biofuels utilizing presently under-utilized resources of land and of molasses and, in the process, generating massive employment for the poor.

Effect of Biofuels on GHG emissions:

In agriculture sector there is no role to play for ethanol because it is produced from industrial byproducts. So biodiesel is mainly used for blending with diesel in agriculture diesel engines. For mitigating climate change by reducing emission of green house gases, meeting rural energy needs, protecting the environment and generating gainful employment Jatropha and Pongamia have multiple roles to play.

The use of biodiesel in conventional diesel/petrol engine results in substantial reduction of GHG emissions like unburned hydrocarbons, carbon monoxide and particulate matter. However, Emissions of nitrogen dioxides are either slightly reduced or slightly increased depending on the duty cycle and testing methods. The use of biodiesel decreases the solid carbon fraction of particulate matter (since the oxygen in biodiesel enables more complete combustion to CO_2), eliminates the sulphur fraction (as there is no sulphur in the fuel), while the soluble or hydrogen fraction stays the same or is increased. Biodiesel can blend with diesel up to 40% in agriculture diesel engines with out any modifications and achieve up to 50% reduction in emissions.

CDM opportunities in energy efficiency areas:
Energy efficiency and fuel switching measures for agricultural facilities and activities:

1. This category comprises any energy efficiency and/or fuel switching measure implemented in agricultural activities of facilities or processes. This category covers project activities that encourage energy efficiency or involves fuel switching. Examples of energy-efficient practices include efficiency measures for specific agricultural processes (such as less irrigation, etc.), and measures leading to a reduced requirement of farm power per unit area of land, reflected in less and smaller tractors, longer lifetime of tractors and less farm equipment. Further energy efficient measures would be reducing fuel use in agriculture, such as reduced machinery use through, e.g. the elimination of tillage operations, reduction of irrigation, use of lighter machinery, etc. y comprises any energy efficiency and/or fuel switching measure implemented in agricultural activities of facilities or processes. This category covers project activities that encourage energy efficiency or involves fuel switching. Examples of energy-efficient practices include efficiency measures for specific agricultural processes (such as less irrigation, etc.), and measures leading to a reduced requirement of farm power per unit area of land, reflected in less and smaller tractors, longer lifetime of tractors and less farm equipment. Further energy efficient measures would be reducing fuel use in agriculture, such as reduced machinery use through, e.g. the elimination of tillage operations, reduction of irrigation, use of lighter machinery, etc.

2. The measures may be replacement on existing equipment or equipment being installed in a new facility.

3. The aggregate energy savings of a single project may not exceed the equivalent of 60 GWh per year.

4. Grid-connected and biomass residue fired electricity generation project activities, including cogeneration.

5. Grid connected Mini hydals integrated in water conservation structures.

This category covers project activities that encourage energy efficiency or involves fuel switching. Examples of energy-efficient practices include efficiency measures for specific agricultural processes (such as less irrigation, etc.), and measures leading to a reduced requirement of farm power per unit area of land, reflected in less and smaller tractors, longer lifetime of tractors and less farm equipment. Further energy efficient measures would be reducing fuel use in agriculture, such as reduced machinery us through, e.g. the elimination of tillage operations, reduction of irrigation, use of lighter machinery, etc.

IMPACTS OF CLIMATE CHANGE ON PLANT PATHOGENS AND ADAPTATION STRATEGIES

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Abstract

Climate –variability and -change are exerting additional pressure on developing countries of tropics and subtropics which are already at the threshold to cope with the increasing demand for food for increasing population pressure. Even a small increase in temperature in these areas will cause significant yield declines in major food grain crops. The changing climate not only influences the crop growth and development but also expected to alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host-pathogen interactions. It is expected that the range of many insects, diseases and weeds will expand or change, and new combinations of pests and diseases may emerge when current natural ecosystems respond to altered temperature and precipitation profiles. Although, the research in establishing the impacts of pathogens and their natural enemies is at its infancy, independent studies conducted across the laboratories could be used to draw inferences. Elevated CO_2 levels are known to increase foliar density which in turn will influence the microclimate of the pathogen, altered host morphology which in turn may influence host-pathogen interaction, enhanced sporulation of anthracnose pathogen, and increased dry-root rot under moisture stress conditions. For instance, an increase in temperature may lead to increased host susceptibility, a new/rapid development of the pathogen, more rapid vector development leading to faster spread of the insect-borne viruses, a variable overwintering/oversummering of the pathogen/vector; shift in spread pattern of the pathogens. Initial studies show an increased sporulation and altered biocontrol traits in *Trichoderma*, a known biocontrol agent. Efforts are underway at CRIDA to assess climate change impacts on important pathogens and their natural enemies. The present paper reviews the interaction of different weather variables with different insects, diseases and weeds and the probable threats for food grain production, availability and quality.

Introduction

Modern commercial agricultural systems are constantly under threat of outbreak of disease epidemics. In conventional agricultural systems, crops and their pathogens established a harmony and hence, equilibrium was established through a natural evolution process over decades. This equilibrium also included biocontrol systems wherein other living organisms were parasitizing the plant pathogens. This equilibrium helped in minimal crop losses due to diseases. However, increasing pressure on food security demanded increased agricultural output and there by disturbing the 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 impacts on all biological systems. The elevated CO_2 levels coupled with increasing temperatures do affect host-pathogen interactions.

Elevated CO2 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*., 1996a, 1996b); greater accumulation of carbohydrates in leaves; more waxes, extra layers of epidermal cells and increased fibre content (Owensby, 1994); production of papillae and accumulation of silicon at penetration sites (Hibberd *et al*., 1996a); 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% 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% 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. Jones et al (2003) have reported differential response of host resistance in wheat against *Puccinia recondita* at differential temperatures. 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.

Research needs

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. A process-based approach is required to quantify the impact on pathogen/disease cycle 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 these opposing changes in pathogen behavior at elevated levels of atmospheric CO_2, it is difficult to know the ultimate outcome of atmospheric CO_2 enrichment for this specific pathogen-host relationship. More research, especially under realistic field conditions, will be needed to clarify the situation; and, of course, different results are likely to be observed for different pathogen-host 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

In summation, the vast bulk of 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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ENVIRONMENTAL IMPACTS OF NUTRIENT RECYCLING AND ADAPTATION STRATEGIES FOR INTEGRATED NUTRIENT MANAGEMENT

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Food grain production in India has made a quantum jump from a mere 50.8 million tonnes in1950-51 to above 255.4 million tonnes by 2012-13(4th estimate). This was made possible by the introduction of dwarf wheats in 1968, which set in the "Green Revolution". A parallel increase in the consumption of fertilizers from 69.8 thousand tonnes in 1950 to 27.7 million tonnes (N + P_2O_5 + K_2O) was witnessed by 2011-12. In spite of serious efforts made in recent years to produce more, sustainability in agricultural production is remaining still as a goal to be achieved. Agriculture is the mainstay of the Indian economy, contributing about 14.0 % of the gross domestic product and providing livelihood to two-thirds of the population. In India livestock rearing is complementary to agriculture, with an expected livestock population of over 480 million.

Nutrients in an ecosystem recycle through soil organisms, plants, and grazing livestock. Appropriate management can enhance the nutrient cycle, increase productivity, and reduce costs. Rising levels of gases in the Earth's atmosphere have the potential to cause changes in our climate. Some of these emission increases can be traced directly to organic wastes. The disposal and treatment of waste can produce emissions of several greenhouse gases (GHGs), which contribute to global climate change. The most significant GHG gas produced from waste is methane. It is released during the breakdown of organic matter in landfills. Other forms of waste disposal also produce GHGs but these are mainly in the form of carbon dioxide. The annual contribution to global methane budget from Indian rice paddies is less than 4 Tg and not 37 Tg as was propagated by the western agencies. CO_2 equivalent emissions from agriculture have also been quantified. These estimates helped Indian policy makers greatly in their negotiations on global climate change. The possible strategies for mitigating methane and nitrous oxide emissions from agriculture have also been identified.

Forms of N (NO–3 and NH+4) which are taken up by plants can be made available for crop production through chemical fertilizers, natural and anthropogenic biological N fixation and through recycling of plant and animal wastes. These can be then converted into several other forms (NH3, NOx, N2O), which can move readily among terrestrial, aquatic and atmospheric realms. Galloway et al. labelled this diverse pool of N forms as 'reactive N' and defined the term to include all biologically, radiatively and/or photochemically active forms of N. The fate of reactive N in agroecosystems in India assumes great importance since reactive N fixed biologically or applied as fertilizer not only leads to increased crop production, but can also leak from agroecosystems in the form of N2O, NH3 and NOx gases, depending on how efficiently plants use it. Industrial fixation of N for use as fertilizer represents by far the largest human contribution of new reactive N to the N-cycle, with fertilizer use in India during the 11 years (1995–2005) equalling the total quantity used up to 1994.

Food and Agricultural Organization, Rome , is concerned with the effect of agriculture on climate change, the impact of climate change on agriculture and with the role that agriculture can play in mitigating climate change. Historically, land-use conversion and soil cultivation have been an important source of greenhouse gases (GHGs) to the atmosphere. It is estimated that they are responsible for about one-third of GHG emissions. However, improved agricultural practices can help mitigate climate change by reducing emissions from agriculture and other sources and by storing carbon in plant biomass and soils.

The National Agricultural Policy envisages annual growth of 4 per cent in agricultural production. Government of India has already initiated concerted action to double the agricultural production by 2025, which means increasing production from agricultural crops, horticultural crops, animal husbandry and fishery sectors. The country will need 301 million tonnes of food grains by 2025 to feed its 1.4 billion population. This will raise demand for supply of nutrients through chemical fertilizers to the extent of 35 million tonnes in addition to around 10 million tonnes coming from organic manures and use of bio fertilizers. It will be a gigantic task to supply such a huge quantity of nutrients through chemical fertilizers and also organic manures. Though the total potential for organic sources in the country is estimated as about 442 million tonnes with the nutrient content of 10.75 million tonnes, the present utilization is only about 1/3 indicating meager supplies of nutrients through this source. Since either of the sources cannot be totally depended upon to produce the targeted level of food, and as fertilizers are becoming costly and availability of organic manures is becoming difficult due to mechanization and decline in domestic animal populations, it is becoming imperative to find out options to blend both these inorganic and organic sources for crop production purposes.

Integrated Plant Nutrient Supply System (IPNSS) or Integrated Nutrient Management (INM):

Crops remove nutrients from soil. However, the soil is not an eternal supplier of nutrients required for crops growing on it. There is always a need to supplement the nutrient supply to crops through external sources like fertilizers and manures. Continuous use of inorganic fertilizers might harm the soil though the nutrients are supplied in adequate amounts. Though several types of organic manures are available, they are not having considerable amounts of N, P and K in their composition to facilitate their application alone to meet the crop needs. Application of organic manures has long term beneficial effects leading to improvement in soil conditions and making them favorable for sustainable agriculture. Excess usage of fertilizers also leads to loss of energy spent on their manufacture besides leading to increase chemical loads in soil and water.

Integrated plant nutrient management is the combined application of chemical fertilizers along with organic manures, green manures, bio fertilizers and other organic recyclable materials for crop production. The INM encourages the use of in house organic wastes, which also helps in keeping environment clean and safe. The INM or IPNSS as a concept is much more complex and does not end at combined use of chemical fertilizers, organic manures and bio fertilizers and when fully put into practice, holds key for sustainable agricultural production. Plant nutrients are involved in cycles and INM must monitor the pathways of flow of plant nutrients in an agricultural production system to maximize the profit on a farm so that farming as a profession is continued.

Most Indian farmers practice a farming system involving crop husbandry and raising livestock for dairying and draught. If all the pathways of nutrient flow are well controlled, a large part of plant nutrient cycling can be assured. This is very well practiced in China, where all animal (as well as human) excreta is returned to the farm. However, due to social system and traditions in India, human excreta is never returned to the farm except in a small way in peri urban agriculture where some sewage sludge and urban solid wastes are used for crop production. Cattle dung is mostly wasted as dung cakes for fuel purpose.

A number of researchers in India have reported the advantages of INM on crop yields and soil fertility. Results from a long term fertility experiment clearly show the advantage of addition of FYM along with chemical fertilizers on crop yield . Data on the effect of addition of 50% N through FYM, wheat straw or green manures to rice on soil properties after 12 cycles of rice-wheat cropping system showed the advantage in increasing organic carbon and available N, P and K in soil over application of chemical fertilizers alone.

Most studies, thus, indicate a definite improvement in the soil organic matter content due to INM. This is beneficial as it supports the life of organisms and acts as a source and sink for plant nutrients in soils. It is also involved in maintaining soil tilth, free movement of air, and infiltration of water, promoting water retention and reducing soil erosion thus, improving in general, the soil health. Application of organic manures and residues also increases the efficiency of nutrients added through chemical fertilizers by temporary immobilization, which even protects the nutrients by reducing leaching losses.

Integrated nutrient management includes the utilization of bio fertilizers such as Rhizobium, Azotobacter and Azosprillum to meet part of nitrogen needs of crops. Use of phosphate solubilizing micro organisms (PSM) helps in more efficient utilization of native P and also absorption of P from difficultly available source like rock phosphate. Time, source and method of application of fertilizers besides use of materials like nitrification inhibitors, slow releasing N fertilizers also come in the fold of INM. Thus, focussed attention is needed on these three principal areas i.e. improving fertilizer use efficiency, efficient use of organic sources and efficient use of biological nitrogen fixation (BNF) for practicing INM in any crop or cropping system.

Integrated nutrient management involves preparing a complete balance sheet of plant nutrients added to an agricultural production system and those taken out of it and, thus, also calls for monitoring the plant nutrients added to the system by rainfall and irrigation and those taken out by surface runoff and soil erosion.

In the integrated nutrient management in cropping systems, the residual effects of applied materials are to be taken into account so that the last crop in the sequence can be applied sufficiently less quantities of inorganic fertilizers to supply, N, P_2O_5 and K_2O to bring down the cost of cultivation besides improving the soil physical conditions for sustainable crop production. While doing this exercise, the fertilizer equivalence of the components involved in the INM package must be taken into account to bring economy in usage of inorganic fertilizers. Further. the options may be made available to suit the economic conditions of farmers.

Nitrogen in Indian agriculture: Inputs, use efficiency and leakages:

In the last three decades, use of reactive N in the form of chemical fertilizers has kept pace with the production of food grains, although the consumption is concentrated in certain areas with intensive farming. As for cereal-based agriculture, recovery of N by rice and wheat at on-farm locations in India rarely exceeds the 50% mark. Agricultural activities in India account for more than 80% of the total N2O emissions, including 60% from the use of N fertilizers and 12% from burning of agricultural residues. In Asia, reactive N transfers to the atmosphere by NH3 volatilization are expected to reach 19 Tg N yr–1 in the next three decades; 29% being India's contribution. Of the total anthropogenic emissions of NOx and N2O from Asian agriculture, about 68% is due to the combined contributions of India and China. Additionally, riverine discharge of dissolved inorganic N derived from N in river basins and leaching of nitrate-N to the surface and ground water bodies also contributes to the application of reactive N in agriculture. Integrated management of organic amendments and fertilizer N can improve efficiency of reactive N use by crop plants, while achieving targets of productivity and quality. The greatest challenge in improving N use efficiency lies in developing precision management of reactive N in time and space. Approaches to maximize synchrony between crop-N demand and the supply of mineral N from soil resources along with reactive N inputs in high-yielding agricultural systems are critical towards this end. Among a host of upcoming technologies aimed at improving N management strategies, leaf colour charts, chlorophyll meters and optical sensors, which allow in-season estimation of N requirement of crops, are the most promising.

From 1960 to 1990, genetic improvements led to the development of highly fertilizer-responsive rice and wheat varieties with improved management strategies, resulting in a dramatic rise in productivity and production of rice and wheat in India. This has witnessed a linear increase since then and at present contributes to more than 75% of the total food grains produced in the country, with nitrogen fertilizers contributing largely to this remarkable increase . In the years to come, Indian agriculture will have to strike a delicate balance between inputs and outputs of reactive N. Substantial reactive N inputs will have to be linked to minimal leakage of reactive N. Extent of losses of reactive N forms from agro-ecosystems and possibility of reducing leakage of N by enhancing N use efficiency through the adoption of precision technologies is needed.

Nitrogen Use Efficiency Of Agricultural Crops:

During the last half-decade while fertilizer N consumption in India has been touching new heights, production of both rice and wheat is plateauing.. In fact,
fertilizer N efficiency in foodgrain production expressed as partial factor productivity of N (PFPN) has been decreasing exponentially since 1965. PFPN is an aggregate efficiency index that includes contributions to crop yield derived from uptake of indigenous soil N, fertilizer N-uptake efficiency, and the efficiency with which N acquired by the plant is converted to grain yield. An initial decline in PFPN is an expected consequence of the adoption of N fertilizers by farmers and not necessarily bad within a systems context. While fertilizer use increased exponentially during the course of the green revolution, resulting in a steep decrease in PFPN due to low fertilizer N-uptake efficiency. This is of particular concern for the reactive N budget as fertilizer N use in India is continuously increasing .

Nitrogen needs of crop plants are met with by applying fertilizer N and net N mineralization from soil organic matter and organic manure. Fertilizer N is applied in forms readily available to plants, but mineralization of N is controlled by soil, water, temperature and aeration. Once these factors become optimum, the amount of N that is mineralized depends upon the quality and quantity of organic matter in the soil. High rates of net N mineralization can result in dilution of fertilizer N. But if crop demand for N and the amount of fertilizer N remain constant, an increase in net N mineralization will lead to a decrease in observed N use efficiency. Loss of N via denitrification, ammonia volatilization and leaching may lead to low N use efficiency, particularly when conditions for plant growth are favourable and plant-N demand cannot be met because of large N losses. Relative magnitude of different N loss mechanisms will depend upon soil type, weather, fertilizer-use and crop management, with climate exerting the strongest influence on the amount and pathways of N losses.

Current status of INM

Keeping the importance of organic resources in view, a lot of research has been done on integrated nutrient management during last two decades in natural resource management (NRM) institutions and state agricultural universities. This research has led to:

- Development of INM practices for major crops;
- Understanding the enhanced role of organic manures in increasing input use efficiency due to their favourable effect on physical, chemical and biological condition of the soil;
- Establishing the beneficial role of integrated use of organic manures in improving nutrient cycling in different production systems in various types of soils;
- Beneficial role of INM in improving soil chemical, physical and biological quality for sustainable crop production; and
- The work on INM has been compiled and published in the form of books/bulletins by several institutions.

Research gaps in INM:

The research gaps include:

- Mismatching of INM practices developed at research stations with the farmers' resources and their practices;
- INM recommendations for different crops are not based on soil testing and nutrient release behaviour of the manures;
- Nutrient balance/flow analysis vis-à-vis soil fertility management practices with special reference to INM at farm level needs to be worked out;
- Nutrient release characteristics of farm residues in relation to their quality to develop decision support systems;
- Biofertilizers were not included as component of INM in many cases; and Integrated Farming Systems (IFS) approach needs to be encouraged for sustaining livelihood in rural areas particularly for small and marginal farmers.

Organic Agriculture:

According to International Federation of Organic Agriculture Movements (IFOAM), organic Agriculture could contribute significantly to reduce GHG releases and to sequester carbon in soils and biomass. There is sufficient evidence that Organic Agriculture is superior to mainstream agriculture. This is even more important as the capacity of Organic Agriculture to contribute to the mitigation of climate change can be considered as an ancillary benefit to its primary goal of sustainable land use. This primary goal is achieved by gains in soil productivity, consecutive food security, biodiversity conservation and many other benefits. As opposed to the focus of conservation agriculture on a single technology, Organic Agriculture follows a site-specific and systematic approach that includes a comprehensive set of integrated technologies. Because of the inspection and certification systems required in Organic Agriculture, monitoring and evaluation of carbon sequestration is simplified and cost-effective in comparison to conventional agricultural practices. Policymakers should recognize the potential of organic farming for GHG reduction and develop appropriate programs for using this potential. Such programs may look into the emission reduction potential, in the sequestration potential, in the possibility for organically grown biomass, or in combinations of all the aspects. This is as relevant in developed countries as in developing countries(IFOAM,2004).

Recommendations(Peter et al ,2000)

A. Promote effective and environmentally sound management of plant nutrients:

A1. The balanced and efficient use of plant nutrients from both organic and inorganic sources, at the farm and community levels, should be emphasized; the use of local sources of organic matter and other soil amendments should be promoted; and successful cases of integrated plant nutrient management should be analyzed, documented, and disseminated.

A2. Innovative approaches to support and promote integrated plant nutrient management should be pursued.

A3. Encouragement should be given to develop further, in cooperation with all relevant organizations, a Code-of-Conduct on the effective and environmentally sound management of plant nutrients, for dissemination at both international and national levels.

B. Improve Database, Research, Monitoring, and Extension of Effective Plant Nutrient Management:

B1. Participatory forms of design, testing, and extension of improved plant nutrient management strategies that build upon local institutions and social organizations, including trained farmer groups, should be promoted.

B2. A network of benchmark sites on representative farmers' fields in major farming systems should be developed to monitor the stocks and especially the flows of plant nutrients.

B3. A comprehensive data base needs to be developed for all mineral and organic sources of nutrients, including their amount, composition, processing techniques, their economic value, and their availability.

B4. The impact of micro- and macro-economic policies on plant nutrient management should be evaluated.

C. Support Complementary Measures to Lower Costs, Recycle Urban Waste, Secure Land Tenure, and Increase Production Capacity:

C1.Ways and means should be sought to lower the price of fertilizers at farm gate and to reduce the farmers' perception of the risk in the use of fertilizers by:

(i) investing in distribution infrastructure;

(ii) researching innovative ways to share risks and to provide finance;

(iii)encouraging subregional cooperation for country-level fertilizer production facilitiesand/or procurement; and

(iv) improving dialogue between different sectors and agencies to arrive at a common approach to improved plant nutrition.

C2. Improvement of security of access to land is essential for the intensification of fertilizer use and the successful promotion of integrated plant nutrient management systems.

C3. The recycling of pollutant-free organic urban waste into the wider peri-urban agricultural sector should be promoted, considering that such waste constitutes an increasingly significant and so far largely untapped source of plant nutrients.

C4.Investment in production capacity for mineral and organic fertilizers should be increased and facilitating the procurement of raw materials and energy for their processing enhanced.

Conclusions:

Integrated nutrient management has a great potential to offset the growing heavy nutrient demands to achieve the maximum yields and to sustain the crop productivity on long term basis. A widening gap of 8 to 10 million tonnes exists between annual nutrient removal and addition. Despite the existing constraints in availability and usage of different organic and biological sources, efforts should be made to synthesis the available data for developing agro-ecological specific and practically feasible and economically viable INM packages for different crops and cropping systems. A recent survey on awareness of farmers about bio fertilizers, soil testing, INM and balanced use of fertilizers indicates, lot of extension work is needed to educate farmers on organic waste recycling and use of different components of INM in better ways for crop production purposes. Surveys also show that in certain areas imbalanced use of fertilizers is being practiced. Such areas have to be monitored regularly and the farmers be advocated to resort to INM to overcome the bad effects of excess use of fertilizers. Materials such as bio fertilizers, green manure seeds etc. may be made available to farmers at the place where soil testing service is done to encourage them adopt INM package. Provision of alternate energy source is also important to make rural poor not to burn crop residues and dung for fuel purposes. Research efforts on improving the fertilizer and water use efficiencies specifically in dry land and rain fed areas must be made more seriously and options be made available to farmers for adopting INM as a routine in future years to come.

Use of increasing amounts of reactive N in the form of fertilizers in Indian agriculture and proper management of fertilizer N will remain at the forefront of issues to improve the global reactive N balance over both the short and long term. To achieve the tripartite goal of food security, agricultural profitability and environmental quality in a country like India, improving N use efficiency in agriculture will have to be the top priority. Efficiency with which reactive N is utilized by crop plants is governed by N requirement of crops, N supply from soil, and fertilizer and N losses from the soil–water–plant system. While optimum moisture,temperature, supply of adequate amount of nutrients other than N, and pest and weed management define crop N requirement, large field-to-field variability of soil N supply restricts efficient use of N fertilizers when broad-based blanket recommendations are used in rice and wheat. Integrated management of organic and inorganic N sources can help achieve high N use efficiency. Innovative fertilizer management has to integrate both preventive and field-specific corrective N-management strategies to increase profitability in irrigated rice and wheat systems, and to ensure that there exists synchrony between crop N demand and supply of mineral N from soil reserves and fertilizer inputs. This will lead to maintenance of plant-available N pool at the minimum size required to meet crop N requirements at each growth stage, with little vulnerability to loss of N to the environment.

Dryland farming has led to historically large emissions of CO_2 from stored soil carbon and high rates of soil erosion and water-borne sediment. With the development and adoption of reduced tillage systems over the past 20 years, significant strides have been made in reducing soil erosion and water quality degradation. However, the potential for dryland farms to sequester carbon by returning soil organic matter levels to near native condition has not been reached. These systems also rely on inputs of nitrogen fertilizer made from fossil fuel. Several strategies are being explored to improve specific aspects of the environmental performance of these systems, but few attempts have been made to analyze and optimize dryland systems for greenhouse gas mitigation, soil and water conservation, energy efficiency, and economic performance.

There is significant potential to increase N use efficiency at the farm level, because concepts and tools needed to achieve it are already available. However, new technologies need to be cost-effective and user-friendly, so that these become attractive to farmers. Collaborative effort of agronomists, soil scientists, agricultural economists, sociologists, ecologists and politicians can help agriculture make substantial contribution to reduce the global GHG load.

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TRENDS IN CLIMATE BASED PEST FORECASTING SYSTEMS & CONTINGENCY PLANNING

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Introduction

Integrated pest management (IPM) has been a response to the need for improving pest management and reducing the environmental impacts of synthetic pesticides. IPM is an ecosystem-based strategy that focuses on short- and long-term prevention of pests or their damage through a combination of techniques. Integrated crop management (ICM) adds to IPM other components of the system such as soil, fertility, and water management. Climatic descriptions aid management of some aspects of the cropping system, such as long-term choices of location for planting, and between-season sanitation measures. For in-season pest management, forecasts or warning systems that use past and future weather data for predicting the likelihood of pest outbreaks are useful. Large-scale regulatory control programs use both weather and climate information to plan and take preventive and emergency action to solve particularly damaging pest problems.

Weather is the short run of the physical factors experienced by an insect population, and climate is the long-term pattern of expected weather. Assessing the impacts of weather and climate on insects is more than the matter of taking the temperature and determining the state of the system, because different species are affected in different ways and to different degrees, and weather can thereby modify the outcome of biotic interactions. The outcomes of interactions on short time scales add up to trends and consequently climate modifies the qualities of the whole ecosystem in the long run.
One of the earliest works on forecasting was the formulation of the Dutch rules for forecasting of potato late blight. Uvarov published his monumental work, *Insects and Climate*, in 1931 in which he reviewed more than 1150 articles written in 11 languages on every conceivable aspect of the subject. There have been a number of discussions of the effect of weather on insect abundance that examine this complex topic from specialized points of view. Since 1931, numerous reviews and thousands of papers have appeared that describe the effects of single variables, such as temperature, on one or the other biological processes thought to be important to insects.

In India, the earliest reviews on entomological and plant pathological research (Pant, 1964 and Singh, 1968) pointed that awareness of the role of weather on pests and diseases existed in the early forties. Mehta (1940) pioneered the work on the role of environmental factors in the epidemiology of wheat rust. Pradhan (1946) did pioneering work on effect of temperature on insect development rates and durations and also devised biometer and biograph for simplified practical application of these relationships. Cataloguing of pests and diseases that are known to be weather sensitive in their proliferation and determining weather conditions conducive for their growth and spread can help in locating the likely regions and periods of occurrence and initiation of control measures on the basis of weather warnings. Venkataraman (1992) summarized approaches that have been used to anticipate the occurrence of a pest or disease through several approaches like geographical, phenological, biological and bioclimatic analysis.

Weather warnings against pests and diseases

Short- and medium-range forecasts of required variables make models useful planning tools. Improved forecasts with longer lead times could reduce dependence on pesticides in the control of some insects and diseases. While short- and medium-range forecasts can assist with in-season decision making, quantification of climatic variability and long-lead forecasting are needed to help farmers make strategic choices such as the crops to grow, variety to plant, or planting date. One example on the utility of long-range forecasting would be to predict weather conditions favoring outbreaks of a pest at a susceptible crop growth stage, based on risk assessment of long-term weather patterns such as El Nino events. In the United States and the Netherlands, commercial firms are applying mesoscale modeling techniques to forecasting disease and insect development, and producing gridded products for regional and on-farm planning and pest management (Strand, 2000).

Monitoring one or more important weather parameters for initiation of a pest and disease, the occurrence of an incubation period is identified. This stage would merit the issue of a warning. A forecast of the outbreak could be issued based on a forecast of the anticipated weather. However, since this forecast covers only a short period, one is obliged to assume that normal weather follows incubation and an amended forecast is issued on the basis of deviation of the weather conditions actually occurring. This type of forecast is of primary use to alert survey teams regarding the likely areas and times of appearance of a pest or disease in a particular stage of development. Real time surveys to actually locate the foci of infestation are crucial for this type of alerts. Once the pest and disease has been monitored, an advisory regarding the general weather conditions and conduciveness favoring a rapid spread can be issued to facilitate timely control operations.

Data requirements

Models require access to weather and climate data, in addition to pest and plant data. The models usually require as inputs measurements of temperature, rainfall and humidity, although other variables may be required either as direct inputs or in computing values for variables not measured. Weather variables need to be measured at the field level, at regional stations, or on a broader scale depending on the need. For many farm management actions, data representative of the field conditions are expected.

Various types of pest/disease incidence data (trap catches, population counts and crop damage assessments) could be made use of. Many research articles published on pest-weather relationships used pest monitoring data from light traps (for example yellow stem borer in rice), pheromone traps (for American bollworm) and sticky traps (for whitefly) apart from population counts and damage assessment data. Long-term data is preferable as it better captures the patterns in relationships. However, historical data collected from several sources suffer from several inadequacies: lack of ancillary data such as sowing times, crop damage assessments, lack of time-series data, missing and non-uniform pest/disease data.

Pest forecasting: Approaches to modeling

In model development important points for consideration are: the level of detail at which a given model is to be developed as the level of detail is linked to the objective and data availability to develop and run the model. Models can range from strictly empirical to most complex and sophisticated descriptive models. A model may be discrete or continuous, static or dynamic, and deterministic or stochastic.

The rates at which insects complete their life cycles depend mainly on temperature, so that the times of activity of a given pest insect can vary greatly both from region to region and from year to year. Many models have been developed using temperature data to forecast insect activity. Relatively crude methods of computing day-degrees are sufficient for many applications. Most forecasting models on diurnal variation rely on approximations using sine waves. However, day-degree forecasts in general cannot readily predict insect populations that have polymodal patterns of activity.

Empirical approaches involve estimating pest and disease incidence and intensity through experimentation and surveys on crops not subjected to control interventions and establishing relationships with concurrent, prevailing weather and/or past weather factors. The studies could be conducted at single stations in which the emphasis is on delineation of differences in meteorological conditions in epidemic and non-epidemic years or multi-station studies in which the emphasis is on delineation of meteorological conditions leading to changes in periods and intensity of infestations. A multi-station study is preferred as it facilitates corroboration of the general surmises and leads to maximization of data in a short period if observations are recorded on crop stands sown at periodic intervals at a number of stations. It should be noted that findings from empirical field studies can straight away be applied in climatologically analogous areas but can give misleading results when applied to other areas.

Development of an empirical forecast model is not an end in itself. Even the simplest model (even simple prediction rules) must be tested to be proven, but validation over a wide range of conditions will be most important for models based on empirical rather than biological and physical processes, or where there is insufficient understanding and quantification of how interactions change under varying environmental conditions. Any type of forecast model needs to be fully described for running the model, correct interpretation of the output and its effective dissemination and operational use.

Thorough descriptions of cropping systems being managed or studied are needed to explain the interactions among pests, plants, and environment, and to assess the efficacy of available controls for reduction of pest damage. Systems models or other prediction schemes can be used with appropriate biological, environmental, economic, or other inputs to analyze the most effective management actions, based on acceptable control, sustainability, and assessment of economic or other risks.
Crop system models, when available, can be used to generate information on the status of the crop, its pests, and its environment under different scenarios, including different management options. In practice, there are few examples of these models that include all the necessary components and can be used for practical decision making. However, individual crop and pest components have been developed and can be analyzed at the same time to give information that can improve decisions.

Trends in Pest Forecasting Research Since 1980 in India

An exercise to look into research articles that appeared in pest forecasting related aspects after 1980 within and outside India (Fig. 1) in two crops of global importance reveals the pattern in research outcomes. A significant percentage of research effort has been directed towards studies on monitoring and seasonal occurrence followed by studies that establish insect pest relationships with weather in India in both the crops. Despite the availability of a variety of information that can become input to building reliable forecast models, the trend reflects a lack of concerted and directed research to develop forecast models in India vis-à-vis the trend abroad particularly in a crop like cotton where pesticide use is the highest in the country.

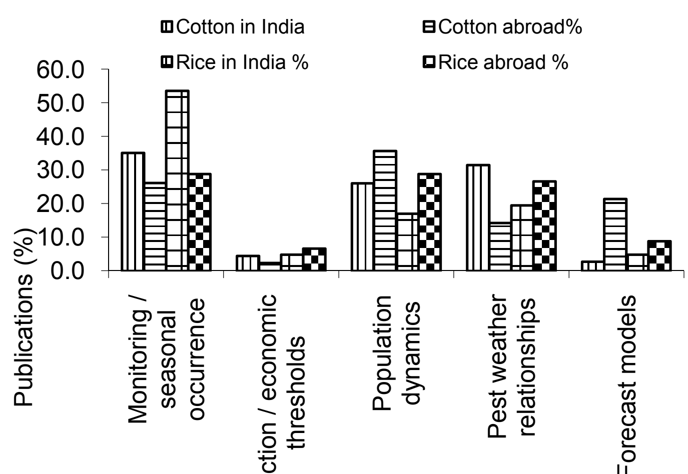


Fig. 1. Trends in publications

Developments in cotton

It appears that the amount and distribution of rainfall plays a significant role in the population dynamics of *Helicoverpa armigera* Hubner on several crops across regions in India. Several studies indicate that rainfall at critical times during the crop growth and growing season is crucial for the build up of *H. armigera*. Chari and Rao (1988) attributed prevalence of continuous drizzle and cloudy weather condition as one of the factors responsible for the severe outbreak of *H.armigera* on tobacco in Andhra Pradesh. An agroecosystem analysis led to the observation that all other factors remaining constant, excessive and heavy rainfall concentrated for about 8-10 days at a stretch at the time of flowering and square formation stage is one single important factor that triggers the build up of *H. armigera* on cotton (Diwakar, 1998). An analysis of the rainfall data and outbreak years of *H. armigera* both in Punjab, Haryana and Rajasthan in the North zone (1990, '91, '96 and '97) and Andhra Pradesh, Tamil Nadu and Karnataka in the South zone (1987, '88, '89 and '97) also led to the same conclusion. Rainfall in the last fortnight of September in the outbreak years was twice the rainfall received in normal and non-outbreak years in the North Zone. Similarly in the southern states, heavy cyclonic rainfall in the last fortnight of October or November was double the amount received in non-outbreak years.

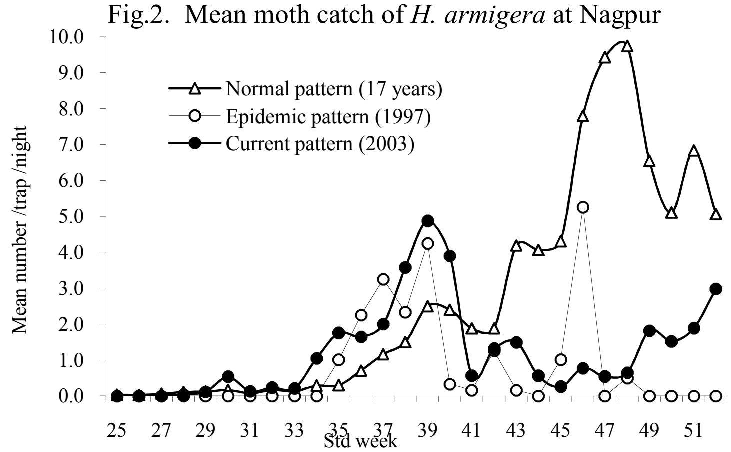
Das et al. (2000) developed prediction models for *H. armigera* based on monthly pheromone trap catch data (1983-90) from PAU, Ludhiana. The first multiple regression model (R^2 0.75) for predicting population density in October (P_{M-A}) on cotton used previous population of October to February (P_{O-F}), relative humidity and minimum temperature of February (RHE_F and $Tmin_F$) as independent explanatory variables. The second model predicts the population density (R^2 0.87) during October (P_O) using pest population density of June (P_J) and total amount of rainfall during June and July (R_{J-J}).

Another approach was to develop a simple rule to predict the attack of *H. armigera* on crops grown in Andhra Pradesh using the pheromone trap moth catch data and rainfall - amount and distribution pattern. Deficit rainfall during monsoon (June-September) combined with surplus rainfall during November indicated a severe pest attack. The deviations in rainfall taking into account the actual rainfall received in a given year and long-term averages for that location could be used to forecast the level of attack of *H. armigera* in several crops in Andhra Pradesh (Das et al. 2001). The thumb rule was extended to chickpea-pigeon pea based cropping system at Gulbarga, Karnataka using both historical as well as current season data. After studying the historical data on monthly rainfall and percent pod damage in pigeonpea at Gulbarga, the thumb rule was modified to take account surplus rainfall in the month of October instead of November to suit this ecosystem. By using the prediction rule it was possible to predict the level of attack (low = <30% pod damage; moderate = 30-60%; severe = >60%) by end of October.

Recent attempts to develop models for *H. armigera* in cotton suggested that forewarnings based on comparison of current seasonal pattern in pheromone trap catch and weather (relative humidity and rainfall) with normal pattern and pattern in epidemic years of occurrence could be useful for this pest (Fig.

2). This method of tracking was made use in 2003 season for issuing a forewarning in the Central cotton-growing zone in September. Lack of rainfall in October in 2003 was reflected in low catches, a deviation from the normal trend.

Fig.2. Mean moth catch of *H. armigera* at Nagpur



Developments in Rice

In India a number of studies depended on light trap catches of rice yellow stem borer to identify adult activity periods and relationships with weather during the rainy and post-rainy seasons across several states. Trap catches and relationships with key weather parameters differed depending on the location, prevailing cropping system and cropping intensity. However, models on both long range forecasting of peak occurrences and intensity of attack using weather information of periods well ahead of the season and in-season short-range forecasting based on light trap or pheromone trap data or field populations are limited. Ramakrishnan et al. (1994) developed a mathematical model for predicting adult activity levels relating monthly indices of weather factors such as temperature, wind velocity and rainfall with light trap catches. Krishnaiah et al. (1997) calculated the degree-days required for egg and larval stages of yellow stem borer. Analysis of long-term light trap data (1975-2000) through regression approach indicated that despite using multiple input weather variables of current and 1-6 preceding weeks prior to peak catches, the variability accounted for was 69% in *rabi* and 51% in *kharif* season. However, minimum temperature in the last week of January showed a significant linear positive relationship (R^2=0.75) with the peak catch in March during *rabi*, while in *kharif* a quadratic relationship (R^2=0.86) with rainfall during the third week of June was evident. Possible reasons could be that the key factors during the identified periods have a bearing on either completion of the life cycle or activation of diapausing population, respectively.

Developments in Groundnut

The groundnut leaf miner, *Aproaerema modicella* (Deventer), is a major insect pest of groundnut and soybean in many south Asian and Southeast Asian countries. Several articles deal with weather relationships of this pest. At Anantapur, the largest groundnut growing district in India, a simple rule was developed for short-term prediction of leafminer severity based on maximum temperature variations A sharp increase in maximum temperature by >2^{0}C followed by persistent heat wave and dry conditions for a few days lead to outbreak of leafminer 3-4 days after such a rise (AICRPAM, 1993).

A soil-moisture model was adopted for estimation of leaf miner severity in Karnataka (Gadgil et al. 1999). In the model it is assumed that leaf miner populations are always present at a low level. Whenever favorable weather conditions occur in the appropriate growth stage of the crop, population builds up rapidly. However, if a drenching shower (> 2 cm/day) occurs in the first 14 leaf miner days (starting 35 days after sowing), it is assumed that the leaf miner is eliminated. A leaf miner day has been defined as a non-rainy day with dry soil (< half of the available soil moisture). In this model the loss in crop yield due to leaf miner incidence is taken to depend upon the number of leaf miner days. The soil moisture model attempts to estimate the sowing dates in a given region based on rainfall and soil data and then estimates the leafminer days 35 days after sowing based on model assumptions.

Emergence of red hairy caterpillar was closely associated with the amount and distribution of rainfall in the months of July and August at Anantapur. A rain event of 10 mm or above in these two months resulted in emergence of red hairy caterpillar moths in large numbers after 3 to 4 days. This information is being successfully used for early warning of red hairy caterpillar in Andhra Pradesh (AICRPAM, 1998).

Developments in Mustard

Among the insect pests, mustard aphid, *Lipaphis erysimi* (Kaltenbach) is the most important. A number of statistical models have been reported in literature to explain the relationships among aphid infestation, weather parameters, crop age and yield. Prasad et al. (1984) suggested using initial population level in preceding week as an explanatory variable in prediction equations. Thermal time calculations for phenological stages in mustard and aphid have been the subject of research in recent years. Accumulation of 250 or more degree-days during the month of January at New Delhi indicated low aphid attack, whereas 200 or less during the month indicated high aphid incidence on mustard in the ensuing month. Slower accumulation of heat units in a given year is likely to promote aphid infestation (Chakravarthy and Gautam, 2002).

Using weekly data on weather parameters starting from the week of sowing up to 50th meteorological weeks (second week of December) for several years, models for forecasting time of first appearance of aphid, time of peak aphid infestation and intensity of attack were developed for several locations such as Behrampur, Pantnagar, Hissar, Ludhiana, Morena, Bharatpur and Kanpur (Agrawal et al. 2004).

Institutional Endeavor in Pest Forewarning Related Work

In India, crop pest surveillance and monitoring activities are being undertaken by various agencies such as Department of Plant Protection and Quarantine, State Departments of Agriculture, ICAR and State Agricultural Universities (SAUs). The All India Coordinated Research Project on Agrometeorology with its 25 centres spread across the country is vested with the mandate of issuing agro-advisories based on medium range weather forecasts on crop and pest status. A sizable database has been fed into the centralized agromet data bank at the Central Research Institute for Dryland Agriculture (CRIDA). The National Agricultural Technology Project on "Weather based forewarning systems for crop pests and diseases" also contributed to the development of relational database management system (RDBMS) on climate, crop pests and diseases covering 6 crops and 75 locations. A dynamic website (http://www.cropweatheroutlook.org) has been launched in July 2003 by CRIDA. Similarly, 83 Agromet field units of NCMRWF issue agro-advisories. The National Centre for Integrated Pest Management (NCIPM) is also vested with the mandate of developing and validating pest-forecasting models. All India Coordinated Research projects for several crops include monitoring and surveillance of pests and diseases as one of the activities in their yearly technical programs. There is a need to aim and put in place a system for integration of efforts by various agencies on the subject of making pest forecasting operational.

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IMPACT OF CLIMATE CHANGE ON CROP-PEST INTERACTIONS

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Introduction

Global atmospheric CO_2 concentration has increased by approximately 30% since the industrial revolution and is believed to be responsible for an increase of ~0.6°C in mean annual global surface temperature. Elevated CO_2 can directly stimulate plant growth, affect plant resource allocation patterns and change plant tissue quality and is consequently predicted to indirectly affect insect-herbivory. Increased CO_2 causes a decline in nutritional quality of host plant. This reduction in nutritional quality of the host plant results in decline in performance of herbivorous insects. Thus effects of elevated CO_2 on the foliar chemistry of plants that prolong the developmental time, increase the food consumption and reduce the growth of insect herbivores lead to an increase in their susceptibility to natural enemies. Survival of natural enemies will also be affected under high CO_2. This review summarizes the results from several years of research on the effects of elevated CO_2 and temperature on plant chemistry and subsequent effects on the performance of insect herbivores and also the direct effects of elevated CO_2 and temperature on insects and natural enemies.

Effect of elevated CO2 on phytochemistry of plants

Among the host plants, forest trees and grasses have been extensively studied for insect-plant interactions under elevated CO_2. Few studies are available on cultivated crops. Among forest trees, birch followed by quaking aspen has been studied the most. (Table1). From the table it is clear that plant species show great variability in response to CO_2. Increased CO_2 causes a decline in nutritional quality of the host. The elevated CO_2 concentrations used in the studies mentioned ranged from 530 ppm to 1050 ppm.

A decrease in nitrogen concentration was reported in birch, quaking aspen, oak and pine. An increase in condensed tannin levels was reported in birch trees, quaking aspen and oak. However, it was reported no effect on condensed tannins in birch trees An increase in tremulacin levels was observed under elevated CO_2 in birch trees. Increase in starch was observed in birch oak and pine trees. The other effects of elevated CO_2 on forest trees are decrease in flavonyl glycosides and increase in catechin and cinnamoylquinic acids in European white birch, increase in drymatter production and root to shoot ratio of aspen, high carbohydrate: N ratio in white oak, decrease in monoterpenes and Starch: N ratios in loblolly pine, *Pinus taeda*

As in case of forest trees and grasses a decrease in nitrogen was observed in cultivated plants like cotton, *Gossypium hirsutum*, soybean, *Glycine max*, mungbean, *Vigna radiata*, spring wheat, *Triticum aestivum*, plantain, *Plantago lanceolata* and birdsfoot trefoil, *Lotus corniculatus*. Increase in C:N ratio in cotton and birdsfoot trefoil was observed. Starch concentration increased in mungbean, wheat and common beet, *Beta vulgaris*. There was an increase in sugars in mungbean wheat and birdsfoot trefoil.

In elevated CO_2 conditions across types of plants viz., forest trees, grasses and cultivated plants the change in phytochemistry of plants was significant. In majority of cases decrease in nitrogen, increase in condensed tannins, tremulacin levels, starch, drymatter production and root shoot ratio was observed. These changes in phytochemistry of plants lead to deterioration of nutritional quality of plants.

Effect on insects

The impact of elevated carbon dioxide on host plants and insects is comprehensively reviewed and presented in table 1. Insect performance and host plant chemistry was influenced by elevated CO_2. Among the orders of class insecta, Lepidoptera was mainly studied with gypsy moth *Lymantria dispar* and forest tent caterpillar, *Malacosoma distrria* being studied the most.

Lepidoptera

It can be inferred from the table 1 that 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% on sessile oak, *Quercus petraea* and it increased by 29% 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% under elevated CO_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. Thus the decline in larval performance was host-species-specific.. The larval consumption increased on quaking aspen, *Populus tremuloides* as well as paper birch, *Betula papyrifera* when exposed to 700 ppm of CO_2. Though there was an increase in consumption by the larvae, the final weight of the larvae was reduced on quaking aspen while an increase was noticed on paper birch.. Prolonged larval development time was observed on eastern white pine, *Pinus strobus* and quaking aspen. The studies conducted with forest tent caterpillar, *M.distria* indicate that larval feeding varies with host plant. Faster development time and 20% decrease in growth rate was observed on quaking aspen. Larvae preferred aspen to paper birch under elevated CO_2 conditions. No effect on the performance of the larvae was noticed on quaking aspen and white oak, *Quercus alba.*

Thus it can be summarized that lepidoterans were negatively affected. The performance of the same insect varied from host to host indicating host species specificity. The effect of elevated carbon dioxide is significant across various species of lepidopterans. The response of insects varied differently and it was not consistent across host plants (eg. The effects of elevated CO_2 on gypsy moth (table

1) varied on several host plants) while the response of different insects feeding on same host was different (eg. Differential response of insects (table 1) feeding on Birch tree)

Homoptera

The family aphididae in this order was widely studied, and mixed response of aphids was reported under elevated CO_2. It was reviewed the aphid response to elevated ozone and CO_2 and observed that among 26 aphid host plant combinations under elevated CO_2, six cases indicated increased aphid performance and five cases indicated reduced aphid performance, while 12 aphid host plant combinations did not differ from ambient CO_2 level. The effect of different host plants on same aphid was different and on the same host the effect was different on two different aphid species

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 elevated CO_2. The aphid, *Uroleucon nigrotuberculatum* feeding on golden rod, *Solidago canadensis* produced more winged offspring in response to search cues from predators under elevated CO_2. *Myzus persicae* population on bittersweet (*Solanum dulcamara*) increased by 120%.

Direct effects on Insects

If the effect through the host plants is eliminated none of the studies had a direct effect on insect growth, consumption and development. However, insects have been shown to respond directly to carbon dioxide concentrations. Wireworm larvae can locate a food source from distances of up to 20 cm and respond to a CO_2 concentration increase as small as 0.002%. The ability to locate host plants of some herbivores may be affected. Fluctuations in CO_2 density as small as 0.14% or 0.5 ppm were detected by the labial palps of *Helicoverpa armigera*. Other insects are able to locate their plant hosts following the plume of slightly higher CO_2 concentrations, as does the moth *Cactoblastis cactorum* with its host plant *Opuntia stricta. Diabrotica virgifera virgifera* (Le Conte) uses CO_2 concentrations in soil to locate corn roots.

In most of the studies on impact of elevated CO_2 on insect-plant interactions the insects in ambient conditions were fed with detached leaves of host plants grown under elevated CO_2. However, there are a few studies in which both insects and host plants were exposed to elevated CO_2 but these studies couldn't pinpoint the direct effects of elevated CO_2 on insects. Hence there is a need to further examine how insects get affected when exposed directly to elevated CO_2 concentrations.

Effect of elevated temperature on plants

The consequence of rising atmospheric carbon dioxide would be an increase in ambient temperature. But they are usually treated separately because of experimental difficulties of varying both independently. However, there are a small number of studies in which both temperature and elevated carbon dioxide were considered.

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.

A +3° C rise in temperature adversely affected the nutritional quality of primay leaf growth of *Quercus robur* to a much greater extent than doubling of atmospheric carbon dioxide. Differential response was noticed due to elevation of temperature in different species. Temperature caused a decrease in foliar nitrogen in *Q.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*. Stem biomass of dark-leaved willow (*Salix myrsinifolia*) increased, branching and leaf material decreased in relation to stems. The concentrations of phenolic compounds decreased in *S. myrsinifolia*. 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 *Q.robur* .

Effect of temperature on herbivorous 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.

There was no effect of elevated temperature except early pupation on larvae of winter moth, *Operophtera brumata* feeding on oak leaves, *Q.robur*. Larval development and adult fecundity of *O.brumata* was adversely affected by increased temperatures on *Q. robur*. Temperature had no effect on the growth or consumption of gypsy moth larvae, however 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. Hence it was concluded that alterations in leaf chemistry due to elevated CO_2 atmosphere are more important in the plant-insect interactions than either the direct short time effects of temperature on insect performance or its indirect effects on leaf chemistry. In some tree-herbivorous insect systems the direct effects of an increased global mean temperature may have greater consequences for altering plant-insect interactions than the indirect effects of an increased temperature.

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Impact of elevated CO_2 on insect-plant interactions

Insect		Family	Host plant		CO_2 conc.	Effect on host plants	Impact on insects	Reference
Common name	**Scientific name**		**Common name**	**Scientific name**				
Gypsy moth	*Lymantria dispar*	Lymantridae	Gray birch	*Betula populifolia*	700 ppm	***DECREASE IN N FROM 2.68% TO 1.99% INCREASE IN CONDENSED TANNINS FROM 8.92% TO 11.45%***	38% smaller pupal mass Declined in relative growth rate less compared to yellow birch	Traw *et al*., 1996
Western Flower Thrips	*Frankliniella occidentalis*	Thripidae	Common milkweed	*Asclepias syriaca*	700 µL/L	Decreased N, Increased C:N Ratio, Higher above ground biomass,	Density decreased, consumption increased and leaf area damaged increased by 33%	Hughes and Bazzaz, 1997
Red-headed pine sawfly	*Neodiprion lecontei*	Diprionidae	***LOBLOLLY PINE***	**PINUS TAEDA**	Ambient + 300 µL/L	Decreased N, Increased starch, Decreased monoterpenes, High starch:N ratios,	Overall laval growth higher, corsumption lower	Williams *et al.,* 1997

Insect		Family	Host plant		CO_2 conc.	Effect on host plants	Impact on insects	Reference
Common name	**Scientific name**		**Common name**	**Scientific name**				
Gypsy moth	*Lymantria dispar*	Lymantridae	***WHITE OAK***	**OUERCUS ALBA**	Ambient + 300 µL/L	Decreased N, Higher total non structural carbohydrate:N ratio	Significant growth reduction of early instar larvae	Williams *et al.,* 1998
CHRYSANTHEMUM LEAFMINER	*Chromatomyia syngenesiae*	Agromyzidae	Common sowthistle	*Sonchus oleraceus*	Ambient + 200 ppm	High C:N ratio, thicker leaves	Slow development, low pupal weight	Smith and Jones, 1998
Spittle bug	*Neophilaenus lineatus*	Cercopidae	Heath rush	*Juncus squarrosus*	600 ppm	Increased C:N Ratio, Reduced transpiration rates	20% reduction in nymph survival, delayed development	Brooks and Whittaker, 1999
Beet armyworm	*Spodoptera exigua*	Noctuidae	Upland cotton	*Gossypium hirsutum*	900 µL/L	Decreased N, Increased C:N Ratio	25% increase in consumption Longer development time	Coviella and Trumble, 2000

Insect		Family	Host plant		CO_2 conc.	Effect on host plants	Impact on insects	Reference
Common name	**Scientific name**		**Common name**	**Scientific name**				
Gypsy moth	*Lymantria dispar*	Lymantridae	Red maple	*Acer rubrum*	Ambient + 300 μL/L	Decreased N and C:N ratio	Reduced larval growth	Williams *et al.*, 2000
Crane fly	*Tipula abdominalis*	Tipulidae	Quaking aspen	*Populus tremuloides*	720 ppm	Decreased N, Higher levels of structural compounds	Decrease consumption and assimilation. Growth 15 times slower	Tuchman *et al.*, 2002
Small heath	*Coenonympha pamphilus*	Satyridae	*Grasses*	*Brumus erectus* *Festuca spp* *Carex caryophylla*	600 μL/L	Decreased N, Increased non structural carbohydrates and condensed tannins	Increased lipid concentration in adults, Higher no: of eggs in ovaries of females	Goverde *et al.*, 2002

Insect		**Family**	**Host plant**		**CO_2 conc.**	**Effect on host plants**	**Impact on insects**	**Reference**
Common name	**Scientific name**		**Common name**	**Scientific name**				
Willow beetle	**Phratora vitellinae**	Chrysomelidae	***Dark leaved willow***	**Salix myrsinifolia**	700 ppm	Increase in stem, leaf total aerial biomass and specific leaf weight, decreased N and phenolics	Reduced relative growth rate of larvae, increased consumption	Veteli *et al.*, 2002
Common blue butterfly	*Polyommatus icarus*	Lycaenidae	Birdsfoot trefoil	*Lotus corniculatus*	700 ppm	Increased carbon based defense compounds, Greater shoot vs roots, shoot and root allocation	Greater pupal weight, shorter development time	Bazin *et al.*, 2002
Tobacco caterpillar	*Spodoptera litura*	Noctuidae	Mung bean	*Vigna radiata*	600 ± 50 μL/L	Decreased N, Increased starch and total soluble sugars	Increased feeding and growth rate	Srivastava *et al.*, 2002
Green Leaf Weevil	*Phyllobius maculicornis*	Curculionidae	***European white birch***	**Betula pendula**	700 ppm	Decreased N, flavonyl glycosides Increased total phenolics, condensed tannins, (+)-catechin and cinnamoylquinic acids	Weevils preferred leaves grown under elevated co2 given a choice between treatments	Kuokkanen *et al.*, 2003

Insect		**Family**	**Host plant**		**CO_2 conc.**	**Effect on host plants**	**Impact on insects**	**Reference**
Common name	**Scientific name**		**Common name**	**Scientific name**				
Small heath	*Coenonympha pamphilus*	Satyridae	***RED FESCUE***	**FESTUCA RUBRA**	750 ppm	Decreased N, Increased C:N Ratio	Larval growth slower	Mevi-Schutz *et al.,* 2003
Forest tent caterpillar	*Malacosoma distria*	Lasiocampidae	Quaking aspen	*Populus tremuloides*	560 µL/L	Decreased N, Increased tremulacin levels	No effect on larval performance	Kopper and Lindroth, 2003
Common blue butterfly	*Polyommatus icarus*	Lycaenidae	Birdsfoot trefoil	*Lotus corniculatus*	600 µL/L	Decreased N, Increased C:N Ratio and sugar concentration	Marginal negative effect on larval mass gain	Goverde *et al.,* 2004
Grain aphid	**SITOBION AVENAE**	Aphididae	Spring wheat	*Triticum aestivum*	750 ppm	Higher ear starch, sucrose, glucose, total nonstructural Carbohydrates, free amino acids and soluble protein, Decreased N	Local populations increased, Alate aphids on sticky traps decreased, alate forms deposited more aphids on plants	Chen *et al.*, 2004

Insect		**Family**	**Host plant**		**CO_2 conc.**	**Effect on host plants**	**Impact on insects**	**Reference**
Common name	**Scientific name**		**Common name**	**Scientific name**				
Cotton aphid	*Aphis gossypii*	Aphididae	Bt cotton	*Gossypium hirsutum*	1050 ppm	Increased C:N Ratio, Plant height, biomass and leaf area were higher	Aphid fecundity significantly increased	Chen *et al.,* 2005

FARMERS' KNOWLEDGE, PERCEPTION AND ADAPTATION MEASURES TOWARDS CLIMATE VARIABILITY

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Introduction

Indigenous knowledge is generally defined as the "Knowledge of a people of a particular area based on their interactions and experiences within that area, their traditions, and their incorporation of knowledge emanating from elsewhere into their production and economic systems". It is culturally appropriate, holistic and integrative. Incorporating indigenous knowledge is less expensive than bringing in aid for populations unprepared for catastrophes and disasters, or than importing adaptive measures, which are usually introduced in a top- down manner and difficult to implement, particularly because of financial and institutional constraints. Indigenous people that live close to natural resources often observe the activities around them and are the first to identify and adapt to any changes. The appearance of certain birds, mating of certain animals and flowering of certain plants are all important signals of changes in time and seasons that are well understood in traditional knowledge systems. Farmers have been confronted with changing environments for millennia and have developed a wide array of coping strategies, and their traditional knowledge and practices provide an important basis for facing the even greater challenges of climate change. Participatory research and farmer-back-to-farmer models of technology transfer are examples of attempts towards establishing a bridge between traditional knowledge and scientific knowledge. The increasing attention to adaptation to climate change has not come with sufficient emphasis on the local nature of climate adaptation and on the role of local institutions and local governance in shaping adaptation practices (Agrawal *et al*., 2009). Local knowledge is therefore a major priority in the planning of adaptation (Allen, 2006). Indigenous knowledge systems can facilitate understanding and effective communication and increase the rate of dissemination and utilization of climate change mitigation and adaptation options. While the importance of indigenous knowledge has been realized in the design and implementation of sustainable development projects, little attention has been drawn to their incorporation into formal changing climate mitigation and adaptation strategies (Nyong *et al*., 2007).

Climate change is becoming a major driver of disasters, with increasingly frequent and intense floods and storms affecting more people globally. Increased forced displacement is an extremely likely consequence of such events. Heightened drought risk, desertification, sea level rise and changes in the availability of water and fertile land, coupled with reduced access to basic resources, will also fuel longer term migration and forced displacement.

Climate change: Impacts on Agriculture in India

Agriculture is one of the largest contributors to India's Gross Domestic Product (GDP), approximately 20%. It is the main source of livelihood for almost 60% of the country's total population. The impacts of changing climate on agriculture will therefore be severely felt in India. It has been projected that under the scenario of a 2.5^{0}C to 4.9^{0}C temperature rise in India, rice yields will drop by 32%-40% and wheat yields by 41-52%. This would cause GDP to fall by 1.8%-3.4% (GOI, 2011; Guiteras, 2007; OECD, 2002). Despite the gloomy predictions about the negative impacts for India's agricultural sector, climate change is expected to bring opportunities as well e.g.: production gains through the CO_2 fertilization effect or the expansion of cultivated land to higher altitudes and northern latitudes. However, it must be noted that to date all climate change projections have been accompanied by uncertainty-not primarily concerning trends but extent (IFPRI, 2009; UNFCC, 2009).

Adaptation to Climate change

Agriculture in developing countries is one of the most vulnerable sectors of the global economy to changing climate (Kurukulasuriya *et al.,* 2006; Seo and Mendelsohn 2008c). Farmers whose livelihoods depend on the use of natural resources are likely to bear the brunt of adverse changing climate impacts. Farmers will be hard hit if they do not adjust at all to new climates (Mendelsohn *et al*., 1994, Rosenzweig and Hillel 1998; Reilly *et al*., 1996). Adaptation to climate change requires that farmers first notice that climate has changed, and then identify useful adaptations and implement them (Maddison, 2006). Adaptation is widely recognized as a vital component of any policy response to climate change. Studies show that without adaptation, climate change is generally detrimental to the agriculture sector; but with adaptation, vulnerability can largely be reduced (Easterling *et al*., 1993; Rosenzweig and Parry 1994; Smith 1996; Mendelsohn 1998; Reilly and Schimmelpfennig 1999; Smit and Skinner, 2002). The degree to which an agricultural system is affected by climate change depends on its adaptive capacity. The adaptive capacity of a system describes its ability to modify its characteristics or behavior so as to cope better with changes in external conditions. Adaptive capacity is determined by various factors including recognition of the need to adapt, willingness to undertake adaptation, and the availability of, and ability to deploy, resources (Brown, 2010). Recent empirical studies indicate that farmers have already adapted to the existing climates that they face by choosing crops or livestock or irrigation (Kurukulasuriya and Mendelsohn 2007, 2008; Nhemachena and Hassan 2007; Seo and Mendelsohn 2008a, 2008b) ideal for their current climate. The adaptation strategies must not be used in isolation. For instance, the use of early maturing crop varieties must be accompanied by other crop management practices such as crop rotation or the use of cover crops. This, however, requires additional institutional support, such as credit, access to input and output markets and information.

The objective of the present study was to identify farmers' knowledge perceptions towards climate change along with their farm-level adaptation measures with a view to suggest appropriate research/policy issues which help in facilitating farmers' adaptation to changing climate.

Research Results

A sample of 180 farmers @60 each from Anantapur, Mahbubnagar and East Godavari districts of Andhra Pradesh in South India was selected randomly. Data was collected using a pre-tested interview schedule from the farmers. Percent analysis, correlation and regression, and composite index developed in the study were used for analyzing data.

a) Farmers' perceptions and Adaptation Measures towards Climate change:

Table 1. Farmers' Perceptions regarding Climate change in Anantapur

S.No.	Farmers' Perception	Number*	%	Rank
1.	Rise in temperatures	57	95	I
2.	Decrease in rainfall	56	93	II
3.	Advanced onset of monsoon	54	90	III
4.	Middle, long dry spells	53	88	IV
5.	Terminal heavy rains	50	83	V
6.	Uneven distribution of rainfall thereby, affecting length of growing season	49	82	VI
7.	Prevalence of pests and diseases	47	78	VII
8.	ITKs for weather forecast failing	41	68	VIII

*Multiple responses

Table 2. Farmers' Adaptation Measures towards Climate change in Anantapur

S.No.	Farmers' Adaptation Measures	Number*	%	Rank
1.	Buy insurance	56	93	I
2.	Change in planting dates of groundnut (go or early sowings may be between May end to early June)	55	92	II
3.	Intercrop with red gram in 8:1 or 12:1 ratio.	48	80	III
4.	Intercrop with castor contemplated	47	78	IV
5.	Construct water harvesting structures under MGNREGA	45	75	V
6.	Require quick maturing, drought resistant varieties	42	70	VI

From table 1, it is clear that rise in temperatures followed by decrease in rainfall, advanced onset of monsoon, middle long dry spells, terminal heavy rains, prevalence of pests and diseases and ITKs for weather forecast failing are the major farmers' perceptions in that order of magnitude regarding climate change in

Anantapur. Bryan et al. (2009) in their study in Ethiopia and South Africa reported that farmers experienced increased temperature and decreased rainfall. Similar observations were reported by Vedwan and Rhoades (2001), Hageback et al. (2005), Maddison (2006), Gbetibouo (2009) and Dejene (2011) in their studies. Results of a study conducted in Bundi district of Rajasthan, India revealed farmers' perceptions to climate change as increase in temperatures, decreased rainfall and long dry spells. The chief adaptation measures followed by farmers' are change in planting time, intercropping, soil and water conservation and planting drought tolerant crops (Dhaka *et al*., 2010).

It is clear from table 2, that buying insurance, changing planting dates of groundnut, intercrop with red gram, construct water harvesting structures, and require quick maturing, drought resistant varieties in that order of magnitude are the major adaptation measures followed by farmers' towards climate change in Anantapur. This finding is consistent with that of Swanson *et al*., (2008) who reported that crop insurance was widely used by farmers in Foremost and Coaldale regions of Canada and the common feeling was that even though it might not provide sufficient returns for losses incurred it does offer some protection. It has allowed them to continue farming. Agricultural insurance can help people to cope with the financial losses incurred as a result of weather extremes. Insurance supports farmers in their adaptation process and prevents them from falling into absolute poverty. Apart from stabilizing household incomes by reducing the economic risk, insurance can also enhance farmers' willingness to adapt, to make use of innovations and invest in new technologies (Ilona *et al*., 2011). Agricultural adaptation involves two types of modifications in production systems. The first is increased diversification that involves engaging in production activities that are drought tolerant and or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors. Crop diversification can serve as insurance against rainfall variability as different crops are affected differently by climate events (Orindi and Eriksen 2005; Adger *et al*., 2003). The second strategy focuses on crop management practices geared towards ensuring that critical crop growth stages do not coincide with very harsh climatic conditions such as mid-season droughts. Crop management practices that can be used include modifying the length of the growing period and changing planting and harvesting dates (Orindi and Eriksen, 2005).

Table 3. Farmers' Perceptions regarding Climate change in Mahbubnagar

S.No.	Farmers' Perception	Number*	%	Rank
1.	Rise in temperatures	55	92	I
2.	Decrease in rainfall	53	88	II
3.	Advanced (some places timely) onset of monsoon	51	85	III
4.	Middle long dry spells accompanied by cloudy weather during flowering	48	80	IV
5.	Terminal heavy rains	46	77	V

6.	Prevalence of pests and diseases (powdery mildew, mold in castor; smut and jassids in paddy)	41	68	VI

From table 3, it is clear that rise in temperatures followed by decrease in rainfall, prolonged dry spells in between rains, terminal heavy rains and prevalence of pests and diseases (powdery mildew, mold in castor; smut and jassids in paddy) are the major farmers' perceptions in that order of magnitude regarding climate change in Mahbubnagar. It is striking that farmers across the world show a remarkable unanimity in observations of seasonal change, particularly regarding rain falling in most intense bursts; and generally higher temperatures and longer hot, dry spells within rainy seasons, with effects on soil moisture (Jennings and Magrath, 2009). Kemausuor *et al*., (2011) reported that a large percentage (93%) of farmers was of the opinion that the timing of the rains is now irregular and unpredictable.

Table 4. Farmers' Adaptation Measures towards Climate change in Mahbubnagar

S.No.	Farmers' Adaptation Measures	Number*	%	Rank
1.	Staggered sowings (dry paddy, castor, red gram and cotton in kharif), (groundnut, paddy, chillies and tobacco in rabi)	50	83	I
2.	Change in Planting dates and planting different crops	49	82	II
3.	Require drought resistant varieties	45	75	III
4.	Water harvesting structures started under MGNREGA	41	68	IV

It is clear from table 4, that staggered sowings, change in planting dates, require drought resistant crops, and construct water harvesting structures are the major adaptation measures followed by farmers' towards changing climate in Mahbubnagar.

Also, the farmers' in Mahbubnagar are accustomed to observe the rainy season and if the season is favourable with good rains, they will continue farming. Otherwise, they migrate and work as construction labour at Gangavati, Hyderabad and Bangalore. Higher temperatures, pest and disease attack on crops were the chief perceptions of farmers towards climate change, while, planting different crops and water conservation were the main adaptation strategies of farmers in Ogbomosho agricultural zone of Oyo state in Nigeria. (Ayanwuyi *et al*., 2010).

Table 5. Farmers' Perceptions regarding Climate change in East Godavari

S.No.	Farmers' Perception	Number*	%	Rank

1.	Rise in temperatures.	54	90	I
2.	Decrease in rainfall.	53	88	II
3.	Pest and disease incidence is high for kharif paddy like BPH, BLB and stem borer (at transplanting stage).	51	85	III
4.	Terminal heavy and unseasonal rains.	49	82	IV
5.	ITKs for rain forecasts are failing.	45	75	V

From table 5, it is clear that rise in temperatures, followed by decrease in rainfall, incidence of pests and diseases, terminal heavy cyclonic rains, and ITKs for rain forecasts failing are the major farmers' perceptions in that order of magnitude regarding climate change in East Godavari.

Table 6. Farmers' Adaptation Measures towards Cimate change in East Godavari

S.No.	Farmers' Adaptation Measures	Number*	%	Rank
1.	Go for early (June) sowings to avoid November cyclones coinciding with harvests.	56	93	I
2.	Salt water spray for harvested paddy stalks to avoid discoloration and regermination. For paddy in field, tying with rope and sticks on four sides to keep them erect and not falling down.	55	92	II
3.	Strengthening of river banks and improved drainage.	53	88	III
4.	Survey number wise insurance covering low lands.	50	83	IV
5.	Loans to tenant farmers though introduced, falls short of actual requirements in terms of coverage.	48	80	V

It is clear from table 6, that early sowings, salt water spray for harvested paddy stalks, strengthening of river banks and improved drainage, survey number wise insurance, and loans to tenant farmers are the major adaptation measures perceived by farmers' towards climate change in East Godavari. Migrate as construction labour if monsoon fails, particularly in rainfed areas of the district is another common phenomenon (Ravi Shankar *et al*., 2013). Improving the adaptive capacity of disadvantaged communities requires ensuring access to resources, income generation activities, greater equity between genders and social groups, and an increase in the capacity of the poor to participate in local politics and actions (IISD 2006). Thus, furthering adaptive capacity is in line with general sustainable development and policies that help reduce pressure on resources reduce environmental risks, and increase the welfare of the poorest members of the society.

Since most smallholder farmers are operating under resource limitations, lack of credit facilities and other inputs compound the limitations of resource availability and the implications are that farmers fail to meet transaction costs necessary to acquire the adaptation measures they might want to and at times farmers cannot make beneficial use of the available information they might have (Kandlinkar and Risbey 2000). Lack of access to credit has been observed in previous studies (Nhemachena and Hassan, 2007) to be a barrier to responding to climate change. A better understanding of how farmers' perceive changing climate, ongoing adaptation measures, and the factors influencing the decision to adapt farming practices is needed to craft policies and programmes aimed at promoting successful adaptation of the agricultural sector (Bryan *et al*., 2009).

- The mean adaptation index value for floods (12.13) (East Godavari) is greater than that for droughts (11.90, 11.65) (Anantapur and Mahbubnagar respectively).
- Practices like construct water harvesting structures, plant drought resistant crops, crop management by adjusting planting dates and soil management by mulching, conservation tillage showed highest adaptation in Anantapur and Mahbubnagar. This amply illustrates the need for water harvesting, storage and reuse.
- Practices like flood forecasting and early warning systems, drainage aspects, better soil and crop management and community based water management showed highest adaptation in East Godavari. The problem here is managing excess water.
- Education, farming experience, and farm size were contributing significantly at 0.01 level with farmers' adaptation to climate change.
- Extension's role is in providing knowledge related to adaptation to changing climate and communication, so that farmers' can make informed decisions.

Conclusion

Capacity building at local, national and regional levels is vital to enable developing countries like India to adapt to changing climate. Capacity building, for example to integrate changing climate and socio-economic assessments into vulnerability and adaptation assessments, helps to better identify effective adaptation options and their associated costs. Education and training of stakeholders, including policy-level decision makers, are important catalysts for the success of assessing vulnerabilities and planning adaptation activities, as well as implementing adaptation plans. The different policy options include raising awareness about changing climate and the appropriate adaptation methods, facilitating the availability of credit, investing in yield increasing technology packages to increase farm income, creating opportunities for off-farm employment, conducting research on use of new crop varieties and livestock species that are better suited to drier conditions, encouraging informal social networks, and investing in irrigation. Extension can make a significant contribution through enhanced farmer decision making in the light of changing climate. The most important purpose for extension today is to bring about the empowerment of farmers, so that their voices can be heard and they can play a major role in deciding how they will mitigate and adapt to changing climate.

As national and international policy makers turn their attention to changing climate adaptation, they should keep in mind that constructing an enabling environment that minimizes these vulnerabilities will be central to any meaningful and lasting increase in the adaptive capacity of the rural poor. Govt. policies designed to promote adaptation at the farm level will lead to greater food and livelihood security in the face of changing climate.

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CDM OPPORTUNITIES IN LIVESTOCK SECTOR

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The performance, health and well-being of the livestock are strongly affected by climate both, directly and indirectly. The direct effects involve heat exchanges between the animal and its environment that are linked to air temperature, humidity, wind-speed and thermal radiation. These linkages have bearing on the physiology of the animal and influence animal performance (e.g., growth, milk and wool production, reproduction) and health. Hot and humid environmental conditions stress the lactating dairy cow and reduce intake of the nutrients necessary to support milk yield and body maintenance. The primary factors that cause heat stress in dairy cows are high environmental temperatures and high relative humidity. In addition, radiant energy from the sun contributes to stress if cows are not properly shaded. The tremendous amount of body heat that the high yielding dairy cow produces is helpful in cold climates but is a severe liability during hot weather. Short-term extreme events (e.g., summer heat waves, winter storms) can result in the death of vulnerable animals, which can have substantial financial impacts on livestock producers. Although the level of vulnerability of the farm animals to environmental stresses varies with the genetic potential, life stage and nutritional status of the animals, the studies unambiguously indicate that the performance of farm animals is directly sensitive to climate factors. Summer weather reduces production of high-producing dairy cows and also the conception rates of dairy cows as much as 36%. With predicted global warming, an additional decline in milk production beyond expected summer reductions may occur particularly in the hot/hot-humid regions.

Besides the direct effects of climate change on animal production, there are profound indirect effects as well, which include climatic influences on Quantity and quality of feed and fodder resources such as pastures, forages, grain and crop by-residues and The severity and distribution of livestock diseases and parasites.

Lowland sites in relatively low rainfall areas expected reduction of herbage yield a lot in dry seasons. Climate driven models of the temporal and spatial distribution of pests, diseases and weeds have been developed for some key species *e.g*. the temperate livestock tick *Haemaphysalis longicornis* and the tropical cattle tick *Boophilus microplus*. Potential climate change impacts on buffalo fly and sheep blowfly have also been inferred (Sutherst *et al*. 1996). Climate scenarios in New Zealand and Australia have indicated increased incidence of epidemics of animal diseases as vectors spread and extension of cattle tick which is directly related to changes in both temperature and rainfall (Sutherst, 1995). Thus, in general, climate change-related temperature increase will have adverse impacts on the animal production system.

Indian context:

The mean summer (April to June) temperature of India ranges from 25 to 450C in most parts of the country. Higher temperature during summer months would increase the heat stress in animals, particularly in crossbred cows. The crossbred cows, which are high yielders and more economic to farmers, are more susceptible to heat stress compared to local cows and buffaloes. The proactive management counter measures during heat waves (e.g. providing sprinklers or changing the housing pattern etc.) or animal nutrition strategies to reduce excessive heat loads are often expensive and beyond the means of small and marginal farmers who own most of the livestock in India. Where high temperatures are associated with decline in rainfall or increased evapotranspiration, the possibility of economically rearing animals would be further limited as decline in rainfall shall aggravate the feed and fodder shortage in the area. The greatest impact would perhaps be on the pastoral families, who would migrate to arable areas to secure their livelihood. This would entail significant dislocation costs for these livestock keepers. However, at the same time positive impacts can also be or in the in high altitudes would decrease maintenance requirement of animals and increase the productivity of winter pastures. Possible benefits of climate change during cooler seasons though not well documented, are likely to be less than the consequential negative hot weather impacts (Hahn *et al*., 1992), especially if the cold season is much shorter than the hot one.

Contribution of Livestock to Climate Change

The animal production system which is vulnerable to climate change is itself a large contributor to global warming through emission of methane and nitrous oxide. About half of the annual global emission of 75.8 Tg from enteric fermentation came from only five countries; viz. India (10.27 Tg), the erstwhile USSR (8.05 Tg), Brazil (7.46 Tg), the USA (6.99 Tg) and China (4.37 Tg). Species-wise cattle contributed 75%, buffaloes 8%, sheep 9% and goats 3% to the total emission. The annual methane production per animal was estimated to be 95 kg for the German dairy cows, nearly three fold higher than 35 kg for the Indian cattle (Crutzen *et al*., 1986). Estimates of enteric emissions from Indian livestock vary widely from 6.17 Tg/year to 10.3 Tg/year of which 60% from cattle, 30% from buffaloes and 3% from sheep and 6% from goat and 1% from other livestock.

Methane's radiative activity refers to properties that cause it to trap infrared radiation (IR), or heat, enhancing the greenhouse effect. Its chemically active properties have indirect impacts on global warming as the gas enters into chemical reactions in the atmosphere that not only affect the period of time methane stays in the atmosphere (i.e. its lifetime), but that also play a role in determining the atmospheric concentrations of tropospheric ozone and stratospheric water vapour, both of which are also greenhouse gases. These indirect and direct effects make methane a large contributor, second only to carbon dioxide, to potential future warming of the earth. Methane concentration in the atmosphere is largely correlated with anthropogenic activities and these sources currently represent about 70% of total annual emissions, The global warming potential (GWP) of methane is 21 times more than carbon dioxide. Additionally, methane's chemical lifetime is relatively short, about 12 years compared to 120 years for carbon dioxide.

Nitrous oxide (N2O) is another potent greenhouse gas, the primary anthropogenic emissions of which are thought to come from agricultural fertilizers, and to a lesser degree, fossil fuel combustion and biomass burning. The GWP of nitrous oxide is 321.

There are two sources of GHG emissions from livestock:

1) From the digestive process

2) From animal wastes

Emissions from digestive process:

Methane is produced in herbivores as a by-product of 'enteric fermentation: a digestive process by which carbohydrates (polysaccharides) are broken down by micro-organisms into simple molecules for absorption into the bloodstream. The level of methane production by animals depends on the type of digestive system the animal has. Methane is produced by the methanogenic archaebacteria located mainly in the rumen, and is released as gas into the atmosphere.

***Factors affecting enteric emissions*:** The average daily feed intake and the percentage of this feed energy which is converted to methane are the two important determinants of methane emissions from livestock.

Average daily feed intake: All dairy cows and young cattle are recommended to have a conversion rate of 6.0 percent (± 0.5%) of feed energy intake and all non-dairy cattle, other than young stall-fed animals, are recommended to have a conversion rate of 7.0% (± 0.5%). Conversion rate for grazing cattle is 6.0% (± 0.5%). The feeding situations (grazing or stall-fed) also have a bearing on the energy requirement as additional energy is required by grazing animals to obtain their food.

Methane conversion efficiency: The other important determinant of methane emission in livestock, depends on rumen microflora6 and the quality (digestibility, nutrient composition and energy value) of the feed. In fact, the diversity, size and activity of the microbial population in the rumen which determines the efficiency of fermentation in the rumen (and hence methane emissions) is itself largely influenced by diet. Therefore, type of feed and fodder intake by the livestock has a dominant influence on the production of methane in the rumen.

Emissions from animal wastes:

Methane and Nitrous oxide are the two important GHG emitted from animal wastes.

Methane emissions from manure: Animal wastes contain organic compounds such as carbohydrates and proteins. These relatively complex compounds are broken down naturally by bacteria. In the presence of oxygen, the action of aerobic bacteria results in the carbon being converted to carbon dioxide. The emission of carbon dioxide is part of the natural cycling of carbon in the environment and results in no overall increase in atmospheric carbon dioxide. The carbon dioxide, originally absorbed from the atmosphere through photosynthesis by the plants which formed the livestock feed, is simply being released. However, in the absence of oxygen, anaerobic bacteria transform the carbon to methane and so the decomposition of livestock wastes under moist, oxygen free (anaerobic) environments results in an increase in the concentration of greenhouse through production of methane.

The amount of methane released from animal manure depends on many variables such as:

Methane producing potential of manure: Each type of animal waste has its characteristic content of degradable organic matter (material that can be readily decomposed), moisture, nitrogen and other compounds. As a consequence, the maximum methane producing potential of the different manures varies both across species and, in instances where feeding practices vary, within a single species.

Quantity of manure produced: which depends on feed intake and digestibility

Waste management system used: The most important factor affecting the methane emissions from animal wastes is how the manure is managed (e.g. whether it is stored as a liquid or spread as a solid). Metabolic processes of methanogenes leads to methane production at all stages of manure handling. In the modern intensive livestock practices, where animals are often housed or kept in confines spaces, manure is often stores in tanks or lagoons. Liquid systems tend to encourage anaerobic conditions and to produce significant quantities of CH_4. On the other hand, when livestock are in fields and their manure ends up being spread thinly on the ground, aerobic decomposition usually predominates and these aerobic solid waste management approaches may produce little or no methane at all, which is true under grazing.

Climate: The warmer the climate the more biological activity takes place and the greater is the potential for methane evolution. Also, where precipitation causes high soil moisture contents, air is excluded from soil pores and the soils become anaerobic again increasing the potential for methane release even for wastes which have been spread. Hence, higher temperatures and moist conditions also promote CH_4 production.

Nitrous oxide emissions from animal wastes: Animal wastes contain nitrogen in the form of various complex compounds. Nitrous oxide forms and is emitted to the atmosphere via the microbial processes of nitrification and denitrification. The majority of nitrogen in wastes is in ammonia form. Nitrification occurs aerobically and converts this ammonia into nitrate, while de-nitrification occurs anaerobically and converts the nitrate to nitrous oxide.

The generation of nitrous oxide is influenced by

Nitrogen concentration: The rate of nitrification will be higher for animal wastes which contain more nitrogen. The nitrogen excreted by the animals in turn depends upon the quantity and quality of feed intake. For example, the dairy cows consuming more protein supplements excrete more nitrogen.

Animal waste management system: The method of managing the animal wastes determine the oxygen concentration and microbial community which have bearing on the emission rate of nitrous oxide. For nitrification, the optimal conditions imply that oxygen is available and pH is low. Increasing aeration initiates the nitrification-denitrification reactions, and hence makes release of N_2O possible. Nitrous oxide is a side-product which is produced in larger quantities Therefore, as fresh dung and slurry is highly anoxic and well-buffered with near neutral pH, it is expected that higher nitrification will occur. After the initial aerobic reaction, when conditions are suboptimal for nitrification, for example when oxygen is deficient, as in situations with high biological activity consuming oxygen, large amounts of N_2O is produced. A dry aerobic system of waste management may therefore provide a more conducive environment for N2O emission than the waste managed in anaerobic lagoon and liquid system.

Relevance of CDM for the Indian Livestock sector:

United Nations Framework Convention on Climate Change (UNFCCC) divides countries into two groups: Annex I parties, the industrialized countries who have historically contributed the most to climate change, and non- Annex I Parties, which include primarily the developing countries, like India. In order to grasp reduction opportunities in the non- Annex B countries, the Kyoto Protocol instituted a mechanism called Clean Development Mechanism (CDM), defined in Article 12 of the Protocol. The CDM allows countries with emission targets to buy emission credits from projects in countries without targets and hence is of relevance for India, unlike the first two mechanisms mentioned above which are applicable to only Annex I countries. Under the CDM, an Annex I party is to implement a project that reduces greenhouse gas emissions (or subject to constraints, removes green house gases by carbon sequestration) in the territory of a non-Annex I party. The resulting certified emission reduction (CERs), can then be used by the Annex I party to help meet its emission reduction target. CERs are tradable under Article 3.12 of the Kyoto Protocol.

The developing countries like India can benefit from this mechanism as the CDM can:

* attract capital for projects that assist a more prosperous but less green house gas-intensive economy;

* encourage and permit the active participation of both private and public sectors;

* provide a tool for technology transfer, if investment is channelled into projects that replace technologies which lead to high emissions and

* help define investment priorities in projects that meet sustainable development goals.

The two broad criteria stipulated under the Kyoto Protocol that CDM projects must satisfy are broadly classified as **additionality** and **sustainable development**. The real, measurable, and long-term benefits related to the mitigation of climate change, the additional greenhouse gas reductions are calculated with reference to a defined "baseline".

Sustainable development: Under this the CDM should have

<u>Social well-being:</u> The CDM project activity should lead to alleviation of poverty by generating additional employment, removal of social disparities and contributing to provision of basic amenities to people leading to improvement in their quality of life.

<u>Economic well-being:</u> The CDM project activity should bring in additional investment consistent with the needs of the people.

<u>Environmental well-being:</u> This should include a discussion of the impact of the project activity on resource sustainability and resource degradation, if any, due to the proposed activity; bio-diversity-friendliness; impact on human health; reduction of levels of pollution in general;

<u>Technological well-being:</u> The CDM project activity should lead to transfer of environmentally safe and sound technologies with a priority to the renewable sector or energy efficiency projects that are comparable to best practices in order to assist in upgradation of the technological base.

Options for reducing Enteric emissions:

The strategies for reducing methane emissions from enteric fermentation can be broadly focused in two main areas: 1) reducing livestock numbers and 2) improving the rumen fermentation efficiency.

Increase in Productivity of the animals: The rising demand for food from animal origin needs to be met by increasing the productivity levels rather than increasing the numbers. Unless the emission reduction strategies are accompanied by increase in productivity they will not be in consonance with the sustainable development of livestock sector.

Improving rumen fermentation efficiency: The growth of rumen microbes is influenced by chemical, physiological and nutritional components. The major chemical and physiological modifiers of rumen fermentation are rumen pH and turnover rate and both of these are affected by diet and other nutritionally related characteristics such as level of intake, feeding strategies, quality of fodder and fodder: concentrate ratios. The options for increasing rumen efficiency can meet the sustainable development criteria only if they do not lead to any adverse affect on the health of the animal. For instance, feeding ruminants on diets containing high levels of readily fermented non-structural carbohydrate has been shown to minimize methane production by reducing the protozoal population and lowering rumen pH. However, this can give rise to an overall depressed ruminal fermentation, which may lower the conversion of feed energy into animal product and may be detrimental to the animal's health. The options identified to increase rumen efficiency without threatening the animal health can be classified as: improved nutrition through

o year round supply of green fodder
o feed additives,
o strategic supplementation, and
o dietary manipulation,
changing rumen microflora by
o adding specific inhibitors or antibiotics,
o biotechnological manipulation and
o genetic engineering.

Year round supply of green fodder: A number of options like Alley cropping (is a system in which food/fodder crops are grown in alleys formed by hedgerows of trees or shrubs), Ley farming (A rotation is a cropping system in which two or more crops are grown in a fixed sequence. If the rotation includes a period of pasture, a ley, which is used for grazing and conservation, the system is sometimes called "alternate husbandry" or mixed farming), cultivation of short duration fodder and contingency crops like African tall, Horse gram etc on tank beds and unlined ponds with left over moisture in the middle of winter season, back yard cultivation of Para grass and production of Azolla, storing excess greens as silage and hay as haylage would ably augment the year nutritious fodder demand and enhance the productivity in livestock by better digestibility of feed and fodder. Seeding common property resources (CPR) with improved high yielding fodder varieties and legume fodders along with social regularization of rotational grazing substantially strengthen the local fodder resource base and indirectly reduce enteric methane emissions. Further, practice of chopping and soaking of hay will enhance digestibility and reduce GHG emissions from livestock.

Feed additives: A wide range of feed additives are available that can reduce rumen methanogenesis (Chalupa, 1980; Mathison *et al*. 1998) such as propionate precursors and ionophores.

Propionate precursors: Within the rumen, hydrogen produced by the fermentation process may react to produce either methane or propionate. By increasing the presence of propionate precursors such as pyruvate, oxaloacetate, malate, fumarate and succinate more of hydrogen is used to produce propionate.
The dicarboxylic organic acids, fumarate and malate, have been suggested as potential hydrogen acceptors to reduce methane in the ruminants
Ionophores: The ionophores are known to inhibit methanogenesis and shift VFA (volatile fatty acids) patterns towards higher propionate. The main ionophores (monensin, lasalocid, salinomycin) in use have shown improved feed efficiency by reducing feed intake and maintaining weight gain or by maintaining feed intake and increasing weight gain. The experiments conducted in India with monensin pre-mix showed that using this technique methane production can reduce by 20-30% depending on the diet of animals viz. 14-23% for animals fed at maintenance diet, 23-32% at medium production diet and 14-25% at high production diet (Singh, 1998).
Strategic supplementation: Strategic supplementation provides critical nutrients such as nitrogen and important minerals to animals on low quality feeds. The use of molasses/urea multinutrient blocks (MNBs) has been found to be a cost effective diet supplementation strategy with a potential to reduce methane emissions by 25 to 27% (Robertson *et al*., 1994) and increase milk production at the same time.

Dietary manipulation: The substitution of low digestibility feeds with high digestibility ones tends to reduce methane production (Table 1), as with the improvement in digestibility same level of production can be achieved through lesser feed intake and hence the enteric emissions are reduced.

Table 1. Effect of feed quality on Methane emission of cows at the same level of milk production

Dry matter (DM) Digestibility (%)	55	65	75
Milk Production (kg/d)	20	20	20
Feed intake (kg DM/day	21.6	17.5	14.6
Methane emission (g/d)	309	296	285
Methane emission (g/kg milk)	15.5	14.8	14.3

Source: O' Hara *et al*

Changing rumen microflora: Probiotics, the microbial feed additives contain live cells and growth medium. Probiotics based on *Saccharomyces cereisiae* (SC) and

Aspergillus oryzae (AO) are widely used for increasing animal productivity. There are mixed reports as to whether these probiotic additives can reduce methane emissions. AO has been seen to reduce methane by 50% which was directly related to a reduction in the protozoal population (Frumholtz *et al*., 1989).

Strategic supplementation using molasses-urea products (MUP) like urea molasses mineral blocks: It has beneficial effect both on enhancing production and reducing methane emissions from livestock

Dietary manipulation through increasing concentrate feeding: on an average less than 500 grammes of concentrate was fed to dairy animals per day. For the non-dairy animals the quantity was even lower. Over the years an increase in the proportion of the concentrate in the livestock feed has been observed. But even the existing proportion of 7.5% concentrate is not sufficient to cater to the recommended nutritional requirement of 40% concentrate and 60% roughage on dry mater basis for the Indian cattle. For high milk producing dairy animals the concentrate to roughage ratio is still higher at 50:50.

Hexose partitioning: In hexose partitioning, by varying diet, it may be possible to

manipulate the amount of the feed carbohydrate going directly into microbial growth as opposed to fermentation.

Immunogenic approach: The removal of one species of protozoan from the rumen will invoke the improvements in productivity associated with defaunation (improved protein:energy ratio of the nutrients available for absorption). It is also believed that by modifying the activity of the rumen protozoan, there will be an indirect effect on the activity of methanogens, due to their commensal relationship with rumen protozoa. Therefore, by reducing the protozoal population, there may be a corresponding effect on the production of methane.

Genetic engineering: Suggestions have also been made about the potential use of

genetic engineering viz. recombinant deoxyribonucleic acid (DNA) technology to

modify the fermentation characteristics of rumen micro-organisms ruminal methane production.

Bacteriocins: Bacteriocins are antibiotics, generally protein or peptide in nature, produced by bacteria. Callaway *et al* (1997) used the bacteriocinnisin which is produced by *Lactococcus lactis*, to produce a 36% reduction of methane production *in vitro*. Further research is on to evaluate the efficacy of bacteriocins.

Other techniques: Other techniques to inhibit methanogen growth and methane are the use of inhibitors, mevastatin and lovastatin (Miller and Wolin 2001). Also certain microbes in the rumen are known to promote reactions that minimise methane production and it may be possible to introduce such microbes directly as feed supplements. Such microbes include acetogens and methane oxidisers. Acetogens are bacteria that produce acetic acid by the reduction of carbon dioxide with hydrogen, thus reducing the hydrogen available for reaction to produce methane (methanogenesis)

Transfer of safe technologies: Bovine somatotropin (bST) is an example of one such controversial biotechnology. It is imperative to ensure that there is no 'technological dumping' in the developing nations under the CDM projects.

Key constraints for potential CDM projects:

There are a number of constraints in implementing the enteric methane mitigation strategies at the field level. These barriers which include,

Technical issues:
- *Access to farmers for implementation and monitoring*
- *Inadequate field testing of technologies*

Financial issues:
- *Lack of capital with farmers*
- *Direct economic incentives lacking for non-dairy animals*

Socio-cultural issues
- *Cultural taboos on rearing animals for meat*
- *Poor extension outreach to women*

Institutional issues
- *No Capacity Building in the Agriculture sector*
- *Research and Policy Imperatives*

Possible remedial measures to the constraints:

• ***Assessment of baseline using disaggregated level data:*** An appropriate baseline being the first step in design and formulation of CDM project, research needs to be carried to work out the total enteric emissions at the district level and the regional emission factors for the purpose of identifying the 'hot spots' for CDM projects in the dairy sector.

• ***Assessment of cost-effective regional animal nutrition strategies for methane reduction***

•***Assessment of transactions cost for potential CDM project***

• ***Initiation of Capacity Building Efforts in the Indian Livestock Sector***

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ASSESSMENT OF VULNERABILITY TO CLIMATE CHANGE

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The Intergovernmental Panel on Climate Change (IPCC) has projected that the global mean temperatures will increase by 1.4 – 5.8^{0} C by 2100. Climate change, in general terms, is referred to as a permanent shift in the rainfall (amount and distribution), temperature and other climate related variables. Though the variability in climate is natural, there is some marked change in this variability since the beginning of the industrial revolution and much of this change is attributed to the anthropogenic factors. Unabated increase in the emission of what are called Green House Gasses (GHGs) is the single most important reason for the observed climate change. All the sectors of the economy are exposed to climate change directly and indirectly. However, agriculture is the most vulnerable sector for obvious reasons.

Nature of climate change: Climate change is global in its causes and consequences and the effects are unevenly distributed across the globe. Ironically, the nations and communities which contributed most to the climate change are least affected and the nations which contributed least are most affected. It is the poor and developing countries that are more vulnerable to climate change. The impact is also more on the countries nearer to the equator than on those which are far from the equator. The impact is also likely to be long-term and persistent, and if not acted up on now, may as well be irrevocable and irreversible. In economics, it is viewed as a case of failure of markets in getting the polluters pay for the negative externalities that are both spatial and temporal.

Sinha and Swaminathan (1991) – showed that an increase of 2^{o}C in temperature could decrease the rice yield by about 0.75 ton/ha in the high yield areas; and a 0.5^{o}C increase in winter temperature would reduce wheat yield by 0.45 ton/ha.

Impacts on Indian Agriculture –Literature

Rao and Sinha (1994) – showed that wheat yields could decrease between 28 to 68% without considering the CO_2 fertilization effects; and would range between +4 to -34% after considering CO_2 fertilization effects. Aggarwal and Sinha (1993) – using WTGROWS model showed that a 2^{o}C temperature rise would decrease wheat yields in most places. Lat et al. (1996) – concluded that carbon fertilization effects would not be able to offset the negative impacts of high temperature on rice yields. Saseendran et al. (2000) – showed that for every one degree rise in temperature the decline in rice yield would be about 6%. Aggarwal et al. (2002) – using WTGROWS and recent climate change scenarios estimated impacts on wheat and other cereal crops. All these studies focused only on agronomic impacts of climate change.

The following table indicates the potential impact of climate change on food systems:

Table: Impact of climate change on the food systems

Change in temperature (^{0}C)	Impact
1	Modest increase in cereal yields in temeprate regions
2	Sharp declines in crop yields in tropics
3	150-550 millions at risk of hynger; yields in higher latitudes likely to peak
4	Yields decline by 15-35% in Africa and many other regions
5	Increase in ocean acidity disrupting marine ecosystems
>5	Catastrophic and far outside human experience

Source: Stern (2007)

What is vulnerability?

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed as well as the system's sensitivity and adaptive capacity.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climaterelated stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and frequency and magnitude of extremes. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range, or variability of

temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

How is agricultural development affected by climate change and variability?

Exposure to a high degree of climate risk is a characteristic feature of rainfed agriculture in the drylands of sub-Saharan Africa and South Asia (Brown and Jansen, 2008).

Climate variability directly affects crop production, primarily by driving supply of soil moisture in rainfed agriculture, and surface water runoff and shallow groundwater recharge in irrigated agriculture. Because biological response is nonlinear and generally concave over some range of environmental variability, climate variability tends to reduce average yields.

Climate-driven fluctuations in production contribute substantially to volatility of food prices, particularly where remoteness, the nature of the commodity, transportation infrastructure, stage of market development or policy limit integration with global markets. Because market forces tend to move prices in the opposite direction to production fluctuations, variability in food crop prices tends to buffer farm incomes, but exacerbates food insecurity for poor net consumers.

The uncertainty associated with climate variability creates a moving target for management that reduces efficiency of input use and hence profitability, as management that is optimal for average climatic conditions can be far from optimal for growing season weather in most years. Crop responsiveness to fertilizer and planting density, and hence optimal rates and profitability of production inputs, varies considerably from year to year as a function of water supply.

Climate variability and risk aversion on the part of decision makers cause substantial loss of opportunity in climatically-favorable seasons as a result of the precautionary strategies that vulnerable farmers employ *ex ante* to protect against the possibility of catastrophic loss in the event of a climatic shock. Farmers' precautionary strategies – selection of less risky but less profitable crops, under-use of fertilizers, shifting household labor to less profitable off-farm activities, and avoiding investment in production assets, and improved technology – come at a substantial cost when climatic conditions are favorable.

Many of the coping responses that vulnerable households employ ex-post to survive an uninsured climate shock can have adverse, long-term livelihood consequences. Coping strategies that include liquidating productive assets, defaulting on loans, migration, withdrawing children from school to work on farm or tend livestock, severely reducing nutrient intake and over-exploiting natural resources, even permanent abandonment of farms and migration to urban centers or refugee camps, sacrifice capacity to build a better life in the future (Brown and Jansen, 2008).

It is imperative to understand the impact of climate change on agriculture to devise policies and measure needed to adapt to climate change. There are basically three approaches to do this. They are agro-economic approach, agro-ecological approach and Ricardian approach. Agro-economic approach incorporates crop yield changes associated with various equilibrium climate change scenarios into an applied general equilibrium model. Agro-ecological approach assigns crops to agroecological zones and estimates potential crop yields. As climate changes, the extent of agroecological zones and the potential yields of crops assigned to those zones changes. These acreage and yield changes are then included in economic models to assess socio-economic impacts. Ricardian approach is based on the argument that, 'by examining two agricultural areas that are similar in all respects except that one has a climate on average (say) 3°C warmer than the other, one would be able to infer the *willingness to pay* in agriculture to avoid a 3°C temperature rise'.

Assessing vulnerability

Vulnerability is a function of exposure and sensitivity to climate change and the adaptive capacity of the region or the individual exposed to climate change. One of the methodologies to assess vulnerability is to construct indices of sensitivity, adaptive capacity and finally vulnerability as was done by TERI. A number of biophysical and socio-economic variables go into the construction of these indices. Using the district-level database for India, TERI constructed a map showing the vulnerability to climate change. They constructed a climate sensitivity matrix as defined by dryness and monsoon dependency and based on a 0.5° × 0.5° gridded dataset for 1961–90 developed by the Climatic Research Unit of the University of East Anglia in UK, and then recaluculated the index using the output from the HadRM2 downscaled general circulation model to show the potential shifts sensitivity to climate change. The resulting climate vulnerability map (Figure 1) illustrates the spatial distribution of vulnerability within India. It is notable that the districts with the highest climate sensitivity under exposure to climate change are not necessarily the most vulnerable, and vice versa. For example, most districts in southern Bihar have only medium sensitivity to climate change, yet are still highly vulnerable to climate change as the result of low adaptive capacity. By contrast, most districts in northern Punjab have very high sensitivity to climate change, yet are foundto be only moderately vulnerable as the result of high adaptive capacity. Assessment of both adaptive capacity in combination with climate change sensitivity andexp osure is thus crucial for differentiating relative vulnerability to climate change.

Vulnerability assessment – case studies

To supplement the district level vulnerability mapping as described above, some case studies were also conducted to understand the ground level issues in climate change. These were conducted in Jhalawar district of Rajasthan, Anantapur district of Andhra Pradesh and Chitradurga district of Karnataka. "What the case studies show, which was not visible through the national profiles, is the effect that institutional barriers or support systems have on local-level vulnerability. In the cases of Jhalawar and Anantapur, institutional barriers leave farmers who are ''double exposed'' poorly equipped to adapt to either of the stressors, let alone both simultaneously. In Chitradurga, on the other hand, institutional support appears to facilitate adaptation to both climatic change and globalization. However, these supports tendto disproportionately benefit the district's larger farmers" (OBrien et al., 2004).

Rainfed agriculture is more vulnerable to climate change because of the projected changes in rainfall behaviour: Incidence of droughts and floods is likely to be more frequent, rainfall delivered in a smaller number of high intensity rainy days necessitating the high storage needs. On the other hand, the increased temperatures will enhance to evapo-transpiration needs of the plants. One immediate implication is that huge investments are needed to create large scale water storage structures to take care of the longer dry periods. *In-situ* and small scale water conservation methods are best useful when the rainfall is normal or little sub-normal.

A multi-pronged approach that includes technological, institutional and policy-related measures is needed to cope with the potential adverse effects of climate change. Technological advances must include breeding of crop varieties that do well in altered climate, water conserving technologies such as micro-irrigation, and methods that reduce water evaporation from surface water bodies. In terms of institutional interventions, better pricing of water and power, more efficient allocation of water resources between regions and sectors are needed. At a more general level, it is important to strengthen those features such as education, markets, connectivity, etc. which will contribute to enhancing the adaptive capacity of communities vulnerable to climate change.

Efforts for Mitigation of Climate Change in India

India has for quite some time pursued GHG friendly policies in her own interest. India's obligation to minimize energy consumption - particularly oil consumption - and to deal with its environmental problems prompt it to follow many such policies. Directly or indirectly these efforts are made by Government as well as by people to reduce energy consumption. These include:

a) Emphasis on energy conservation.

b) Promotion of renewable energy sources.

c) Abatement of air pollution.

d) Afforestation and wasteland development.

e) Economic reforms, subsidy removal and joint ventures in capital goods.

f) Fuel substitution policies.

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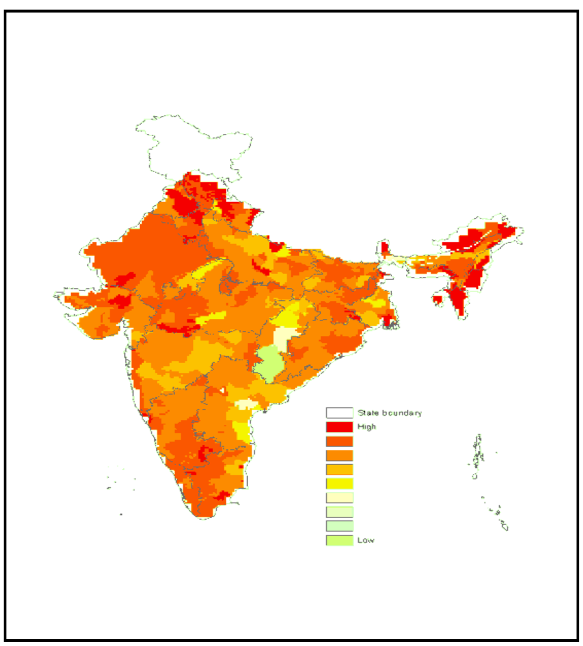
Table 1. Ricardian estimates of effect of climate change on net revenues

ΔT/ΔP	Impacts as percentage of Net Revenue		
	Without Variation Terms	With Variation Terms	With Variation Terms and 5% Higher Variation
2°C/7%	-7.8	- 6.8	-9.5
3.5°C/14%	-24.0	- 17.8	-28.1

Source: Kavikumar

Fig 1. Vulnerability of districts to climate change



WEATHER INSURANCE BASED CLIMATE RISK MANAGEMENT IN RAINFED CROPS

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Introduction

Climate has always presented a challenge to those whose livelihoods depend on the weather. Even though a drought (or flood, or a hurricane or cold wave or heat wave) may happen infrequently, the threat of the disaster is enough to block economic vitality, growth and wealth generation during all-years-good or bad. The risk of drought and flooding can keep people in poverty traps, as risk-adverse behavior limits productivity and willingness of creditors to lend to farmers, for example. Lack of access to financial services, especially in rural areas, in turn restricts access to agricultural inputs and technologies, such as improved seeds and fertilizers. At the national level, when disaster strikes, many developing countries rely on humanitarian aid, whose delay can led to higher human and economic costs. Climate change is one of the most important global environmental challenges facing by human beings, which affects food production, property, natural ecosystems, freshwater supply and health sector. The Intergovernmental Panel on Climate Change (IPCC) projects that the global mean temperature may increase between 1.4 and 5.8 °C by 2100 (IPCC, 2007). At the same time, the Intergovernmental Panel on Climate Change's fourth assessment report has warned us that climate change is likely to reduce food production potential, especially in some already food-short areas. It further states that there is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts which will be hardest felt by the most vulnerable, who are often in the weakest economic position.

Climate change will greatly exacerbate this situation; and developing countries, which are least responsible for climate change, face its greatest impacts. New tools are urgently needed to help vulnerable people deal with climate change, and the uncertainty that accompanies this. It is not only the poor who need such tools. After a climate-related disaster, governments struggle to finance relief and recovery efforts and maintain essential government services. Disaster response can be delayed for several months as humanitarian aid trickles. One innovative response to enable poverty reduction through better climate risk management is weather insurance.

Climate Risk Management and Agriculture

Climate risk is a particular challenge for the hundreds of millions whose livelihoods depend on rainfed agriculture in marginal, high-risk environments. Climate risk is not a new phenomenon, and climate risk management in the broad sense has long been practiced. Farmers anticipate the rains, using indicators,and time their planting and inputs based on their best estimates; they install irrigation system if they can; and they reduce risk exposure by diversifying their livelihoods as far as possible (Decron,1996; Ellis,2000). Scientists have also sought ways to help manage the risk that climate presents. Agriculture research has developed crop varieties that are drought tolerant, for example, and soil management practices that increase soil moisture-holding capacity. Weather forecasts have been a major advance in helping people plan appropriately. Rainfed agriculture is often characterized by high variability of production outcomes, that is, by production risk. Unlike most other entrepreneurs, agricultural producers cannot predict with certainty the amount of output their production process will yield, due to external factors such as weather, pests, and diseases. Agricultural producers can also be hindered by adverse events during harvesting or collecting that may result in production losses. In discussing how to design appropriate risk management policies, it is useful to understand strategies and mechanisms employed by producers to deal with risk, including the distinction between informal and formal risk management mechanisms and between ex-ante and ex-post strategies. The-ex ante or ex-post classification identifies the time in which the response to risk takes place: ex-ante responses take place before the potential harming event; ex post responses take thereafter. Ex-ante informal strategies are characterized by diversification of income sources and choice of agricultural production strategy. One strategy producers employ is risk avoidance. Extreme poverty, in many cases, makes producers very risk-averse, pushing them to avoid high-risk activities, even though the income gains to be generated might be far greater than those gotten through less risky choices. This inability to accept and manage risk respectively reflected in the inability to accumulate and retain wealth is sometimes referred to as the "the poverty trap" (World Bank 2001).

According to Clarkson *et al*., (2001), there are six requirements that must be met if rainfed farmers are to manage risks related to climate extremes, variability and change. These include:

- Awareness that weather and climate extremes, variability and change will impact on farm operations
- Understanding of weather and climate processes, including the causes of climate variability and change
- Historical knowledge of weather extremes and climate variability for the location of the farm operations
- Analytical tools to describe the weather extremes and climate variability
- Forecasting tools or access to early warning and forecast conditions, to give advance notice of likely extreme events and seasonal anomalies
- Ability to apply the warnings and forecasts in decision-making

Agriculture Insurance Company of India Ltd. (AIC)

Agriculture Insurance, including livestock insurance has been practiced in the country for over 25 years. Prior to 2002-03 General Insurance Corporation of India (GIC) was implementing National Agricultural Insurance Scheme (NAIS**)**. Recognizing the necessity for a focused development of crop insurance program in the country and an exclusive organization to carry it forward, Government created an exclusive organization - Agriculture Insurance Company of India Limited (AIC) on 20th December 2002 (www.aicofindia.org). AIC commenced business from 1st April 2003. AIC introduced rainfall insurance known as 'Varsha Bima' during the 2004 South-West Monsoon period. Varsha Bima (Varsha Bima covers anticipated shortfall in crop yield on account of deficit rainfall. Varsha Bima is voluntary for all classes of cultivators who stand to lose financially upon adverse incidence of rainfall can take insurance under the scheme. Initially Varsha Bima is meant for cultivators for whom National Agricultural Insurance Scheme (NAIS) is voluntary) provided for five different options suiting varied requirements of farming community. These are – (i) seasonal rainfall insurance based on aggregate rainfall from June to September, (ii) sowing failure insurance based on rainfall between 15th June and 15th August, (iii) rainfall distribution insurance with weights assigned to different weeks between June and September, (iv) agronomic index constructed on the basis of water requirement of crops at different pheno-phases and (v) catastrophe option, covering extremely adverse deviations of 50 percent & above in rainfall during the season. Varsha Bima has been piloted in 20 rain gauge areas spread over Andhra Pradesh, Karnataka, Rajasthan and Uttar Pradesh. During 2005, Varsha Bima was fine-tuned and extended to 120 locations in 10 States during *kharif* 2005, and further to 150 locations in 15 States during *kharif* 2006 AIC also introduced weather insurance pilots on wheat insurance, mango insurance, and coffee insurance during 2005-06, and is looking ahead for expansion. Thanks to the sustained efforts and launch of innovative insurance products in the past 6 to 7 years, the number of farmers and the cropped area covered under crop insurance has seen spectacular growth. For the year 2009-10 as many as 27 million farmers growing crops on over 38 million hectares were insured under various crop insurance programs of AIC. The numbers seem very impressive, yet a great majority of farmers who actually need insurance protection are still outside its purview.

Crop Insurance

The idea of crop insurance emerged in India during the early part of the twentieth century. Yet it was not operated in a big way till recent years. J.S. Chakravarti proposed a rain insurance scheme for the Mysore State and for India as a whole with view to insuring farmers against drought during 1920s. Crop insurance received more attention after India's independence in 1947. The subject as discussed in 1947 by the Central Legislature and the then Minister of Food and Agriculture, Dr. Rajendra Prasad gave an assurance that the government would examine the possibility of crop and cattle insurance. In October 1965 the Government of India

decided to introduce a Crop Insurance Bill and a Model Scheme of Crop Insurance in order to enable the States to introduce, if they so desire, crop insurance. In 1970 the draft Bill and the Model Scheme were referred to an Expert Committee headed by Dr. Dharm Narain. Different experiments on crop insurance on a limited, ad-hoc and scattered scale started from 1972-73. The first crop insurance program was on H-4 cotton in Gujarat. All such programs, however, resulted in considerable financial losses. The program(s) covered 3110 farmers for a premium of Rs. 4, 54,000 and paid claims of Rs. 3.79 millions. It was realized that programs based on the individual farm approach would not be viable in the country. Obviously, "individual farm approach" would reflect crop losses on realistic basis and hence, most desirable, but, in Indian conditions, implementing a crop insurance scheme at "individual farm unit level" is beset with problems, such as:
(i) Non availability of past record of land surveys, ownership, tenancy and yields at individual farm level (ii) Large number of farm holdings (nearly 116 millions) with small farm holding size (country average of 1.41 hectares) (iii) Remoteness of villages and inaccessibility of farm-holdings (iv) Large variety of crops, varied agro-climatic conditions and package of practices (v) Simultaneous harvesting of crops all over the country (vi) Effort required in collection of small amount of premium from large no. of farmers (vii) Prohibitive cost of manpower and infrastructure

Weather Insurance

As the name suggest, weather insurance is an insurance coverage against the vagaries of weather. Many agrarian economies owe their strength to favourable weather parameters, such as rainfall, temperature, relative humidity etc. Around sixty five percent of Indian agriculture is heavily dependent on rainfall, and, therefore, is extremely weather sensitive. Many agricultural inputs such as soil, seeds, fertilizer, management practices etc. contribute to productivity. However, weather, particularly rainfall has overriding importance over all other inputs. The reason is simple - without proper rainfall, the contributory value of all the other inputs diminishes substantially. An analysis of Indian Crop Insurance Program between 1985 and 2003 reveals that rainfall accounted for nearly 95 percent claims – 85 percent because of deficit rainfall and 10 percent because of excess rainfall (AIC, 2006). Reducing vulnerability to weather in developing countries may very well be the most critical challenge facing development in the new millennium. One of the most obvious applications of weather risk management products, weather insurance or weather derivatives. Weather impacts on many aspects of the agricultural supply and demand chain. From the supply side, weather risk management can help to control both production risk and quality risk. Weather events like warmer than normal winter or a cooler than normal summer can impact all sorts of companies like utilities, food and agricultural groups and even retailers.The basic idea of weather insurance is to estimate the percentage deviation in crop output due to adverse deviations in weather conditions. There are statistical techniques to workout the relationships between crop output and weather parameters.

Advantages of Weather Insurance over Traditional Crop Insurance

There are many shortcomings in the traditional crop insurance. The important ones are: (a) adverse selection (b) multiple agencies and their huge administrative cost (c) lack of reliable methodology for estimating and reporting crop yields (d) delays in settlement of claims (f) program limited to growers (farmers). Majority of these shortcomings could be overcome in the weather insurance, as follows:
(i) Trigger events (like rainfall) can be independently verified & measured.

(ii) Compared to yield based insurance, weather insurance is inexpensive to operate. Since very few agencies would be involved in implementation, the aggregate administrative cost would be far lower.
(iii) Unlike traditional crop insurance where claim settlement can take up to a year, quick payouts in private weather insurance contracts can improve recovery times and thus enhance coping capacity.
(iv) Scientific way of designing product and transparency.

(v) Individual farmers are generally unable to influence the weather index value.

Weather-Index

Index-based weather risk insurance contracts in agriculture have emerged as an alternative to traditional crop insurance. These are linked to the underlying weather risk defined as an index based on historical data (for example, for rainfall, temperature, snow, etc.) rather than the extent of loss (for example, crop yield loss). Weather insurance is a creative product that can be used for situations ranging from sales promotions to income stabilization, unlike regular insurance, which would only cover physical damage, weather insurance protects against additional expenses or loss of profit from a specific weather event. Insurance generally pays based on actual damages, while weather insurance pay based on the difference between a negotiated "strike price" and the actual weather (or the total of weather related index). As the weather index is objectively measured and is the same for all farmers, the problem of adverse selection is minimized. Weather-indexed insurance can help farmers protect their overall income rather than the yield of a specific crop, improve their risk profile enhancing access to bank credit, and hence reduce overall vulnerability. Some of pilot schemes and delivery models operated in India are:

1. ICICI Lombard pilot scheme for groundnut in Andhra Pradesh

2. KBS pilot scheme for soya farmers in Ujjain

3. Rajasthan government insurance for orange crop

4. IFFCO-TOKIO monsoon insurance

5. AIC Varsha Bima Yojana (rainfall insurance scheme)

6. AIC Sookha Suraksha Kavach (drought protection shield)

7. AIC coffee rainfall index and area yield insurance

8. ICICI Lombard loan portfolio insurance

Weather Insurance Pilots in India

ICICI-Lombard was the first general insurance company in India to introduce rainfall insurance pilot based on a 'composite rainfall index' in 2003. It implemented a pilot project in Mahabubnagar district of Andhra Pradesh for groundnut and castor. Though participation was limited, it held out valuable lessons for future programs. The rainfall index insurance and other weather-based insurances have since been extended to other areas and crops beginning with *kharif* 2004 season.

IFFCO-Tokio General Insurance Company (ITGI) piloted rainfall insurance by the name – 'Baarish Bima' during 2004 in nine districts of Andhra Pradesh, Karnataka, Gujarat & Maharashtra. The product is based on rainfall index compensating farmers for deficit rainfall. The policy pays for deviations in actual rainfall exceeding 30 percent. The claims are paid on graded scale, with 100 percent claims payable when adverse deviation in rainfall reaches 90 percent. This pilot again is expanded to more crops and areas after *kharif* 2004 season. After analysing the impact that temperature has on wheat cultivation, ICICI Lombard had designed a weather insurance product for wheat cultivators which addresses the dual risks of extreme temperature fluctuations and unseasonable rainfall

Table.1. Example for the Weather insurance product for wheat

Time period	**Jan-Mar**	**Mar-Apr**
Stage	Grain filling stage	Harvesting phase
Risk	Extreme temperature fluctuations	Unseasonal rainfall
Weather index	Deviation in fortnightly average Tmin and Tmax on higher side from benchmark	Max. rainfall on any single day

Program evolution at BASIX insurance reported that number of policies are increasing under weather insurance scheme, which endorses the willingness of farmers to take the weather insurance policy to minimize or mitigate the weather related risk (Table 2).

Table.2. Number of weather insurance policies taken by farmers since 2003

Year	Number of policies	No. of States / Stations / District
2003	230	1 State (1 Station in Andhra Pradesh)
2004	427	1 State (3 districts in Andhra Pradesh)
2005	6,703	6 States
2006	11,500	7 States (50 Stations)
2007	4,545	7 States (45 Stations)
2008	10,600	8 States

(Source: Erin Bryla Tressler, World Bank and Michael Mbaka, FSD Kenya, 2009)

Conclusion

In India around 61 % of cultivable area is under rainfed cultivation, which is most vulnerable to vagaries of weather. Economic status of farmers of this region is very poor and the ability to overcome the crop failure due to adverse weather events is abysmal. Weather insurance will continue to be the dominant insurance concept as the coming years will experience more frequent extreme weather events like heavy rains, droughts heat and cold waves etc. Food security and weather risk management are inextricably linked: weather risk management or the lack of it determines the level of systematic risk in the food security system. At the farm level, weather based index insurance allows for more stable income streams and could thus be a way to protect people's livelihood and improve their access to finance. Weather based insurance is an upcoming strategy that has proven its worth in places such as India and it is important that it has given the attention as it deserves to improve the food securities of communities especially the resource poor. The lack of historical data is more difficult to overcome, presenting a real obstacle to scaling up the weather insurance program. Finally, climate change needs to be treated as a major economic and social risk to national economies, not just as a long-term environmental problem.

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