RAINFED AGRICULTURE IN INDIA: ISSUES IN TECHNOLOGY DEVELOPMENT AND TRANSFER

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Abstract

Indian economy is mainly dependent on agriculture, which contributes 21 per cent of the country's GDP and 60 per cent of the employment. Rainfed agriculture occupies 67 percent net sown area, contributing 44 percent of food grains and supporting 40 percent of the population. In view of the growing demand for food grains in the country, there is a need to increase the productivity of rainfed areas from the current 1 t ha^{-1} to 2 t ha^{-1} in the next two decades. The quality of natural resources in the rainfed ecosystem is gradually declining due to over exploitation. Rainfed areas suffer from bio-physical and socio economic constraints affecting the productivity of crops and livestock. In this context a number of economically viable rainfed technologies have been discussed. These include soil and rainwater conservation measures, efficient crops and cropping systems matching to the growing season, suitable implements for timely sowing and saving of labour, integrated nutrient and pest management (INM and IPM). To provide stability to farm income during drought and to utilize the marginal lands, different alternative land use systems like silvipasture, rainfed horticulture and tree farming systems were evolved and demonstrated on watershed basis. Integration of livestock with arable farming systems and incorporation of indigenous knowledge in farming systems perspective are also discussed. Formation of self help groups, use of innovative extension tools like portable rainfall simulators and focus group discussions to help for quick spread of the rainfed technologies in the farmers' fields are highlighted. The farming systems approach in rainfed agriculture not only helps in addressing income and employment problems but also ensures food security.

Introduction

The Indian economy is mainly dependent on agriculture, which contributes 21percent of country's capital GDP and 60 percent of employment potential. India made rapid strides in food production during last three decades culminating in self-sufficiency and surplus production. However, feeding the ever-increasing population through the next millennium remains an uphill task. The country will have to feed about 1.3 billion people by the year 2020 requiring 5-6 mt of additional feed grains every year. Besides, the problem of poverty and malnutrition have their own implication to national food security. Over 70 percent of Indian population, which is predominantly rural, do not have proper access to food and non-food commodities due to poor employment and infrastructure facilities. This reminds all those concerned with the country's food security of the daunting task ahead in order to ensure access to food to the growing population. Rainfed agriculture occupies 67 percent of net sown area, contributing 44 percent of food grain production and supporting 40 percent of the population. Even after realization of full irrigation potential of the country, 50 percent of net sown area will continue as rainfed (CRIDA, 1997).

At present 95 percent of area under coarse cereals, 91 percent under pulses. 80 percent under oilseeds, 65 percent under cotton and 53 percent under rice is rainfed (Government of India, 1994). Livestock forms an integral part of rainfed ecosystem and two out of every three animals are thriving in these regions. These areas are spread-out throughout the length and breadth of the country with semi-arid to sub-humid environments, shallow textured light soils to deep textured black and alluvial soils with varied effective crop growing periods from 90 to 180 days.

Scenario of food demand and resources

The food grain requirement of the country is 243 mt by the year 2007-08, out of which food demand could be about 104 mt of rice, 84.3 mt of wheat, 34.4 mt of coarse grains and 21.5 mt of pulses, 9.5 mt of oilseeds and 119.5 m t of milk and 110.7 mt of vegetables and for fruits 70.5 mt. The food grain requirements have been projected for 2025 at 308 mt with low growth population of 1286 million. But at higher population growth scenario(1333 million), the projected food grain production is 320 mt by 2025 (Kumar et al,2005).More than the calories, ensuring protein security will become an important issue in view of the predominantly vegetarian habits of the populace and the dwindling availability of vegetable (pulses) proteins whose current supply is about 25 g $head^{-1}$ day^{-1} against the minimum dietary need of about 70 g.

The agriculture production increased from 50 mt to over 200 mt, between 1950-2000, thanks to green revolution. This, however, had its own costs in terms of degradation of land and water resources, loss of plant biodiversity, shift of agricultural land to non-agricultural uses, polluted environment, widening gap between the rich and the poor. Thus, physical access to food was the most important food security challenge in the past but economic and access to food has now become the most important cause of hunger and ecological access to food might become the most important concern in the next millennium owing to the damage now being done to land, water, flora, fauna and atmosphere.

Shrinking of natural resources

The per capita availability of agricultural land in India was 0.46 hectares in 1951 which decreased to 0.15 hectares in 2000 as against the global average of 0.6 ha. Number of persons per hectare of net-cropped area was 3 in 1951, 6.5 in 2000 and is estimated at 8 persons in 2025. This situation of rapidly declining land to man ratio is likely to worsen further owing to competitive demand for food, fibre, fuel, fodder, timber and developmental activities such as urbanization and industrialization, special economic zones,mining, road construction and reservoirs etc.

Constraints of production in rainfed areas

The rainfed lands suffer from a number of biophysical and socio-economic constraints which affect productivity of crops and livestock. These include low and erratic rainfall, land degradation and poor productivity (Abrol and Katyal, 1994), low level of input use and technology adoption, low draft power availability (Mayande and Katyal, 1996), inadequate fodder availability low productive livestock (Singh, 1997), and resource poor farmers and inadequate credit availability.

Strategies for Sustained Food Production in Rainfed Region

Identification of viable rainfed technologies

A number of economically viable rainfed technologies have been developed over the years in the country to address the problems of food production in rainfed agriculture through CRIDA and its network centresfor the last three decades. These technologies have been evolved after refining them in farmers' field through Operational Research Projects, Institute Village Linkage Program (IVLP) and farm science centres. These include simple practices like off-season tillage in rainfed Alfisols and related soils for better moisture conservation and weed control. Farmers in Operational Research Project (ORP) areas of Hyderabad adopted this practice in sorghum and castor and realized yield advantage by 40 percent over traditional practice. Lack of adequate draft power with many small farmers, however, is one of the major constraints to popularize this practice. Custom hiring of tractor is effective solution of farm mechanization on these lands.

Soil and rain water conservation techniques

Efficient conservation of rainwater is the central issue in successful dryland farming. Extensive trials conducted by the soil conservation and dryland research centres have led to the identification of a number of inter-terrace land treatments besides contour and graded bunds (Sharma et al., 1982). These techniques are location specific and the benefits from their adoption are highly variable depending on the rainfall intensity, slope and texture of the soil besides the prevailing crop/cropping system. (Katyal and Das, 1993).

Farmers have not widely adopted mechanical measures like contour bunds, graded bunds, grassing of waterways and construction of farm ponds without the government support due to financial constraints. However, studies at Hyderabad, Bangalore and Anantapur revealed that more than 80 percent farmers follow simple conservation measures like sowing across the slope, opening of dead furrows and key line cultivation. The yield improvement by adoption of soil and water conservation measures vary between 12 and 20 percent which are at times not convincing enough to farmers. However, cumulative effects are significantly visible at some locations. Since such measures help in long-term conservation of resources, these are implemented through the Government of India or the respective State Government sponsored watershed management programmes.

Timely planting of crops

Timely sowing and precision are essential for getting good plant stand, higher yield and optimum utilization of rainfall and reduction in the incidence of pests and diseases. A number of demonstrations have been taken up in farmers fields through ORPs, KVKs and IVLP programmes in different rainfed regions of the country .In case of sorghum and castor in farmers fields of Hyderabad , a fifteen day delay in sowing led to reduction of 300 and 850 kg/ha compared to normal sowing . Inadequate availability of farm implements and draft are major constraints. However, seeding and interculture experiments developed by CRIDA and AICRPDA centres helped in overcoming the constraints to some extent.

Adoption of improved crop varieties

A number of improved varieties and hybrids were evaluated in the farmers fields to identify suitable ones for matching growing periods for inter and sequence rainfed cropping systems. For example, farmers gained additional benefit ranging from Rs. 2000-4000/ha by adopting improved varieties of sorghum, castor and sunflower in Alfisols of Hyderabad.

Efficient crops and cropping systems

To achieve appropriate land use, efficient inters and sequence-cropping systems were recommended based on soil type, rainfall and length of growing seasons. The studies at Hyderabad indicated only 25 percent farmers adopted 2:1 ratio of sorghum-pigeonpea. Whereas 45 percent of farmers adopted the finger millet + pigeonpea system (8:1) ratio in Alfisols of Karnataka and maize + soybean system (2:2) was accepted by Ranchi farmers. Groundnut + pigeonpea (7:1) was widely accepted by the farmers in Rayalseema of Andhra Pradesh. Some of the constraints for wider adoption by the farming communities are preference for fodder genotypes in cereals rather than grains for feed to live stock, lack of suitable farm implements to seed in different ratios, delay in planting of kharif for double cropping systems. These have to be refined under on-farm situations for greater acceptance by the farmers

Farm implements

Proper tillage and precise placement of seed and fertilizers in the moist zone are most critical to for successful crop establishment in drylands. Since the sowing of crops must be completed in a short span of time, use of appropriate implements is necessary to cover large area before the seed zone dries out. Suitable implements have been recommended for various locations to meet this requirement. These are designed to suit the soil type, crop and the draught power availability. In many cases, the existing local implement used by the farmers have been improved to increase their working efficiency (Gupta and Sriram, 1987).

Studies at CRIDA in farmers' fields of Telangana indicated that use of the drill plough for sowing of castor and sorghum crops showed no variation in yields of the crops and plant as compared to farmers practice resulted 1 ½ times more coverage compared to farmers' method of seeding . Two labourers who are required for placement of seed and fertilizer in farmers methodcan be saved with the drill plough. Thus a saving of Rs. 187/ha is possible wit a drill plough compared to the traditional plough and plant system.

Nutrient management

Fertilizer recommendations in rainfed crop production have been made primarily for NPK along with the conjunctive use of chemical, organic and bio-fertilizer (Rao and Das, 1982). Inclusion of legumes in cropping systems can supplement fertilizer N to the extent of about 20 kg N per ha. Conjunctive use of fertilizer N with FYM, croppings of luecaena and gliricidia help in reducing the requirement of fertilizer by 50 percent (Reddy et al., 1996).

Integrated pest management (IPM)

Pests and deceases constitutes a major constraint to increased food production. Crop losses due to pest attack range from 10-30 percent depending on the crop and environment. Complete crop failure may occur in case of serious attack. Indiscriminate use of the pesticides in rainfed crops will lead to harmful side effects such as direct toxically to the applicator or consumer, development of strains or pests resistant to pesticides, resurgence of pest species, outbreak of secondary pesticides, destruction of non-target organisms such as parasites and predators and accumulation of harmful residues of food products. Integrated pest management is one of the alternatives for the chemicals used for pest management. IPM encourages the most comfortable and ecologically sound combination of available pest suppression techniques and to keep the pest population below economic threshold. Easily adaptable and economically viable integrated pest management strategies have been developed for the control of major pest in rainfed crops like cotton and pulses.

Alternate Land use Systems

Despite evolving a number of production technologies, arable cropping in drylands continues to suffer from instability due to aberrant weather. To provide stability to farm income and also utilize the marginal lands for production of fodder, fuel wood and fibre, a number of alternative land use systems were evolved based on location specific experimentation and cafeteria studies (Singh, 1988). In addition to the above general guidelines, specific experiments have been carried out to develop land use practices for different categories of soils across the centres integrating annual crops with the perennial component in order to utilize the off-season rainfall (Katyal et al., 1994). Different alternate land use systems include agri-silviculture, silvi-pasture, agri-horticulture, alley cropping etc.

Integration of live stock with rainfed farming systems

Live stock is treated as a part of farming system in rainfed agriculture in India. The soil, plant, animal cycle is the basis for all feed used by the animals. The livestock in the rainfed regions are weak. Farmers in this area often sell their cattle due to the scarcity of fodder. In India the land holdings are being reduced with increased population pressure. Hence, land not suitable for agriculture has to be diverted for raising fodder need of animals through the appropriate alternate land use system such as improved pasture, silvipasture, hortipasture and tree techniques.

Integration of the technologies through watershed approaches

The concept of watershed is important in efficient management of water resources. As the entire process of agricultural development depends upon the status of water resources, the watershed with distinct hydrological boundary is considered ideal for taking up a development programme. In brief, planning and designing of all soil conservation structures are carried out considering the peak runoff. In this context, the watershed concept is of practical significance. Also, the entire development needs are to be taken up on topographic considerations from ridge to valley.

Resource Conservation Measures

Details about conservation measures adopted in cultivated lands have been delineated by Katyal et al., (1995) and Sharma and Mishra (1995). Based on the nature and type of barriers and their cost, the conservation measures in arable lands can be divided into three categories: (i) Hardware treatments (ii) Medium software treatments and (iii) Software treatments.

Farming system approach

Of late, it has been increasingly recognized that unlike irrigated areas, it is difficult to develop profitable technologies for heterogeneous agro-ecological and socio-economic conditions of small holders in arid and semi-arid regions (Osten et al., 1989). Since, the problems are complex ,addressing only a component of the farming system, e.g crop variety, fertilizer use or even crop husbandry *per se* is not expected to bring about a significant increase in the productivity as witnessed in irrigated areas. The extension strategy should be such as to match this challenge. The farming systems perspective, dovetailed on watershed approach therefore can be the appropriate management strategy for such regions (Chambers, 1991).

The following steps constitute the farming systems mode for research, both on-station and on-farm (Watershed)

- PRA and assessment of socio-economic conditions of people.
- Identification of ITK (indigenous technical knowledge)
- Collection of available technological knowledge on various components of the farming system – arable farming, animal husbandry, water harvesting, management of wastelands and alternate land use systems etc.
- Focus group (farmers) interaction to identify appropriate technology for different categories of farmers.
- Identification of lead farmers to function as facilitator in technology application and adoption.
- Identification of points of synergy among systems components.
- Structuring of technological components with maximum synergy.
- Phasing of program over the project period

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GHG EMISSIONS AND CARBON FOOT PRINT FOR INDIAN AGRICULTURE

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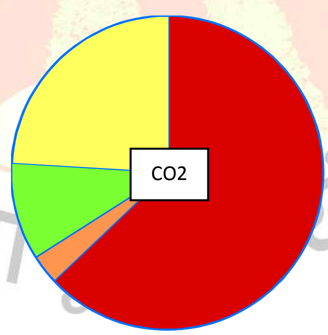
There has been a drastic increase in the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) since the industrial revolution. The atmospheric concentration of CO_2 has increased from 280 ppmv in 1750 to 379 ppmv in 2005 and is currently increasing at the rate of 1.9 ppmv/year (IPCC, 2007). Atmospheric methane (CH_4) concentration has increased from about 715 to 1774 ppbv in 2005 over the same period and is increasing at the rate of 7ppbv/year. Similarly, the atmospheric concentration of nitrous oxide (N_2O) has increased from about 270 ppbv in 1750 to 319 ppbv and increasing at the rate of 0.8 ppbv/year (IPCC, 2007). The current radiative forcing of these gases is 1.46 w/m^2 for CO_2, 0.5 w/m^2 for CH_4 and 0.15 w/m^2 for N_2O (IPCC, 2001). This anthropogenic enrichment of GHGs in the atmosphere and the cumulative radiative forcing of all GHGs have led to an increase in the average global surface temperature of 0.74^0 C since the late 19th century, with the current warming rate of 0.13^{0}C/decade (IPCC, 2007). The observed rate of increase of the global mean temperature is in excess of the critical rate of 0.1^{0}C/decade beyond which the ecosystems cannot adjust. Consequently, land-surface precipitation continues to increase at the rate of 0.5-1% /decade in much of the Northern Hemisphere especially in mid and high latitudes, and decrease in sub-tropical land areas at the rate of 0.3%/decade. These changes may decrease the soil organic carbon (SOC) pool and structural stability, increase soil's susceptibility to water runoff and erosion, and disrupt cycles of water, carbon (C), nitrogen (N), phosphorus (P), sulfur (S) and other elements, and cause adverse impacts on biomass productivity, biodiversity and the environment.

Major Green House Gas (GHGs) in Indian Agriculture (CO2 is major one, followed by methane and nitrous oxide)



Soil carbon sequestration

The term "soil C sequestration" implies removal of atmospheric CO_2 by plants and storage of fixed C as soil organic matter. The strategy is to increase SOC density in the soil, improve depth distribution of SOC and stabilize SOC by encapsulating it within stable micro-aggregates so that C is protected from microbial processes or as recalcitrant

C with long turnover time. In this context, managing agroecosystems is an important strategy for SOC/terrestrial sequestration. Agriculture is defined as an anthropogenic manipulation of C through uptake, fixation, emission and transfer of C among different pools. Thus, land use change can be an important instrument of SOC sequestration. Whereas land misuse and soil mismanagement have caused depletion of SOC with an attendant emission of CO_2 and other GHGs into the atmosphere, there is a strong case that enhancing SOC pool could substantially offset fossil fuel emissions. However, the SOC sink capacity depends on the antecedent level of SOM, climate, profile characteristics and management.

The sink capacity of SOM for atmospheric CO_2 can be greatly enhanced when degraded soils and ecosystems are restored, marginal agricultural soils are converted to a restorative land use or replanted to perennial vegetation. Incorporation of SOC into the sub-soil can increase its mean residence time (MRT). Converting agricultural land to a more natural or restorative land use essentially reverse some of the effects responsible for SOC losses that occurred upon conversion of natural to managed ecosystems. Applying ecological concepts to the management of natural resources (e.g., nutrient cycling, energy budget, soil engineering by macro invertebrates and enhanced soil biodiversity) may be an important factor to improving soil quality and SOC sequestration. The SOC concentration in the surface layer usually increases with increasing inputs of biosolids although the specific empirical relation depends on soil moisture and temperature regimes, nutrient availability (N,P,K,S), texture and climate. In addition to the quality of input, quality of biomass can also be important in determining the SOC pool.

The potential of world soils to sequester carbon

The potential of SOC sequestration is high in the world's degraded soils and ecosystems estimated at 1216 Mha, and agricultural soils estimated at 4961 Mha. These soils have lost a significant part of their original SOC pool, and have the capacity to sequester C by converting to a restorative land use and adopting recommended management practices. All other factors remaining the same, the potential of SOC sequestration is in the following order: degraded soils and desertified ecosystems>cropland>grazing lands>forest lands and permanent crops. Most croplands (1369 Mha worldwide) have lost 30-40 Mg C/ha and most degraded soils (1216 Mha) may have lost 40-60 Mg C/ha (Lal, 2000). A significant part of the historic C loss (estimated at 66-90 Pg) can be sequestered over 25-50 years. The rates of SOC sequestration on cropland range from 0.02 to 0.76 Mg C/ha/year for adopting improved systems of crop management, 0.1 to 1.3 Mg C/ha/year by converting from plow till to no till, and 0.25 to 0.5 Mg C/ha/year for rice land management (Lal, 2000). On rangeland, rates of SOC sequestration range from 0.02 to 1.3 Mg C/ha/year on restoring degraded grasslands, 0.16 to 0.50 Mg C/ha/year by systems that may improve grassland productivity, and 0.5 to 1.4 Mg C/ha/year by systems involving fire management (Follett *et al*., 2001; IPCC, 2001). The rates of SOC gain in forest lands, especially for reforestation, are generally low (Lal, 2000; Kimble *et al*., 2002).

Lal (2000) estimated the potential of world cropland soils to sequester C at the rate of 0.4-0.6 Pg C/year (excluding erosion and biofuel offset). In addition, desertification control has a potential to sequester 0.2-0.6 Pg C/year (without considering erosion control and biofuel offset). Therefore, the total potential of soil C sequestration may be 0.6-1.2 Pg C/year. In addition to decreasing the rate of enrichment of atmospheric concentration of CO_2, enhancing the SOC pool would improve soil quality and agronomic/biomass productivity. Increasing SOC pool in agricultural/degraded soils could offset emissions of CO_2 from fossil fuel combustion. With increasing population from 6 billion in 2000 to 8 billion by 2020, the necessity of food production will be more than ever before. The techniques of SOC sequestration outlined herein (e.g., conservation tillage, mulch farming, cover crops, manuring and fertilizer use, irrigation and restoration of degraded soils) are needed to meet the food demands of the growing population, with an ancillary benefit of SOC sequestration. Loss of SOC, decline in soil structure and overall degradation of the soil resources are standard features of non-sustainable land use, and these features are reserved through adoption of practices which lead to SOC sequestration.

Potential of carbon sequestration in India

Land use and soil management systems which enhance NPP and the amount of biomass returned to the soil; also accentuate the terrestrial C pool . Generic technological options for biotic and soil C sequestration include afforestation of agriculturally marginal soils, restoration of degraded ecosystems, establishment of bio-energy plantations with a large potential for biomass production, establishing perennials with a deep and prolific root system, growing species containing high cellulose and other resistant materials, and developing land use systems characterized by a high NPP. Similarly, strategies for soil C sequestration include adoption of conservation tillage and mulch farming techniques, maintenance of soil fertility, soil and water conservation, and adoption of complex rotations. The objective is to enhance soil quality.

In practical terms, the high priority lies in restoration of degraded soils and ecosystems and management of wastelands. The total potential of SOC sequestration through restoration of degraded and desertified soils in India is 10-14 Tg C yr^{-1}. The largest potential lies in restoring soil fertility, followed by desertification control and erosion control. Restoration of degraded soils and ecosystems provides an opportunity to improve the environments while off-setting fossil fuel emissions and mitigating the climate change.

Adoption of recommended soil and crop management is another option for SOC sequestration. Soil and crop management practices with enhance biomass production, add high below-ground biomass to the soil, improve soil fertility and effectively conserve soil and water, also lead to SOC sequestration. Returning crop residues, animal waste, and other biomass to soil is important to SOC sequestration but not a practical option because of alternate uses for these by-products as fodder, fuel, construction material and numerous other economic uses. Lal (2004) estimated total potential of SOC sequestration through agricultural intensification in India at 12.7 to 16.5 Tg yr^{-1}. The total potential of a SOC sequestration in India is 77.9 to 106.4 Tg yr^{-1} (92.2 ± 20.2 Tg yr^{-1}). Of this potential, 12.9% is through restoration of degraded soils, 45.6% through erosion prevention and management, 15.8% through agricultural intensification, and 25.7% through secondary carbonates.

Greenhouse gas emission from agriculture

Agriculture accounts for about 15% of the global emission of greenhouse gas (GHGs), making it the second largest source after the energy sector (63%). Because of this large contribution, continued GHG emission from agriculture will exacerbate global warming. Agriculture is responsible for emission of all three major GHGs, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). They have different life time and global warming potential (GWP) (Table 3). In particular its, CH_4 and N_2O emission account for about 50 % and 60%, respectively, of global anthropogenic emission of those GHGs. Moreover, although the CO_2 budget is almost in balance, CO_2 fluxes between agricultural lands and the atmosphere are large in both directions (120 Pg C yr^{-1}) (Denman *et al*., 2007). Part of the CO_2 efflux derives from decomposition of soil organic matter. Carbon storage in soils has been estimated to be 1500 Pg C, which is double that in the atmosphere (730 Pg C) (Prentice *et al.*, 2001). To sustain soil carbon storage, it is quantitatively important to reduce CO_2 emission from agricultural soils. Soil carbon sequestration occurs when the amount of carbon input into the land is larger than that emitted to the atmosphere. Soil carbon sequestration has been estimated to account for 89% of the total mitigation potential of agricultural GHG emission, followed by reduction of CH_4 (9%) and N_2O (2%) emission from soils (Smith *et al*., 2007).

Table 3. Global warming potential and other properties of agriculturally important greenhouse gases in the atmosphere.

GHGs	Pre-1750 concentration (ppm)	Current tropospheric concentration (ppm)	Annual increase (%)	Atmosphere life time (years)	GWP (100 years time horizons)	Increased radiative forcing (Wm^{-2})	Contribution to global warming (%)
CO_2	280.0	379.0	0.5	Variable	1	1.46	40-50
CH_4	0.715	1.740	0.8	12	23	0.50	20-25
N_2O	0.270	0.319	1.0	114	296	0.15	5-10

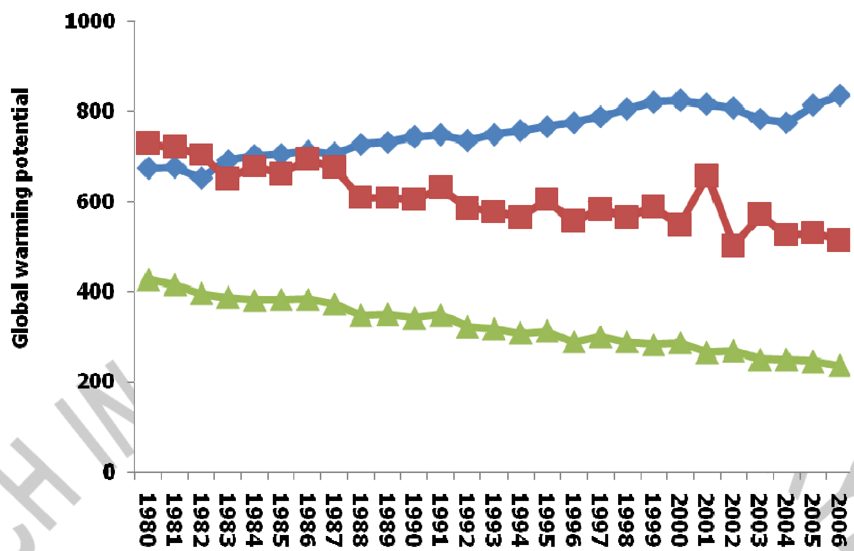


Figure Trend in GHG emission intensity in Indian agriculture (top line is GWP kg/ha; second line GWP per ton of food production)

Carbon stocks in different soil types in relation to rained production systems and climate in tropical India

Agricultural soils are among the earth's largest terrestrial reservoirs of carbon and hold potential for expanded carbon sequestration. They thus provide a prospective way for reducing atmospheric concentration of CO_2 (Lal, 2004). At the same time, this process provides other important benefits in terms of increased soil fertility and environmental quality. Due to low carbon (C) in the dryland soils, there is high potential for C sequestration (Wani et al., 2003). Low soil organic matter (SOM) in tropical soils, particularly those under the influence of arid, semi-arid and sub-humid climates, is a major factor contributing to their low productivity (Syers et al., 1996; Katyal et al., 2001). Therefore, proper management of soil organic matter is important for sustaining soil productivity, ensuring food security and protection of marginal lands (Scherr, 1999). As fertilizer input in dryland agriculture is low, mineralization of organic matter acts as a major source of plant nutrients. Maintaining or improving organic carbon levels in tropical soils is more difficult due to rapid oxidation of organic matter under prevailing high temperatures (Lal, 1997; Lal et al., 2003). However, maintaining or improving soil organic matter is a prerequisite to ensuring soil quality, productivity and sustainability.

The carbon balance of terrestrial ecosystems can be changed markedly by the impact of human activities - including deforestation, biomass burning and land use change, which results in the release trace gases that enhance the 'greenhouse effect' (Bolin, 1981; Trabalka and Reichle, 1986; IPCC, 1990; Batjes, 1996; Bhattacharya et al., 2000; Lorenz and Lal, 2005). Routinely soil surveys conducted for estimating soil organic carbon pool, consider depth of about 1m. However, the subsoil carbon sequestrating may be achieved directly by selecting plants/cultivars with deeper and thicker root systems that are high in chemical recalcitrant compounds like suberin and lignin (Wani et al., 2003; Lorenz and Lal, 2005). Information on global regional soil organic carbon (SOC) pool is limited (Eswaran et al., 1993 and Batjes, 1996). Moreover, conclusions on the effects of land use changes on soil carbon stocks are often hampered by the narrow global database available (Lorenz and Lal, 2005). The size and dynamics of carbon pools in soils of the developing world are still poorly understood (Batjes, 1996). In Indian soils, earlier studies on SOM content (Jenny and Raychaudhuri, 1960) and its stocks (Gupta and Rao, 1994) lacked wider sampling base (Bhattacharya et al., 2001). In recent times, though the role of soil organic carbon (Bhattacharya et al., 2000) and inorganic carbon (Sahrawat, 2003) have been highlighted in sequestering carbon in drylands, relatively little data is available on it. The objective of this study was to determine carbon stocks in a range of Indian soils under diverse climatic and crop production systems.

Stocks in relation to soil type

Organic, inorganic and total carbon stocks varied between and within soil types (Table 3). Vertisols and associated soils contained higher carbon stocks, followed by Inceptisols<Alfisols<Aridisols (Figure 2). In general, soil organic carbon (SOC) content was greater than inorganic carbon in Alfisols and Aridisols, while inorganic carbon was larger than organic carbon in Vertisols and Inceptisols. The SOC stocks ranged from 26.69 to 59.71 Mg ha^{-1} with a mean of 43.74 Mg ha^{-1} in Inceptisols, from 23.28 to 49.83 with a mean of 30.82 in Alfisols, from 28.60 to 95.90 Mg ha^{-1} with a mean of 46.38 Mg ha^{-1} in Vertisols and from 20.10 to 27.36 Mg ha^{-1} with a mean of 23.73 Mg ha^{-1} in Aridisols. The stabilizing effect of clay particles on soil organic matter decreased in the sequence: allophone>amorphous minerals>smectite> illite> kaolinite (Van Breemen and Feijtel, 1990). In our study, Vertisols with smectite as dominant mineral had larger organic carbon stocks than illitic Inceptisols and kaolinitic Alfisols.

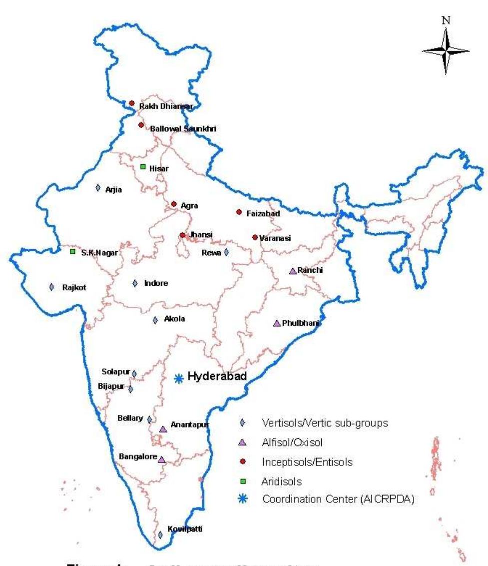


Figure 1: **Soil sampling sites**
All India Coordinated Research Project for Dryland Agriculture in India

Similarly, soil inorganic carbon (SIC) content varied widely among the soil types. Vertisols contained larger inorganic carbon followed by Inceptisols, Alfisols and Aridisols. The SIC stocks ranged from 22.30 to 135.11 Mg ha^{-1} (mean 69.08 Mg ha^{-1}) in Inceptisols, from 8.81 to 57.02 Mg ha^{-1} (mean 26.76 Mg ha^{-1}) in Alfisols, from 16.03 to 367.63 Mg ha^{-1} (mean 178.13 Mg ha^{-1}) in Vertisols and from 14.27 to 20.50 Mg ha^{-1}) (mean 17.39 Mg ha^{-1}) in Aridisols. In most of the cases, surface soil storage of organic carbon was greater than deeper layers; while the reverse was the trend in the case of SIC. Total carbon stocks (TCS) ranged from 52.11 to 192.08 Mg ha^{-1} (mean 112.82 Mg ha^{-1}) in Inceptisols, from 32.10 to 82.43 Mg ha^{-1} (mean of 57.58 Mg ha^{-1}) in Alfisols, from 44.74 to 396.23 Mg ha^{-1} (mean of 224.51 Mg ha^{-1}) for Vertisols, from 34.38 to 47.86 Mg ha^{-1} (mean of 41.12 Mg ha^{-1}) in Aridisols. Total carbon stock was also greater in Vertisols, followed by Inceptisols, Alfisols and Aridisols.

Soil carbon content mostly depends on, climate, soil type and land use (Dalal and Mayer, 1986). Wani et al. (2003) reported increased C sequestration in Vertisols with pigeonpea-based systems with improved management options (32 kg OC ha^{-1} y^{-1}) as compared to sorghum-based systems with farmer's management. The carbon concentrations reported from the Indian tropics are lower than those reported by Dalal and Mayer (1986), Dalal (1989), Murphy et al., (2002), Young et al. (2005). Significantly lower levels of organic carbon in these soils are attributed to high rates of oxidation of soil organic matter due to high temperature in tropics and frequent cultivation (Dalal and Chan, 2001; Wani et al., 2003). Young et al., (2005) reported that Vertisols with high clay content showed higher carbon stocks than other soils. Sahrawat (2003) stated that calcium carbonate is a common mineral in soils of the dry regions of the world, stretching from sub-humid to arid zones, as soils of this region are calcareous in nature. According to an estimate by the National Bureau of Soil Survey and Land Use Planning, Nagpur, India, calcareous soils occupy about 230×10^6 ha and constitute 69% of the total geographical area of India. It was further stated that soil inorganic carbon pool consists of primary inorganic carbonates or lithogenic inorganic carbonates and secondary inorganic carbonates. The reaction of atmospheric carbon dioxide (CO_2) with water (H_2O) and calcium (Ca^{2+}) in the upper horizons of the soil, leaching into the subsoil and subsequent re-precipitation results in formation of secondary carbonates and in the sequestration of atmospheric CO_2. This was the reason why deeper layers showed higher inorganic carbon than surface soils in most profiles (Sahrawat, 2003).

Stocks in relation to production system

Carbon stocks varied with production system and showed significant interaction with soil type. Organic, inorganic and total carbon stocks under each production is presented in Figure 3. Soybean-based production system (62.31 Mg C ha^{-1}) showed higher organic carbon stocks, followed by maize-based (47.57 Mg ha^{-1}) and groundnut-based (41.71 Mg ha^{-1}) systems. Pearl millet and finger millet-based systems showed lower organic carbon stocks. On the other hand, cotton system (275.3 Mg ha^{-1}) and post-rainy (rabi) sorghum production system (243.7 Mg ha^{-1}) primarily on Vertisols and associated soils, showed higher SIC while the SIC was lowest in soils under lowland rice systems (18.15 Mg ha^{-1}). Highest total carbon stocks were found under cotton based production system, followed by *rabi* sorghum-based and was lowest in pearl millet-based system. However, percent contribution of organic carbon to total carbon stock was higher under rice-based system, while the highest inorganic carbon contribution to total carbon was observed under cotton-based system (Figure 4). On a regional scale, above and below ground biomass production is probably the major determinant of the relative distribution of soil organic carbon with depth (Jobbagy and Jackson, 2000). Above-ground organic matter has probably only limited effects on SOM levels compared to below-ground organic matter as has been demonstrated by long-term residue management studies. The dominant role of root carbon in soil was also indicated by greater relative contribution of root vs. shoot tissue to the soil organic carbon pool (Rasse et al., 2004). Root to shoot ratio of corn varied from 0.21 to 0.25, of soybean (0.23) and barley (0.50). Besides root biomass, its composition also has greater impact on carbon sequestration. In general, leafy plants decompose faster than the woody plants, and leaves decompose faster than roots. The second most abundant compounds after proteins are lignins, which largely contribute to terrestrial biomass residues. These compounds exhibit a higher resistance to microbial degradation as compared to celluloses (Martin and Haider, 1986). Suberin is mostly found in root tissues and is a major contributor to soil organic matter (Nierop et al., 2003). Among dryland crops, sorghum plant litter has 4% lignin, soybean (8%), maize roots (10%), millets (9–13%), rice (11–13%) and legumes like alfalfa (6–16%) (Scheffer, 2002; Fernandez et al., 2003; Bilbro et al., 1991; Devevre and Horwath, 2000; Clement et al., 1998). Corn roots contain a wide range of fatty acids beside carbohydrates, lignin, lipids and alkyl-aromatics (Gregorich et al., 1996).

For each soil type, effect of particular production system was also examined. For Vertisols and associated soils, cotton and sorghum systems showed larger SIC stocks (Figure 5 a–b), while soybean and groundnut systems showed higher SOC. Legume-based systems on Vertisols showed higher SOC than cereal based systems in the tropics. In Inceptisols, maize-based systems showed larger inorganic as well as organic carbon content. In Alfisols, rice-based system (Ranchi and Phulbani) showed relatively higher organic carbon content while groundnut-based (Anantapur) system showed larger inorganic carbon (Figure 6 a–b). This could be due to larger carbonate deposits found in the deeper layers of the profile and frequent addition of gypsum to groundnut crop and differences in rainfall, parent base material and other management practices adapted at these locations. Under Aridisols, pearl millet-based system at SK Nagar showed higher total carbon than in Hisar.

Carbon stocks in relation to rainfall

In general, SOC stocks increased as the mean annual rainfall increased (Fig. 7). Significant correlation ($p < 0.05$) was obtained between SOC stock and mean annual rainfall ($r=0.59^*$; Figure 8). On the other hand, SIC stocks decreased with the increase in mean annual rainfall from 156.40 Mg ha^{-1} (<550 mm) to 25.97 Mg ha^{-1} (>1100 mm). As the SIC stocks were more dominant than SOC, total carbon stocks decreased with increase in mean annual rainfall from 183.79 Mg ha^{-1} in the arid environment (<550 mm) to 70.24 Mg ha^{-1} in sub-humid regions (>1100 mm). However, CEC showed significant positive correlation ($r=0.81^{**}$) while clay content in soil showed non-significant positive correlation with organic carbon stocks (Figure 9a-b). This indirectly indicates type of clay mineral with larger surface area is largely responsible for higher carbon sequestration.

Figure 7 Carbon stocks in soils under diverse rainfed production systems in relation with rainfall

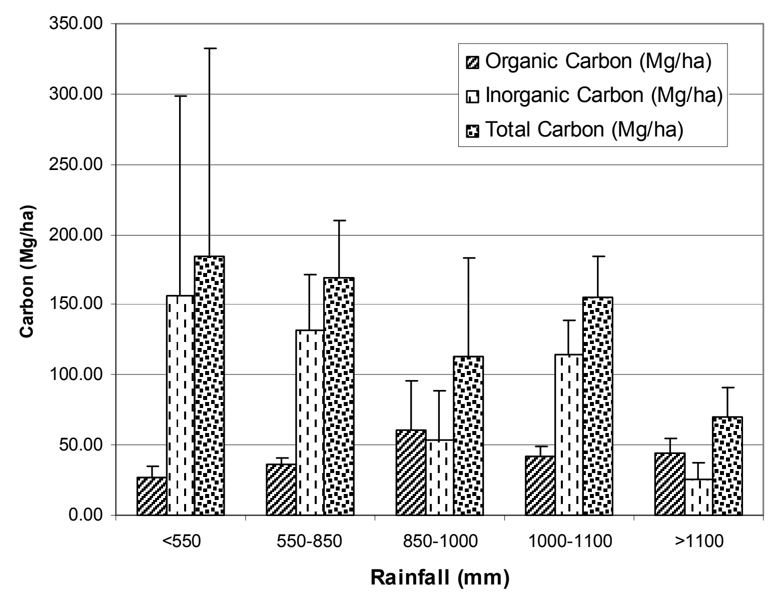
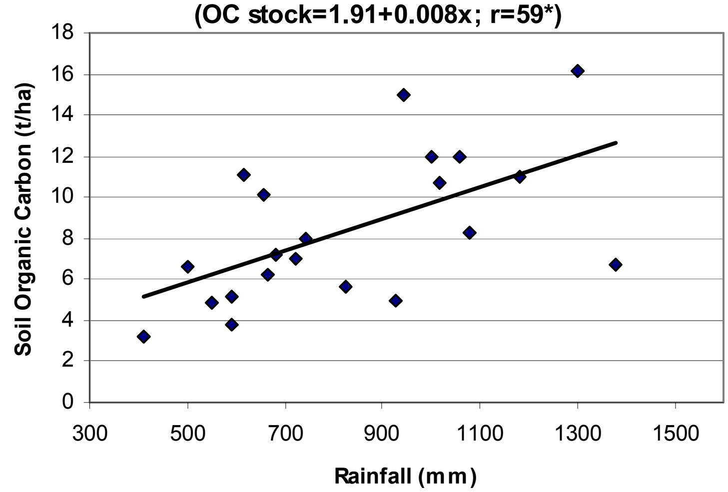


Figure 8. Relationship between mean annual rainfall (mm) and soil organic carbon in surface layer (0-15 cm) under rainfed conditions (OC stock=1.91+0.008x; r=59*)



It has been postulated that aridity in the climate is responsible for the formation of pedogenic calcium carbonate and this is a reverse process to the enhancement in soil organic carbon. Thus increase in C sequestration via soil organic carbon enhancement in the soil would induce dissolution of native calcium carbonate and the leaching of SIC would also result in carbon sequestration (Sahrawat, 2003). In the present scenario of differing climatic parameters such as temperature and annual rainfall in some areas of the country, it will continue to remain as a potential threat for carbon sequestration in tropical soils of the Indian sub-continent. Therefore, the arid climate will continue to remain as a bane for Indian agriculture because this will cause soil degradation in terms of depletion of organic carbon and formation of pedogenic $CaCO_3$ with the concomitant development of sodicity and /or salinity (Eswaran et al. 1993; Bhattacharya et al., 2000).

CONCLUSIONS

Vertisols and associated soils had relatively greater SOC stocks than other soil types while soils of less rainfall regions showed larger inorganic carbon content than soils of high rainfall regions. Amount of rainfall was significantly related with amounts of organic carbon stocks in the soils and legume- based production systems showed higher organic carbon sequestration. As soils of India are very low in organic carbon, its depletion occurs at a rapid rate due to continuous cultivation and exposing the subsoil organic matter. However, long-term manure experiments under rainfed conditions showed marginal improvements in organic carbon levels with regular additions of organic manures. But most of the dryland farmers are not in a position to add FYM or crop residue regularly in absence of their own cattle. Therefore, alternative measures like minimum tillage, green manuring, cover cropping, green leaf manuring like gliricidia, compositing the farm waste, vermicomposting the farm and household waste and inclusion of legumes in the system may be suggested having potential for improving carbon stocks in Indian soils. This could bear long-term consequences in sustaining natural resources.

CONTINGENCY CROP PLANNING FOR EXTREME WEATHER EVENTS

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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 1^{st} week of July. • Sow castor up to the last week of July. • Greengram/cowpea afterwards.
VEGETATIVE	-Drying of leaves -Wilting of plant -Soil cracking in black soils	• Blade harrowing in rows during 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

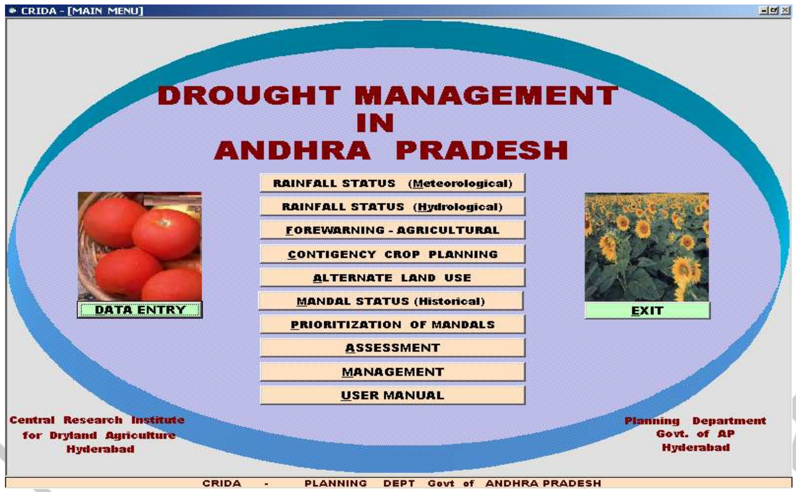
- Emphasis on oilseed and legume based intercropping systems in not so favourable tracts.
- High value (fruits, medicinal, aromatic bushes, dyes and bio-pesticides) and high-tech agriculture (drip irrigation, processing, extraction and value added products).
- Utilization of marginal and shallow lands 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.

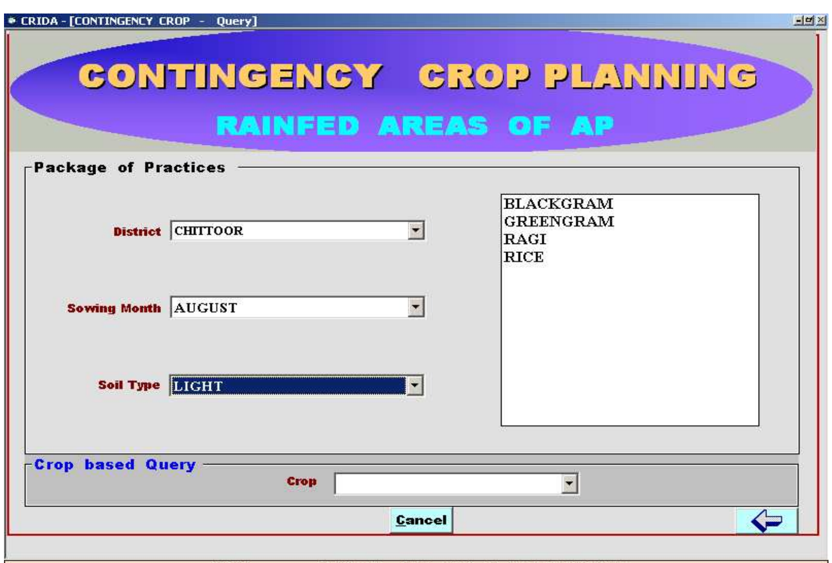


Fig. 2 Contingency crop planning (window frame)

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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CLIMATE CHANGE AND FOOD SECURITY

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Introduction

Twenty first century has brought several of the human made crisis of which climate change and food crisis are major and have adversely affecting the world's poor people. On another, the population is expected to reach 9 billion by 2050 increases food demand, with existing natural resources and limited area suitable for agriculture are added fuel to fire syndrome in the years to come and therefore, food security is expected to be more intensive. Not only food scarcity, but also malnourishment reached alarming levels in poor. Though, the longevity of the populations increased, but with unexpected, uncontrollable disease and health problems making lives at risk. From a global cultivable area of agricultural land 7,08, 495 000 m ha the food production is 24,89,302 mt and INDIA's share is 99,880 and 2,46,774 respectively (FAO 2009). The demand is expected to be at least 40% more than the present day production. Many scientists, economists and policy makers now agree that the world is facing a threat from climate warming. Though, the degree of the impact and its distribution is still debated, with reference to the vulnerable regions, non vulnerable regions and ultimate benefits or dangers in the guise of yield losses. Several of the models of climate changes and scenarios for each of the continent are studied and information for each of the continent and or regions is available, with aid from recent technological interventions in computers and information technology. The awareness created, underlying causes of hunger and malnutrition established, policy makers, institutions, general public should now act to link food security with that of economic development which needs justification. In this brief write up an attempt is made with reference to Climate change and crop adaptations features needing, modifications or technological interventions for situations like, abiotic stresses and biotic stresses and few social issues.

Climate What is it? Climate change, weather and microclimate are not the same though all of them are interrelated to each other. Among these three the former two terms are common and also their usage in the various contexts. For instance, weather is variable in a day is how hot, cold or wet a place is at a particular time i.e., day night temperature, relative humidity variations etc., which have limited or localized influence rather than large scale influences on crop yields. On the other, climate change in this present text, is the average weather of an area over time (not less than a decades) which have larger influence on various weather parameters which are consistently exhibiting a progress increase or decrease or became relatively consistent and constant (! a rarest thing to happen in nature) over time. Unlike, weather variability effects, the effects of climate change are critical as on long run, the productivity, potential of crop yields and food sustainability that gets adversely influenced. Thus, the things that decide climate are relatively different from that of weather in the sense that, how far an area from that of equator, sea, height above sea level and its wind systems. This means the position of the land and area is influenced by climate. Based on these, the world has been divided by into different climatic zones, such as polar, tundra, temperate, tropical, desert and mountains. The continents already divided into different climate zones, further changes in climate therefore are variable on crop production systems across the world. For instance, cereal crops like rice, wheat, maize are differentially influenced based on the type of abiotic stress and natural resources that are prevailing in these zones which could range from 30% reduction (rice) in middle and north Africa to 14% in sub Saharan region for the same crop. On the other hand, the wheat production would reduced to almost 50% in south asia while as low as 6% in Latin America. All these predictions are necessitated based on the current available resources that are considered to be static. Though, to a larger extent knowledge generated over the years on crop yields are identified and reduced Gaps of yield loss predictions, natural vagaries of climate being unpredictable, the capacity of natural resources that are available at a given time are most unpredictable. Therefore, we must anticipate the situation of crop yields could be far lower if, the climate change continues at the same rate.

Why Now? History Climates have changed naturally throughout the history. Currently, the human activities such as burning fossil fuels, are producing greenhouse gases that are causing global warming. The effects include ocean currents altering, ice sheets melting, sea levels rising and severe weather such as cyclones and floods becoming more common. These aberrations are abrupt rather than early or late arrival of monsoons during the prevailing weather situation at a given location. In the later case, the crop activities can be adjusted periodically based on the prediction of crop models/weather by agro- meteorologist. Under these conditions, the yield loss though unavoidable, can be partially alleviated of crop productivities and yield could be managed as in the current situation of 2009. In these crop based weather models, transpiration, a biophysical process contributes significantly for yield prediction. Thus, the models based on weather are local or regional which helps in predictions of yield attributes of a crop that is dominantly grown in that local region. On the other hand, yield predictions by global climate models, largely considers the heat balances based on the evaporation that would lead to changes in the direction of clouds, rainfall, wind, and temperatures. Therefore, universally it was agreed upon the yield losses do occur but the degree of yield losses reported are varied.

Main Contributors : Green house gases alone are contrWhat Global climate change, could adversely impact crop processes and productivity. The atmospheric concentration of carbon dioxide has increased approximately by 30% since the mid-18th century, and projections indicate that CO_2 could increase from current levels of approximately 360 ppm to between 540 and 970 ppm by the end of the 21st century. Atmospheric concentrations of other greenhouse gases (methane, tropospheric ozone, nitrous oxide, chlorofluorocarbons [CFC] etc.) have also increased as a result of anthropogenic activities resulting in increase in atmospheric temperature. The climatic elements which affect plant growth and development, hence agriculture in a wider sense, viz. CO_2 concentration, temperature, precipitation, radiation, humidity and wind speed are likely to be altered with the increased buildup of greenhouse gases in the atmosphere (Sinha, 1993). In India, the mean annual air temperature for the period 1901–1988, as represented by 73 stations, revealed warming of 0.4^0 C/100 years, which is comparable to the global trend of 0.5^0 C/100 years.

Some metabolic aspects: Since plants possessing C_3 metabolism (i.e. 95% of all plant species) are currently CO_2 limited, significant increases in growth and development could occur for a wide range of cultivated and native plant species. Different crops are expected to respond differently under changing climatic conditions. CO_2 is vital for photosynthesis, hence for plant growth. In some crop plants, the reduction in stomatal opening caused by high CO_2 results in reduced transpiration per unit leaf area while enhancing photosynthesis. Thus, water use efficiency is increased. Kimball (1983) estimated from a compilation of greenhouse and experimental studies a mean crop yield increase of 33 ± 6% for a doubling of CO_2 from 300 to 600 ppm for a range of agricultural crops.

Expected temperature increases are likely to hasten the crop maturation thereby reducing the total yield potential of the crops. However, this varies with the crop species that are being subjected to cultivation in particular zone. For instance, the optimal temperature requirement for cereals is generally within a range of 25-320C while for soybean it is relatively more (36oC) while for potato to form tubers it is 200C. Thus, several of the physiological processes that are critical at different developmental stages influenced directly by enhanced temperature regimes. On the other hand, lower temperatures, floods too are adversely influence the crop yields by indirect means such as enhanced pest, disease epidemics since, the temperatures would be favourable for faster growth rates of disease causing organisms such as fungi, viruses, and insect pests. High temperatures also would cause migration of insects and their feeding behaviour such as alternate hosts through which they could cause considerable yield losses. Similar to plants exhibiting phenological changes, insect pests too are vulnerable for such developmental changes and adaptation in either of the directions i.e. early or delaying their life cycles. Examples are pototo late blight, (Irish and US famine) brown spot of rice,(Bengal Famine), corn leaf blight (US).,raising aflatotoxins during drought weakened corn crop and was susceptible to insect pest, reduced the quality grain and wheat scab by fusarium sps reduced grain quality and also lead to health hazards on consumption. All these factors would indirectly influence the costs of production and world food trade. Apart from these, ecological factors are another concern wherein strong competitiveness can lead to insect and pest resistances as well as damage to pollinators and friendly insects such as mosquito predators.

Way Out : Two types of adaptation to climate change are envisaged. One is natural or autonomous adaptation which refers to the address the problems at farm level based on own initiatives, creativity and past experience to over come the effects of climate change. These include, changing sowing times, store rain well water inter cropping etc., This natural wise strategy resolves the issue of climate change to a limited area, period and a short term method. The second is planned or preparedness adaptation where in application of new technologies such as growing climate resilience varieties, natural resource management techniques, developing requisite infrastructure such as watersheds, irrigation facilities, newer varieties by genetic manipulation and utilizing bio diversity of wild resources, etc., Also, developing multi disciplinary adaptation capacity, accessing information and human resource development are strategic way out options. However, for the success of way out there is a need to collect the precise information on weather using remote sensing, GIS tools and spatial resolution for policy makers (climate change) and temporal for current data and its availability to farmers (climate variability) at community level are important and needs integration. Human resources for data interpretation need training and expertise to act as shock absorbers and drivers to focus on multiple arrays of tackling the situation not only for climate resilience but also for developing the socio-economic fronts.

GREEN HOUSE GAS EMISSIONS AND CARBON FINANCE MECHANISMS IN AGRICULTURE

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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^{0}C with accelerated warming of 0.21^{o}C 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. Jvothi. 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 black	3.5	5-8
Dicanthium annulatum	500-1000	Sandy loam ,Clay silty loam	2.5	4-7

Heteropogon contortus	600-1000	Mixed red and black,red soils	3.0	2-3
Chrysopogon fulvus	600-1000	Hilly areas and crevices of rocks	3.5	4-7
Iseilema laxum	700-1000	Low lying,clayey black soils.	3.0	4-6
Arid				
Lasiurus sindicus	100-150	Sandy	3.5	8-14
Cenchrus ciliaris	150-300	Sandy	4.0	8-9
Cenchrus setigerus	150-300	Sandy	3.0	8-9
Panicum antidotale	200-600	Sandy	3.0	9-14

Table: 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	Banarasi, Krishna, NA-10

	Kanchan, NA-7, NA-6	
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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RESPONSE OF RAINFED CROPS TO CLIMATE CHANGE

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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 21st century.

Carbon dioxide is the basic raw material that plants use in photosynthesis to convert solar energy into food, fiber, and other forms of biomass. 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.

TRENDS IN CLIMATE BASED PEST FORECASTING SYSTEMS

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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.

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.

[redacted]

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 >2^0C 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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USE OF AGRO ADVISORIES AT FIELD LEVEL DURING WEATHER RELATED CONTINGENCY

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1.0 Introduction

In Andhra Pradesh, the (7.8 million hectare) *kharif* crops depend mainly on summer monsoon rains. Yields are understood to vary in response to the variable timing of the commencement and conclusion of the rainy season, prolonged dry spells within the rainy season, and flood damage to crops from events of high rainfall intensity. Current vulnerabilities to climate are strongly correlated with climate variability, in particular precipitation variability. These vulnerabilities are largest in semi-arid and arid low-income countries, where precipitation and stream flow are concentrated over a few months, and where year-to-year variations are high. The number of hydro-meteorological hazards (droughts, floods, wind storms etc.,) have significantly increased in recent decades from 195 (1987-1998 average) to 365 (2000-2006 average), indicating that climate-related disaster risk is increasing. Extreme climate events (droughts, floods, cyclones) regularly affect multiple sectors including agriculture, food security, water resources and health. More than 70% of farms in AP are small and marginal and are thus vulnerable to climate variability. Some factors, such as increased temperatures and longer drought periods, are likely to depress production. Managing climate risks is a major challenge of today and for the future.

Agromet advisories are one such means to pass on climate risk management information to mitigate the losses incurred by farmers. Unfavorable weather conditions like delayed monsoon, intermittent dry spells, prolonged droughts and extreme weather events like heat waves, floods and cyclones etc., are major concerns to the Indian farmers. The advance prediction of these weather events, and dissemination of contingent crop planning measures on real time basis using modem information and communication technologies would help the farmer immensely in reducing the crop losses under aberrant weather situations and also taking-up suitable contingency measures. Farmers who incorporate the forecast products in their climate risk management are getting benefited.

2.0 Agromet Advisories

Despite considerable technological advances, Indian agriculture is still subject to vagaries of the weather. The short-range forecasts (24 hours in advance with an outlay for 48 hours), though useful for certain applications, are inadequate for planning weather-based agricultural practices because, longer reaction time is required for implementing the precautionary measures. Information on impending weather 3-10 days in advance is vital for effectiveness of modem farming practices like sowing of weather sensitive high yielding varieties, need based application of fertilizers, pesticides, insecticides, irrigation and harvest planning. Therefore, medium range forecasts are needed to provide sufficient lead-time for the farmers to plan their agricultural operations based on weather based agro-advisories and thereby enhance agricultural production.

To extend the period of forecast for 3-7 days *i.e.,* medium range weather forecast for the benefit of farming community, the India Meteorological Department has been issuing district level medium range forecast to the 127 agrometeorological field units in the country. Under this project apart from weather forecasts, agro-advisories based on weather are also being issued for the benefit of farming community by the AMFU's.

Advisories are farmers bulletin, which take into account the prevailing weather, soil and crop condition, weather forecasts and, suggest measures to minimize the losses (crop or livestock) and effective utilization of inputs (irrigation, fertilizers, pesticides etc.,) and also suggest contingent crop planning.

Presently, the IMD will provide district specific medium range weather forecast valid for coming 4 days on every Tuesday and Friday. Based on the forecast received from IMD the nodal officer or his associate will prepare the final forecast on quantitative rainfall, tendency in maximum and minimum temperatures, wind speed and direction, cloud amount and relative humidity valid for next 4 days beginning 8.30 a.m on Tuesday, by looking into the local conditions.

3.0 Agro-Advisory Services at Angrau

Initially to implement the programme envisaged above, the Department of Science and Technology has sanctioned a project for A.N.G.R.A.U., on "Experimental Agromet Advisory Services for Southern Telangana region of Andhra Pradesh" Rajendranagar, Hyderabad during the year 1993.

3.1 Mode of Preparation on Agro-Advisory Bulletins (AAB)

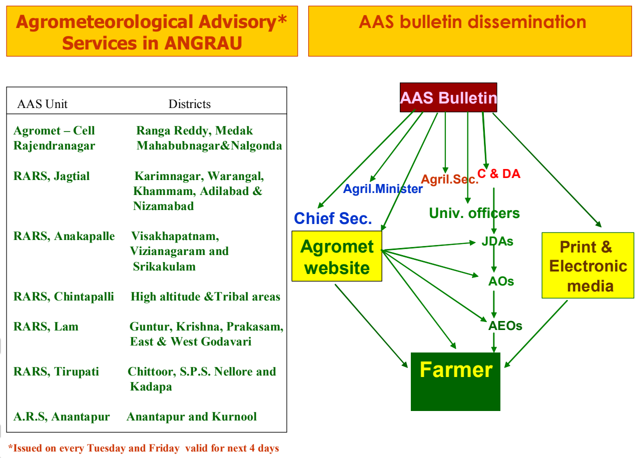
The Agrometeorological Field Unit (AMFU) unit, with the Agrometeorologist as the Principal Nodal Officer, for ANGRAU is functioning at Agricultural Research Institute, Rajendranagar. An expert committee (panel of subject matter specialists) drawn from different disciplines including livestock and poultry has been constituted to help in preparation of Agro-advisories based on impending weather. Taking this into cognizance and considering the location specific crop information, diagnostic visits of the Scientists, DAATT centres, Rythu chaitanya yaathralu (Farmer Awareness Programmes), Rythu polallo sasthravetalu (Scientists in Farmers Fields) etc., the expert committee prepares the agroadvisory bulletin.

On the basis of local agro-meteorological and farming information and the weather forecasts from IMD, the subject matter specialists discuss about the options and consequent effects, and then decide the advice for the action by the farmers in respect of the items related to their expertise. All these together constitute the advisory, which must be as simple as possible in terms of the language and easily understandable by the farmers.

3.2 Dissemination of AAB

Currently, in Andhra Pradesh, agro-advisories are being issued for six agro-climatic zones *viz.,* Anakapalli for North Coastal Zone, Lam for Krishna Godavari Zone, Anantapur for Scarce Rainfall Zone, Tirupati for Southern Zone, Jagtial for Northern

Telangana Zone, Rajendranagar for Southern Telangana Zone. A composite bulletin covering all the regions of state of AP is also being issued both in English as well as local language (Telugu).



4.0 Content of Agro-Advisories

The content of these advisories varies with location, season, weather, crop condition and local management practices. This may include:

•Crop wise farm management information tailored to weather sensitive agricultural practices like field preparation, time of seeding, irrigation, fertilizer, herbicide or insecticide application, harvesting, marketing etc.,

• Special warnings for taking appropriate measures for saving crop from aberrant weather.

•Location specific package and practices for cultivation of different crops suitable for the agroclimatic zone relevant to that period.

• Information or caution on outbreak of pests and diseases under prevailing or forecast weather conditions

• Problems related to animal health etc.,

The advisories also serve an early warning function, alerting producers to the implications of various weather events such as extreme temperatures, heavy rains, floods and strong winds etc.,

The following points are to be kept in mind for preparing effective agro-advisory bulletins:

•Identification of weather sensitive field operations

•Accurate weather forecast taking into cognizance local weather

•Real time information on crops (major crops, varieties, sowing time, phenological stage, status of pests and diseases etc.,)

•Reliable source of information

•Crop weather calendars

•Easily understandable language

The feedback is collected from the contact progressive farmers, on usefulness of the advisories as well as suggestions for its improvement. systematic study conducted by this unit on economic impact of the project in four villages in Ranga Reddy District revealed that there is a benefit of 9 - 15% due to adoption of agromet advisories.

5.0 Case Study - Impact of Aas on Minimizing Loss due to *Botrytis*

Cloudy weather and continuous drizzling during spike development favours disease development.

•Average yield of Castor crop in Rangareddy district = 110.4 kg/acre

•Average crop loss due to *Botrytis* disease (30%) = 33 kg/acre = Rs 495/- @ Rs.l500 /- per 100 kg.

•I spray cost of Carbendazim = Rs 300/- including labour cost

•Net benefit accrued = Yield advantage Rs.495 / acre - cost of chemical Rs.300 = Rs.195/-

•Total area in the district = 28,742 acres.

•Percentage of adoption (50%) to an extent of 14,371 acre

•Total benefit accrued in the district due to adoption of one spray of Carbendazim to control *Botrytis* in castor
disease = 14,371 acres x Rs. 195 = Rs. 28.02 lakhs

6.0 Impact Studies in Other crops

Similarly, during *kharif2004* and 2005 about 12 and 19 per cent profit was realized by rice farmers adopting these agroadvisories over non-adopted farmers, while cotton farmers accrued 12 to 22 per cent profit during *kharif2004* and 2005, respectively. Farmers growing Tomato and Palak realized 10 to 25% and 8 to 42% profit during *rabi* 2003 - 05 by adopting these advisories and saving on cost of inputs, plant protection measures etc., and also taking up timely protection measures with recommended chemicals.

7.0 Contingency Crop Plans

The contingency plans are needed if following conditions prevail:

•Failure of South- West Monsoon

•Delayed onset or early withdrawal of monsoon

•Deficit or erratic rainfall

•Damage to crops due to cyclones, floods etc.,

•Crop loss due to droughts

•Insufficient supply of irrigation water or late release of canal water

•Long dry spells

•Heat or cold waves

•Severe pest or disease outbreaks due to favourable weather conditions

The contingency strategies are to be based on location specific needs and situation based (rainfed or irrigated). Within the region also they vary with soil types. Acharya N. G. Ranga Agricultural University has made noble attempt to develop location specific contingency plans by monitoring the seasonal and crop conditions on real time basis and forecast weather of IMD, for the benefit of farming community to enable them to respond suitably and save the crops with reasonably good yields. Some of the contingency measures suggested during *Kharif2009* are as follows:

8.0 Monitoring of seasonal conditions during *kharif* 2009 and suggestions for contingent crops or strategies

8.1 Rainfed Areas in the State

Region	Situation	Crop	Cut-off date
Telangana	Light soils	Greengram, Jowar, Jowar + Redgram	June 30
		Maize + Redgram, Maize	July 10
		Castor	July 31
	Medium to heavy soils	Jowar, Jowar + Redgram	June 30
		Blackgram, Maize + Redgram,	July 10
		Maize Cotton + Soybean	July 15
		Redgram + Soybean	July 31
Rayalaseema	Light soils	Jowar, Greengram	June 30
		Small millets	July 10
		Groundnut, Redgram, Castor	
		Redgram + Groundnut	July 31
	Medium to heavy soils	Jowar	June 30
		Bajra	July 15
		Castor, Redgram, Cotton	July 31
Coastal Andhra Pradesh	Light soils	Greengram	June 30
		Minor millets,	July 10
		Maize, Redgram	July 31
	Medium to heavy soils	Greengram	June 30
		Blackgram	July 10
		Soybean, Cotton + soybean, Maize, Castor, Redgram + Soybean / Blackgram	July 31

8.2 Rice

8.2.1 Krishna Godavari Zone

Late release of canal water

Due to late release of canal water the sowing of nurseries and transplanting of rice are likely to be delayed beyond the cut off date (1 5th July) and the rice yield of popular long duration varieties may get reduced by 15 to 30%. The pest and disease incidence may increase. To get normal yields the following practices are recommended :

- If sowings are to be taken short duration varieties are preferred.
- Shallow planting of 25 days old seedlings @ 4 to 6 per hill and increasing the plant density from 33 to 44 hill/ m^2.
- Increase N level by 50% and its application in three equal splits (Basal, 20 DAT and PI) in case oflong duration cultivars, 2/3rd basal and l/3rd at 25 DAT in case of late planting of aged seedlings of long duration varieties. Prophylactic plant protection measures to control sheath blight with Propiconazole / Hexaconazole are to be taken up

- Application of phosphorus, potassium and zinc in sufficient quantities at planting is necessary
- Weed control can be achieved with herbicides like 2,4 - DEE, Butachlor or Anilophos
- Timely control of pests like gall midge, stem borer, leaf folder and BPH is necessary

8.2.2 North Telangana and Central Telangana Zone
Late planting beyond August 10

• Short duration varieties like Erramallelu, Jagtiala Sannalu, WGL-44, JGL-3844, MTU 1010 and Tellahamsa are preferred for planting over traditional varieties.
• Plant 25 days old seedlings @ 4-6 per hill and increase the plant density from 33 to 44 hill / tlT

Planting of Aged Seedlings

- Nitrogen application in nurseries may be avoided when the seedlings are over aged.
- Long duration - up to 60 days old seedlings are preferred
- Medium duration- up to 50 days old seedlings are preferred
- Short duration - up to 40 days old seedlings are preferred by taking precautions like maintaining 50 to 60 hills per m^2, no. of seedlings may also be increased to 4 - 6 per hill, apply phosphorus, potash and zinc as a basal dose for good stand establishment and growth and two - third nitrogen may be applied as basal and remaining one - third nitrogen at panicle initiation.
- Increase N level by 50% and its application in three equal splits (Basal, 20 DAT and PI) in case of long duration cultivars, 2/3rd basal and 1/3rd at 25 DAT in case of late planting of aged seedlings of long duration varieties. Prophylactic plant protection measures to control sheath blight with Propiconazole / Hexaconazole are to be taken up.

Optimum Time for Sowing of Rice Nurseries in Different Regions of A.P.

Region	Long duration varieties	Medium duration	Short duration
Coastal A.P (excluding Nellore and Prakasam)	July 20	Aug 15	Aug 15
Rayalaseema	July end	Aug 15	Aug 15
Telangana	June 15	July 15	July end

9.0 Conclusion

Medium range weather forecast is useful in issuing location specific weather based agro-advisories to tailor the agricultural operations. By closely monitoring seasonal conditions and using medium range weather forecast an effective contingency cropping strategy is possible. Timely dissemination of these advisories/contingency crop plans/measures will help the farmers to maximize the yield by optimum use of inputs and enhance the economic returns of the farmers.

ADVERSE EFFECTS OF CLIMATE CHANGE

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Introduction

India is predominantly a rainfed country. 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.

Predominant causes of soil degradation

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.

Climate related risks in Agriculture in India

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.

A) 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.

B) 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

C) 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.

D) 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.

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

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.

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.

Conservation Agriculture vis-a-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: Major soil quality indicators and related 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,

Soil quality indicators	Soil processes and functions
	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)

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.

- **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.
- **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.
- 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.
- 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.

- **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.
- **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.
- **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.

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.

Promotion of Conservation Farming- Steps

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

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.
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
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.
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.

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.

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.

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) 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.

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.

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.

- **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.

- **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'.

- **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.
- **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.
- **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.
- **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.

- **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.

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

Conclusion

Soil is Gods gift to Nation. Mans' success in responding to the latest challenge that of global climate change will depend on how we manage this vital resource Healthy Soils - Better Environment - Better Nutrition – Healthy Society – Healthy Nation

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WEATHER INSURANCE-BASED CLIMATIC RISK MANAGEMENT IN RAINFED CROPS[♣]

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Introduction

The rainfed agriculture plays an important role in Indian economy. In India 68 percent of total net sown area (136.8m.ha) comes under rainfed lands spread over 177 districts. Rainfed crops account for 48 percent area under food crops and 68 percent of the area under non-food crops. Nearly 50 percent of the total rural workforce and 60 percent of livestock in the country are concentrated in the dry districts.

India has about 47 million hectares of dry lands out of 108 million hectares of total rain fed area. Dry lands contribute 42percent of the total food grain production of the country. These areas produce 75percent of pulses and more than 90percent of sorghum, millet, groundnut and pulses from arid and semi-arid regions. Thus, dry lands and rainfed farming will continue to play a dominant role in agricultural production.

In such areas crop production becomes relatively difficult as it mainly depends upon intensity and frequency of rainfall. These areas get an annual rainfall between 400 mm to 1000 mm which is unevenly distributed, highly uncertain and erratic. To feed our ever growing population we will have to harness every inch of our cultivable lands, especially dry lands, with utmost care.

Climate change impacts on rainfed agriculture

Climate change is expected to alter the seasonal timing of rainfall and snow pack melt and result in a higher incidence and severity of floods and droughts. 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) This unprecedented increase is expected to have severe impacts on the global hydrological system, ecosystems, sea level, crop production and related processes. This would be particularly severe in the tropical areas, which mainly consist of developing countries, including India. The impact of climate variability and change on farmers' livelihood in different agro-climatic systems and the changes in risk management approaches have shaped the mitigation and the response strategies of farmers and societies over the years. Farming communities that do not have inbuilt buffering mechanisms, as in resource poor rain-fed regions, are disproportionately vulnerable to the severity of extreme climate events. Climate change threatens to alter the frequency, severity and complexity of climate events, as also the vulnerability of high risk regions in different parts of the country. Both rain-fed and irrigated agriculture will need to be managed more sustainably to reduce resulting production risks.

[♣] Lecture notes for Model Training Course on ''Impact of Climate Change on Rainfed Agriculture system and adaptation Strategies" held at CRIDA during 22-29 November, 2011

In recent years, there has been a dramatic technological progress in the understanding of climate systems, as well as in monitoring and forecasting weather events on the scale of seasons and beyond. The advent of more reliable forecasts goes hand-in-hand with emerging trends in risk management, where reactive strategies are gradually being replaced with more anticipatory, proactive and forward looking approaches. These approaches provide a unique opportunity to mitigate and reduce the vulnerability to adverse weather and climate phenomena, as also to take advantage of the knowledge of anticipated events to improve the quality of life of farmers.

Mitigation and adaptation approaches will need to be strengthened. These are likely to be more effective if they are embedded in longer-term strategies linked to agricultural policy reform, risk management, research and development, and market-based approaches. Examples include crop and disaster insurance, research into crop varieties and breeds better adapted to changing climatic conditions, and incentives for more efficient use of water.

Risks in rainfed agriculture

Rainfed agriculture is often characterized by high variability of production outcomes i.e., production risk. Most often agricultural producers cannot predict with certainity the amount of output their production process will yield, due to external factors such as weather, pests and diseases. Agricultural risks are related to natural disasters and are widespread. Those are neither completely independent nor correlated with any of the discernible events. Rainfed agricultural production totally depends upon monsoon performance. Therefore, bad weather condition and some natural disasters also affect the agricultural production.

Mitigation strategies for production risks

Though farmers are perceived to know their risks better than the Government or other institutions, it is surprising that both farmers and decision makers tend to underestimate the risk of agriculture especially due to unpredictability of the nature's adversity. Agricultural producers are hindered by adverse events during harvesting or collecting that may result in production losses. Identifying weather risk for an agricultural grower or producer involves three steps: a) identifying the regions at risk to weather that reflect the risk; b) identifying the time period during which risk is prevalent; c) identifying the weather index that is the best proxy for the weather exposure.

Insurance is a means of financially managing device for protection against probable hazard and its associated losses. Crop insurance is one of the special forms of non-life insurance. There are mainly two forms of crop insurances viz. crop-yield insurance and crop revenue insurance. Crop insurance safeguards the farmers to protect the agricultural products from future losses due to the occurrences of disasters.

Based on Clarkson et al. (2001), there are six requirements that must be met if 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.

History of agriculture insurances in India

Agriculture, particularly prone to systemic and co-variant risk, doesn't easily lend itself to insurance. Lack of historical yield data, small sized farm holdings, low value crops and the relatively high cost of insurance, have further made it more difficult to design, a workable crop insurance scheme. Despite these constraints, India debated the feasibility of crop insurance schemes, since early part of 20^{th} century, and could settle for 'yield index' based crop insurance on a country-wide basis since 1985. There are mainly two forms of crop insurances viz. crop-yield insurance and crop revenue insurance.

A brief evolution and present status of Indian crop insurance is presented below:

Crop Insurance Evolution

- Program based on 'individual' approach (1972-1978): The first ever crop insurance program started in 1972 on H-4 cotton in Gujarat, and was extended later, to few other crops & states. The program by the time its wound up in 1978, covered nearly 3,110 farmers for a premium of Rs.454, 000 and paid claims of Rs 37.90 lakhs.
- Pilot Crop Insurance Scheme – PCIS (1979-1984): PCIS was introduced on the basis of report of Prof. V.M. Dandekar and was based on the 'Homogeneous Area' approach. The scheme covered food crops (cereals, millets & pulses), oilseeds, cotton, & potato; and was confined to borrowing farmers on a voluntary basis. The scheme was implemented in 13 states and covered about 627,000 farmers, for a premium of Rs 197 lakhs and paid indemnities of Rs 157 lakhs.
- Comprehensive Crop Insurance Scheme – CCIS (1985-1999): The scheme was an expansion of PCIS, and was made compulsory for borrowing farmers. Sum insured which was initially 150 percent of the loan amount, reduced to lower to a maximum of Rs.10,000 per farmer. Premium rates were 2 percent of the sum insured for cereals

& millets and 1 percent for pulses & oilseeds, with premium and claims, shared between the Centre & States, in 2:1 ratio. The scheme when wound up in 1999, was implemented in 16 States & 2 Union Territories and cumulatively covered about 763 lakh farmers, for a premium of Rs 403.56 crore and paid indemnities of Rs 2319 crore.

National Agriculture Insurance Scheme-NAIS (1999)

NAIS replaced CCIS starting from Rabi 1999-00 season, presently administered by Agriculture Insurance Company of India Limited (AIC), that provides coverage to approximately 35 different types of crops during the Kharif season and 30 during the Rabi season. Till Rabi 2008-09, NAIS cumulatively covered 134.66 million farmers with cultivated area of 210.90 million hectares for a premium of Rs 4426 crore and paid / finalized indemnities of Rs 15230 crore. The overall loss cost (indemnities to sum insured) stands at 10.27 percent. NAIS is the world's largest area yield index insurance programme, which during 2009-10 insured about 24.5 million farmers cultivating crop on over 35 million hectares for a sum insured of approx. Rs.42,000 crore (www.aicofindia.org).

NAIS though best suited for Indian conditions, but not without shortcomings. The most important one is 'basis risk' as the area (insurance unit) is rarely homogenous. Presently efforts are made to lower the size of the area in order to minimize the basis risk. As the index is based on yield, the insurance cover primarily operates from 'sowing till harvesting', and for this reason pre-sowing and post-harvest losses are not reflected in the yield index. Yet another challenge is the infrastructure and manpower required to conduct over a million crop cutting experiments across the country to estimate the yields of each specific crop in an area. The process also contributes to delay in settlement of indemnities as the yield estimates' compilation takes almost two to three months after the harvest season. Moreover, yield index based insurance can be designed for only crops with at least 10 years' historical data at insurance unit level. Despite these shortcomings, area yield index is still considered very important insurance programme in Indian conditions.

Agriculture Insurance Company of India Limited (AIC) currently offers area based and weather based crop insurance programs in almost 500 districts of India. It covers almost 20 million farmers, making it one of the biggest crop insurers in the world. The most prominent shortcomings of previous crop insurance schemes were that of 'group insurance schemes' aimed at farmers taking crop loans from banks and the risk were shared among Central Government, State Governments and the General Insurance Corporation, which has its own limitations. Twenty-two states/union territories participated in the Centre for Comparative Immigration Studies (CCIS), while only 16 are participating in the NAIS.

Weather Index Insurance

Weather index based insurance caught the imagination of the policy makers at the beginning of 21st century, and international financial institutions like the World Bank encouraging the pilots in low income countries where traditional crop insurance could not take off for various reasons, including lack of historical yield or loss data.

It's worth mentioning that the pioneering work on weather index insurance commenced as far back as 1912 by J.S. Chakravarthi, as a mechanism to compensate crop losses. It was between 1912 and 1920, Chakravarthi of Mysore State (India) published technical papers on the subject of 'Rainfall Insurance' and a book entitled **'Agricultural Insurance: A Practical Scheme Suited to Indian Conditions'**, in 1920, describing how rainfall index could be used to guarantee payouts to farmers due to adverse deviations. He used rainfall data from 1870 to 1914 from India Meteorological Department (IMD) to demonstrate the utility of the index. Surprisingly, this piece of pioneering work, which is probably one of the earliest monographs on the subject, does not appear to have been taken into account in the analytical literature on agricultural insurance (Mishra P K). It was some 85 years later that the policy makers of the modern world started advocating the very same index for low income countries.

Weather Based Crop Insurance Scheme (WBCIS) is a unique weather based insurance product designed to provide insurance protection against losses in crop yield resulting from adverse weather incidences. Weather Based Crop Insurance aimed to be used as hedging instrument against any vulnerability of crops or any other damage incurred in agricultural activities due to erratic and irregular weather. It is also denoted as 'weather based index insurance' and 'weather event insurance'. In provides payout against adverse rainfall incidence (both deficit and excess) during *kharif* and adverse weather like frost, heat, relative humidity, un-seasonal rains etc during *rabi* season.It is often considered that 'weather insurance' is same as the 'crop insurance' and weather insurance is only based on the 'rain fall index'. However, rainfall index is one of the parameters required for measuring the overall weather impact on the agriculture and weather insurance includes other parameters such as temperature, high wind speed, frost, hail etc. The basic purpose of 'weather index' insurance is to estimate the percentage deviation in crop output due to adverse deviations in weather conditions. There are statistical techniques to work out the relationships between crop output and weather parameters. Techniques like multivariate regression could explain the impact of weather deviations / variations on productivity. These provide linkages with financial losses suffered by farmers due to weather variations, and also estimate the indemnities that will be payable. The weather based insurance schemes are quite easy to administer as claim payment is triggered by more transparent, objective and scientifically determined weather parameters. It provides greater scope of flexibility in terms of indemnity level and coverage also. It is less costly and gives high level of comforts to clients. The clients from their own age old experience try to understand better risk factors as well as payout structure. That is the reason why the claim settlement is relatively hassle-free process, which the beneficiary considers as the most important advantage as he is not required to file a claim for losses.

Weather insurance products are new to India and success of these products depends on close network of weather stations which can capture/record weather data at a micro level. Satellite imagery of Normalized Difference Vegetation Index (NDVI) data can be used to assess crop growth stages, stress due to moisture, pest and diseases attack, etc. and possible loss in production during harvest. NDVI coupled with weather data can be used to offer insurance cover for various crops. The insurance is linked to biomass triggers. Trigger events could be measured using modern technologies like satellite imagery from remote sensing technology which are accurate and could be independently verified and measured. It allows for speedy settlement of indemnities even before the crop is ready for harvesting (Singh, 2010). However, this requires substantial research and demands collaboration amongst interdisciplinary institutions, insurance companies and other organizations functioning in this domain.

In India, hundreds of small farm holders stated to be showing interests in buying insurance policies that protect them against extreme changes in weather patterns. Many insurers have agreed to reinsure weather elements especially rainfall insurance portfolio. The schemes are based on the reliable models acceptable to strike a deal in international reinsurance markets, in itself doubtlessly speaks on the potential for weather insurance around the world. A recent survey highlights that farmers understand and appreciate the structure of the insurance policy as it directly reflects their experience that the distribution of rain throughout the season, sudden large variability of weather elements and occurrence of extreme weather events matter a lot for the yield.

Weather Index – Key Advantages

One key advantage of the weather index based crop insurance is that the payouts could be made faster, besides the fact that the insurance contract is more transparent and the transaction costs are lower. Because index insurance uses objective, publicly available data it is less susceptible to moral hazard (IRI, 2009) Weather based crop insurance scheme has many advantages which make it beneficial for cultivators in their production risk management such as:

- Trigger events like adverse weather can be independently verified and measured based on observation.
- It allows speedy settlement of claims.
- WBCIS is inexpensive and easy to operate, since very few agencies would be involved in monitoring and implementation.
- Government provides subsidy in premium thus making it affordable.
- It provides transparent, fully objective, efficient and direct payouts for adverse weather incidences. This is unlike regular insurance, which would only cover physical damage and production loss.
- Insured is not required to submit claim form or other documents as proof for loss.
- Since the weather data decides the compensation the insured is willing to put extra efforts for getting better yield of crop.
- Insurance generally pays based on actual damages while weather insurance pay based on the difference between a negotiated "strike price" and the actual weather experienced during different growth stages.

Pilot Weather Risk based Crop Insurance

In order to address some of the shortcomings of NAIS, Agriculture Insurance Company of India (AIC) developed a pilot weather risk index-based insurance product in 2004. Building on the existing weather risk insurance products, the Government asked AIC in 2007 to design the **Weather Risk-Based Crop Insurance Scheme (WBCIS)** as a pilot. AIC through WBCIS, introduced a location-specific (Tehsil / Block) and crop-specific pilot on weather risk index-based insurance product on rainfall outputs for the Kharif season, and a composite weather risk index-based insurance like rise in temperature, un-seasonal rainfall, humidity, frost risks, etc. during Rabi season, as a substitute for NAIS during 2007-08.

AIC has found weather risk index-based insurance to be specifically useful for insuring crops that do not have adequate historical yield data. Many of these crops do not lend themselves to 'individual-based insurance' due to either low value or high complexity. Weather risk index-based insurance, thus, can be part of an insurance program in which it is combined with an area yield index-based insurance. That is, in a double-trigger relationship, weather risk index-based insurance provides a trigger to release early payout with a provision that the balance payment will be made against final yield estimates. Additionally, weather risk index-based insurance can be an ideal alternative for protecting a large portfolio at the macro level against drought or floods.

AIC introduced rainfall insurance known as "Varsha Bima" which came into effect on June 01, 2005. Varsha Bima provided for five different options suiting varied requirements of farming community which includes: (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 and above in rainfall during the season. For the first time, the Government had come out with weather insurance in the form of rainfall insurance. The scheme offers farmers quick compensation and it aims to be a buffer against 'erratic rainfall and crop failures'. Varsha Bima 2005 aimed to insure the kharif crop against rainfall inadequacies in 142 rain gauge districts in 10 Indian states - Andhra Pradesh, Karnataka, Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Uttaranchal and Uttar Pradesh. AIC has also introduced weather insurance pilots on wheat insurance, mango insurance and coffee insurance during 2005-06. For the year 2009-10 as many as 27 million farmers growing crops over 38 million hectares were insured under various crop insurance programs of AIC (Golait et al., 2008).

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.

Weather Insurance Pilots in India

Some of pilot schemes and delivery models operated in India are:

- ICICI Lombard pilot scheme for groundnut in Andhra Pradesh
- KBS pilot scheme for soya farmers in Ujjain
- Rajasthan government insurance for orange crop
- IFFCO-TOKIO monsoon insurance
- AIC Varsha Bima Yojana (rainfall insurance scheme)
- AIC Sookha Suraksha Kavach (drought protection shield)
- AIC coffee rainfall index and area yield insurance
- ICICI Lombard loan portfolio insurance

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.

IFFCO-Tokio General Insurance Company (ITGI) piloted rainfall insurance by the name- "Baarish Bima' during 2004 in nine districts of Andhra Pradesh, Karnataka, Gujarat and 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.

After analyzing the impact that temperature has on wheat cultivation, ICICI Lombard had designed a weather insurance product for wheat cultivators which address the dual risks of extreme temperatures fluctuations and unseasonable rainfall.

Weather Risk Insurance – Challenges

The two biggest weaknesses and challenges of the present weather risk index-based insurance product are (i) designing a proxy weather risk index with predictive capability to realistically measure crop losses, and (ii) basis risk. Basis risk results if the actual experience of weather risk (rainfall) in the neighbourhood significantly differ the data recorded at the weather station. The combined effect of the two challenges represents a significant barrier to the scale up of the product. Nevertheless, weather risk index-based insurance performs well on data accuracy, transparency and quick claims settlement, which are very attractive to both farmers and the reinsurance market.

Conclusions

Many agrarian economies owe their strength to favourable weather parameter, such as rainfall, temperature, sunshine, etc. However, these economies are especially vulnerable to the changing weather patterns, specially the extreme weather if no adaptation measures are taken (new seeds varieties, state-of-art production techniques). Therefore reducing vulnerability to weather in developing countries is a critical challenge, facing development in rainfed areas. Proper insurance systems would help farmers to cope with the increasing chance of their losses. Weather based insurance provides a long term sustainable solution, a market-based alternative to traditional crop insurance, which overcomes challenges of high monitoring and administrative cost as well as moral hazard and adverse selection. Its transparency replaces human subjective assessment with objective weather parameter. It is a scientific way of designing product with simple terms of insurance delivery and speedy claims settlement process. 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.

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IMPACT OF CLIMATE CHANGE ON CROP DISEASE INTERACTIONS

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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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ENERGY EFFICIENCY IN AGRICULTURE IN RELATION TO CDM

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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.

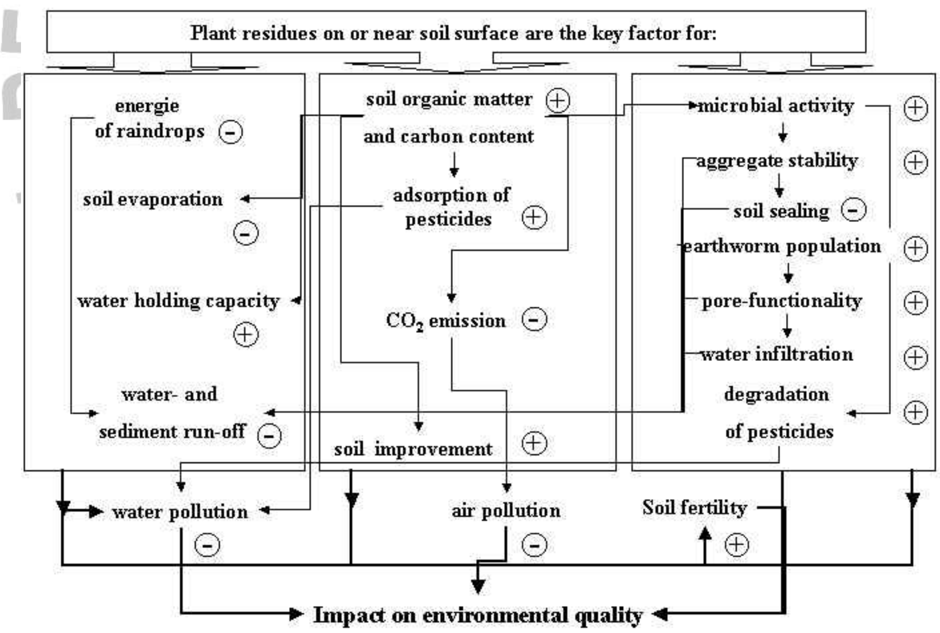
Zero-tillage	Zero till drill, Planter with double disc coulters	Less labor required; soil physical structure is maintained (reduced nutrient loss, soil health maintained); less water required; avoids large cracks in soil after dry periods; can keep previous crop's residue in field for mulch (if appropriate 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 cation (raised seedbeds, intercropping)	Bed planter, Raised bed and furrow planter	Two to three crops grow 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 a 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 a 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 use through, e.g. the elimination of tillage operations, reduction of irrigation, use of lighter machinery, etc.

DROUGHT MANAGEMENT MEASURES FOR RAINFED CROPS

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The drylands in India constitute about 70 per cent arable land and they contribute about 49 per cent food production to our national food basket. Important problems that encounter in crop production of the dryland are unfavourable weather, limited choice of crops and varieties and low and unstable crop productivity.

In India, black soils occupy 73 m ha in total geographical area of 328 million ha and Alfisols occupied 71 m ha. Among the production factors, improved genotypes of crops contribute about 30 per cent increase in yields of rainfed crops. Hence selection of crops and cropping systems in rainfed black soils has to be viewed critically for getting higher and stable yields.

I. Criteria for Selection of Crops and Varieties

1. Land use capability concept:

It is an old concept but rarely used in dryland agriculture production in India. In subsistence farming, food crops are grown according to household needs of the farmers. Hence, in dryland crop production, it is the moisture storage capacity of the soil and water availability periods that play key role in selection of crops and varieties in black soils.

2. Water availability period:

The cultivars that grow in vertisols are sometimes longer in duration than water availability period. As a result, the crops invariably undergo moisture stress and resulting in low yields. The water availability periods for different agro climatic zones were worked out as guiding principle in selection of the crops and cropping systems in Vertisols.

3. Crop substitution:

Many crops often grown by the farmers are more for convenience. The crop is to be matched according to the resources and also should give highest possible yields. According to the productivity, traditional crops have to be replaced with efficient crops with greater stability.

In Vertisols, selection of crops has to be based upon slope and depth of the soil. During kharif season the total quantum and distribution of the rainfall play critical role in deciding crops and cropping systems in Vertisols. While in rabi season the conserved moisture at the time of planting becomes critical in deciding the crops and cropping systems for a given region.

II) Efficient Cropping Systems

The scientists working in drylands in different agro-climatic zones developed appropriate cropping systems for getting stabilized yields in Vertisols (Table 1). Tillage, fertilizer and weed management practiced have to be followed in time to get higher yields in drylands. In regions, where the effective growing season is less than 17 weeks and quantum of rainfall is 300 to 600 mm usually mono-cropping is being adopted. The regions having the rainfall 600 to 750 mm, having more than 17 weeks of effective growing season, are suitable to adopt intercropping system. The regions having more than 700 mm and also effective growing season of more than 20 weeks are suitable for adopting double cropping systems.

TABLE 1: **Efficient cropping systems for different dryland areas in India as per period of water availability**

Soil zone and region	Water availability period (days)	Double cropping system	Intercropping system
Vertisol and related soil zone			
Malwa plateau (MP)	210-230	Maize-safflower/chickpea Soybean-wheat	Maize + soybean (2:2) Soybean + pigeonpea (4 or 6:2)
	190-210	Sorghum – safflower/chickpea Soybean-safflower	Sorghum + pigeonpea (2:1) Sorghum + soybean (2:2)
Baghalkhand (MP)	210-230	Rice-chickpea/lentil	Wheat + chickpea (2:2) Chickpea+linseed (2:1) Sorghum+pigeonpea (2:1)
	190-210	Sorghum-chickpea Blackgram/greengram-wheat Groundnut-chickpea	
Bundelkhand (UP)	190-220	Sorghum-chickpea Black gram-mustard/safflower Fodder cowpea-mustard	Pearl millet + fodder legume (1:1) Sorghum + pigeonpea (2:1)

Soil zone and region	Water availability period (days)	Double cropping system	Intercropping system
Vidarbha (M.S)	190-210	Groundnut-safflower Sorghum-safflower	Sorghum + pigeonpea (2:1) Cotton+pigeonpea (2:1/2) Cotton+greengram/ Cowpea (1:1) Pigeonpea+greengram (1:3)
	170-190	Green gram – safflower	Pearl millet + Pigeonpea (2:1) Sorghum + greengram/blackgram (2:1)
Southern Maharashtra	160-180	Greengram-sorghum/safflower	Pearl millet + pigeonpea (2:1) Pigeonpea (2:1 or 2) Groundnut + sunflower (2 or 3:1) Chickpea – safflower (3:1)
	120-130		Pearl millet + moth bean (2:1)
Southern Rajasthan	160-180	Greengram – safflower	Maize + pigeonpea (1 or 2:1) Sorghum + greengram (2:1) Groundnut + pigeonpea (2:2) Chickpea + mustard (4 or 7:1)
Northern (central Karnataka)	130-150	Cowpea – sorghum Greengram – safflower	Pearl millet + pigeonpea (1:1) Groundnut + pigeonpea (3 or 4:1) Sunflower + pigeonpea (2:1) Chickpea + safflower (2 or 3:1) Sorghum + pigeonpea (2:1)
		100-120	Sorghum + coriander (2:1)
Saurashtra (Gujarat)		130-140	Groundnut + castor/pigeonpea (3:1) Pearl millet + pigeonpea/castor (2 or 4:1)
Southern Tamil Nadu		120-130	Sorghum + blackgram/cowpea (2:1) Cotton + blackgram (2:2)

The possible cropping/farming options that can be considered as per the rainfall are:

For the areas with rainfall < 500 mm (15 million ha arable land)

Linking arable farming with animal husbandry
Adopting arable farming limited to millet and pulses and adoption of agro-forestry, silvi-pastoral and horti-pastoral 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.

For the areas with rainfall 500-750 mm (15 million ha arable land)
Increasing emphasis on oilseed and legume based intercropping systems in not so favourable tracts.
Adopting high value (fruits, medicinal, aromatic bushes, dyes and pesticides) high tech (drip irrigation, processing, extraction and value added products) agriculture.
Encouraging watershed approach in a farming systems perspective
Efficiently utilizing marginal and shallow lands through alternate land use systems with agriculture – forests – pasture system with a range of options
Increasing afforestation in highly degraded undulating lands.

For regions receiving rainfall between 750-1150 mm (42 million ha area)
Developing aquaculture in high – rainfall, double cropped regions with rationalization of area under rice.
Adopting intercropping systems and improved crop varieties of maize soybean, soybean, groundnut and double cropping in deeper soil zones.
Rainfed horticulture
Tree farming

Table 2. Soil and Water Management Measures for Rainfed Crops

Nature of drought	Management options
Delay in on set of monsoon	• Selection of drought tolerant varieties/crops and cropping systems (Mixed or intercropping systems) • Contingency crop planning • Alternate crops/varieties to match effective growing season
Early season droughts	• Formation of conservation furrows for moisture conservation at every 4 rows after 35 DAS

Mid season droughts	• Addl.interculture during dry spells • Closing of cracks in Vertisols • Adjustment of plant population and geometry • Additional Nitrogen (10 kg N/ha) after relief of dry spells • Mulch cum manure techniques Application of mulch of glyricidia @ 5 t ha-1 in addition to the FYM reduced the soil loss from the fields effectively. This glyricidia if grown on outer bunds of the fields reduces the transport cost. Besides this with 3% nitrogen in the leave, it adds to the soil fertility. •
Late season droughts	• Rain water harvesting and recycling

Long-term measures of conservation are; Soil and water conservation structures on watershed basis, Creation of water bodies, Vegetative capping, Alternate Land Use Systems, Relief works for providing employment on conservation of resources and Ley Farming *etc*.

From land preparation onwards till the harvest of crops, all the management practices affect the conservation of soil and water, in turn the crop productivity. Therefore, effective management of every component of agriculture becomes part of the prophylactic drought management measures.

LOCAL SOLUTIONS TO COPE WITH CLIMATE CHANGE EFFECTS ON RAINFED AGRICULTURE: INNOVATIVE NRM INTERVENTIONS

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Around 2200 bce a shift in the Mediterranean westerly winds occurred. And it resulted in a reduction in the Indian monsoon leading to three centuries of lower rainfall and colder temperatures. This phenomenon hit agriculture from the Aegean Sea to the Indus River. This change in climate brought down Egypt's pyramid-building Old Kingdom and Sargon the Great's empire in Mesopotamia (Weiss, and Bradley, 2001).

After only a few decades of lower rainfall, cities lining the northern reaches of the Euphrates, the breadbasket for the Akkadians, were deserted. At the city of Tell Leilan on the northern Euphrates, a monument was halted half-built. (Ristvet and Weiss, 2000).

With the city abandoned, a thick layer of wind-blown dirt covered the ruins for ensuring exciting job for the future archeologists! Even intensively irrigated southern Meso-potamia, which boasted of one of the most sophisticated bureaucracies of its time, could not react fast enough to the new conditions. Without the shipments of rainfed grain from the north, and faced with parched irrigation ditches and migrants from the devastated northern cities, the empire collapsed.

Societies have always depended on the climate but are only now coming to grips with the fact that the climate depends on their actions. The steep increase in greenhouse gases since the Industrial Revolution has transformed the relationship between people and the environment. The fact that climate affects development and development affects the climate has come to be known widely during recent times.

Left unmanaged, climate change will reverse development progress and compromise the well being of current and future generations. It is certain that the earth will get warmer on average, at unprecedented speed. Impacts will be felt everywhere, but much of the damage will be in developing countries. Millions of people from Bangladesh to Florida will suffer as the sea level rises, inundating settlements and contaminating freshwater. Greater rainfall variability and more severe droughts in semiarid Asia and Africa will hinder efforts to enhance food security and combat malnourishment. The hastening disappearance of the Himalayan and Andean glaciers-which regulate river flow, generate hydropower, and supply clean water for over a billion of people on farms and in cities-will threaten rural livelihoods and major food markets.

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

Climate change: Impacts on agriculture

The croplands, pastures and forests that occupy 60 percent of the Earth's surface are progressively being exposed to threats from increased climatic variability and, in the longer run, to climate change. Abnormal changes in air temperature and rainfall and resulting increases in frequency and intensity of drought and flood events have long-term implications for the viability of these ecosystems. As climatic patterns change, so also do the spatial distribution of agroecological zones, habitats, distribution patterns of plant diseases and pests, fish populations and ocean circulation patterns which can have significant impacts on agriculture and food production.

Increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance have implications for future food availability. The potential impacts on rainfed agriculture *vis-à-vis* irrigated systems are still not well understood. The developing world already contends with chronic food problems. Climate change presents yet another significant challenge to be met. While overall food production may not be threatened, those least able to cope will likely bear additional adverse impacts. The estimate for Africa is that 25–42 percent of species habitats could be lost, affecting both food and non-food crops. Habitat change is already underway in some areas, leading to species range shifts, changes in plant diversity, which includes indigenous foods and plant-based medicines. In developing countries, 11 percent of arable land could be affected by climate change, including a reduction of cereal production in up to 65 countries, about 16 percent of agricultural GDP (FAO Committee on Food Security, Report of 31st Session, 2005). Changes in ocean circulation patterns, such as the Atlantic conveyer belt, may affect fish populations and the aquatic food web as species seek conditions suitable for their lifecycle. Higher ocean acidity (resulting from carbon dioxide absorption from the atmosphere) could affect the marine environment through deficiency in calcium carbonate, affecting shelled organisms and coral reefs.

To summarize the climate change impacts, these may be classified as biophysical and socioeconomic impacts. Biophysical impacts of Climate change include physiological effects on crops, pasture, forests and livestock (quantity, quality); changes in land, soil and water resources (quantity, quality); increased weed and pest challenges; shifts in spatial and temporal distribution of impacts; sea level rise, changes to ocean salinity and sea temperature rise causing fish to inhabit different ranges. The effect of these biophysical impact due to climate change will in turn bring strife on socio-economic front with decline in yields and production; reduced marginal GDP from agriculture; fluctuations in world market prices; changes in geographical distribution of trade regimes; increased number of people at risk of hunger and food insecurity; migration and civil unrest.

Acting Locally: An intelligent option for the divided world

The recent failure of Copenhagen Climate Change Summit is only a symptom of the deep divide among the international community. No path-breaking outcome can be expected from a world so divided. The need of the hour, hence, is not to wait for miracles to happen. But to act locally. Intelligently and consistently. For, small and consistent efforts bring big and lasting change. The most important primary industry that sustains the world is agriculture and its allied sectors. It is this sector, which has the potential that largely decides the future of human civilization. It can make or break the very existence of humanity depending on how the communities engage in this sector and conduct themselves during these testing times. There are plenty of opportunities here, if only one took them seriously. This article brings forth just one such bright opportunity in rainfed agriculture, where water is going to be a serious limiting factor as a climate change impact.

Enhancing rainwater use efficiency: Key to Sustainable Production

Water is crucial to the very existence of life. More so in arid and semi-arid ecosystems where rain is the only source of water for agriculture, and human and livestock consumption. With climate change having become a reality the management of rainwater as a resource for agriculture and livestock production is proving to be very challenging. One of the prominent symptoms of climate has been frequent high intensity rains interspersed with long spells of droughts. The met department in the last decade has recorded increasingly higher number of such events. Extreme weather events like these have caused havoc in the fragile rainfed ecosystem. In parts of the dry Anantapur district of Andhra Pradesh for instance, during the year 2008, a high intensity rainfall of 114 mm (more than a fifth of its average annual rainfall of 500mm!) in fewer than 3 hrs after a prolonged drought of over 25 days. This event devastated groundnut the only profitable commercial crop of this region causing heavy economic losses. Such events are being increasingly reported from across the rainfed regions in the recent years. The consequences of such events may vary any where from loss of livelihood and agrarian unrest to farmer suicides. The sustainability of rainfed agriculture therefore depends upon managing drastic changes in weather patterns by local adaptations, which need consistent policy and institutional support.

Institutional and Policy support for Local Adaptations

National Agricultural Innovation Project implemented by the Central Research Institute for Dryland Agriculture (CRIDA-an institute of the Natural Resource Management division, Indian council of Agricultural Research) lays vital emphasis rainwater management in the 8 drought-prone districts of Andhra Pradesh (see map). In each of these districts a cluster of villages is selected as an action research field laboratory. Each cluster represents a unique agro-ecology with opportunities for rainwater harvesting and its efficient use. The rainfall ranges in these clusters ranges from just around 500 mm (in Pampanur cluster Ananthapur) to over 1100 mm (Thummalacheruvu cluster Khammam). Similarly, soil types vary too, from deep black soils (Seethagondi, Adilabad) to medium and shallow red soils (Pampanur, Ananthapur). Hence, the runoff and infiltration rate and therefore the rainwater harvesting potential also vary. The overall strategy for harvesting runoff and using the same has been thus: in farm ponds and tanks in high rainfall black soil areas while allowing the runoff harvested in percolation ponds, trench cum bunds and continuous contour trenches (CCTs) to infiltrate and recharge groundwater resources in shallow red soils.

The Seethagondi cluster of villages in the tribal Adilabad district is blessed with fairly high rainfall (above 1000 mm) and deep black soils. Besides these, the undulated topography in this area provides ideal opportunity for harvesting the runoff, storing and reusing the same for tiding over brief spells of drought during cropping season. The technical and economic feasibilities of runoff harvesting through farm ponds for profitable crop production and diversification was amply proved over two years (2007 to 2009). Emphasis is also being laid on upscaling farm ponds through convergence with NREGS as an option for enhancing productivity (Box-1).

The Pampanur cluster of Anantapur being very arid prefers to harvest rainwater through percolation ponds and recharge groundwater,as it is not feasible to store it in the porous red soils of this region. The groundwater is then judiciously used through sprinklers and drip irrigation systems, which have been deployed across the cluster by converging with development programmes such as Andhra Pradesh Micro Irrigation Project (APMIP) and National Horticulture Mission (NHM). Besides, the custom hiring centers at Pampanur and Y.Kothapalli have been equipped with good number of sprinkler sets and pipelines which are in great demand among farmers. Farmers hire the sprinkler sets and pay user fee to a committee of fellow farmers (called *salaha samiti* meaning advisory committee), which maintains indents and accounts. The amount thus collected is used for maintenance and repair expenses of the equipment.

In B.Yerragudi cluster of Kadapa district in the dry Rayalaseem region, attempts are on to augment water availability through de-silting of the Gajulakunta tank near Konampeta village. This work was undertaken in convergence with NREGS in which the participation of the households of the clusters was ensured. The de-silting initiative was moved project staff after the villagers expressed the need for increasing the volume of the silted up tank. The project team assisted the villagers with systematic survey and a detailed estimate of the work which helped them to approach the District Water Mangement Agency (DWMA), the nodal agency for implementing the scheme with a concrete proposal. The community is now feels empowered to articulate and interface with NREGS and get assets created for the village common good. Says a small farmer Veeranna ' we knew that government is spending a lot of money to help us. But were unable how get that use it for creating good facilities for our villages.'

Thummalacheruvu cluster of Khammam district bordering the Naxal-prone areas of Chhattisgarh has unique features. The rainfall is around 1100 mm and the topography is undulated with good forest cover. There are a number of tanks across the villages, which cater to the needs of the farmers. However, a long-standing demand of Bheemavaram was to have an aqueduct constructed across the Bandlavagu cheruvu (tank) so that the spill away water could be effectively used for irrigating an additional 120 acres. This dream was realized when the Bandlavagu aqueduct work was executed by empowering the local Rythu mithra (farmer friend) group to construct the aqueduct (see Box-2).

Jamisthapur cluster of Mahbubnagar is highly drought-prone with an average annual rainfall of just around 600 mm. The soils are shallow and gravelly with poor water holding capacity. The rainwater harvesting strategy here comprised of digging a series of percolation ponds, trench cum bunds and repair of old check dams and other water harvesting structures. Besides, promotion of nursery and plantation activities to green the barren hillocks in the ridge area was pursued. An old check dam which was leaking without being able to arrest the runoff and store it for recharging groundwater was repaired at a cost of a meager Rs.38,000/- with people contributing their labour towards the repair. Trench cum bund was dug in the ridge area to a length of over 5200 m spending about 670 man-days and planting of tree species was taken up along the bunds. Two percolation tanks were dug in the cluster to enhance groundwater resources. Local youth have been trained to monitor the groundwater level periodically so that the community knows for itself the relation among rainfall, conservation measures and groundwater exploitation. The custom hiring center here also is equipped with efficient groundwater using systems like sprinklers. The farmers are being motivated to go for irrigated dry crops in place of paddy during rabi season. Zero till maize is being promoted in paddy fallows by careful training and capacity building activities.

Dupahad cluster, Nalgonda is one of the most drought-prone areas of Andhra Pradesh. The groundwater resources are meager and soils are porous and shallow. Agriculture for ages here was dependent on water harvesting structures like tanks and open wells. However, the tanks are highly silted up while the open wells are dry as a result of breakdown of people's institutions and indiscriminate digging of bore wells. Two strategies were adopted to augment water resource in the cluster. The Jalamalakunta (kunta meaning tank) was de-silted by mobilizing people's participation under NREGS. A detailed survey and the estimate of the work was carried out by the project staff and the village community was encouraged to submit the same for including the work in the shelf of works of NREGS. An amount of Rs.2.5 lakh amounting to 2500 man-days was sanctioned for completing this work. The work was taken up during the summer of 2009. Though there was severe drought during kharif 2009, the rains at the end of the season, helped harvest some runoff, which in turn has pushed the water table up in this land of parched fields and dried up wells. Secondly, the large number of open wells (around 50), which were abandoned as these dried up, posed a great challenge to the project staff right from the beginning. After a detailed topo survey five open wells were selected for recharging by using low cost techniques. The technique involves diverting the runoff from a nearby waterway into a silt trap (a pit filled with loose pebbles) and then leading the clear water into the open well through a PVC duct, the whole appendage costing just around Rs 1500/-. The initial results have been encouraging, as farmers were able to take up short duration vegetable crops by lifting the harvested water from the open wells.

An entirely different approach was adopted in the Ibrahimpur cluster of Rangareddy district, which is abetting the peri-urban areas around the mega city of Hyderabad. The intervention involved increasing the use efficiency of available groundwater by networking six bore wells belonging to different farmers and distributing the same to about 18 farmers (45 acres) with the help of sprinklers. The detailed process of linking and networking the bore wells required more of social engineering than irrigation engineering (Box-3).

Jaffergudem cluster, Warangal is progressive in terms of agricultural practices adopted by farmers. However, the shallow and gravelly soils have poor water holding capacity and need protective irrigation support for better productivity. Thus, the farmers resort to groundwater for irrigation support. The strategy for rainwater harvesting and use in this cluster is mainly through farm ponds and percolation ponds and right appropriate cropping options. The entire soil conservation and rainwater harvesting interventions in this cluster are being carried out in convergence with NABARD funded watershed project. The farmers owning bore wells generally cultivate paddy in *kharif* and *rabi* as well leading to the impairment of water balance. While the technical support for watershed activities were provided to the NABARD project, simultaneous training and capacity building initiative were launched for educating farmers about importance of water balance. The farmers who were taking two crops of paddy, one each in rabi and khairf, were engaged over time and convinced for practice change at least during rabi season. Of the group of 5 farmers who initially agreed to take up zero till maize in paddy fallow during rabi, one was able to finally sow zero till maize in rabi 2007. A sustained campaign and farmer-to-farmer training and interaction facilitated by the project team resulted in this practice spreading to 20 farmers during rabi 2008. Now zero till maize has been accepted as not only a viable water conservation option but also a remunerative alternative.

The success of proofing rainfed agriculture for climate change lies in the judicious use of scarce resources like water, nutrients and biomass by facilitating a support system and developing people's capacity. The project documenting evidence and experiences to show that technologies need a favourable environment to work and produce results. For, technologies themselves are inert and cannot perform in vacuum. They need catalysts in form of community capacity to make the technologies work besides supporting institutions, which can sustain change of practice even beyond the period of project implementation. The project also shows way how the synergy between different development schemes can be harvested to bear upon sustainable development. These need based and site pecific local solutions, innovations and methods show how these can be more suited to climate change than the technology-intensive solutions pushed in a top-down approach.

Box-1: Farm Ponds: Upscaling and Converging with Ongoing Initiatives like NREGS

Farm ponds as an option for harvesting and recycling of rainwater has been recommended for over two decades now. Farm ponds are essentially meant for providing life saving irrigation to a small patch of crop when the crop suffers from midterm drought which is very common in rainfed agriculture. However, this technology has not really taken off. The reasons are many. The most important being this: by the time the need arises for life saving irrigation, the water in the pond would have dried up. This is because either the soil is so porous that it does not retain any water for long enough in the pond. Or the pond is so small that it just doesn't have enough water to drench even a small patch of land. Keeping these in mind, several options like lining the pond with different materials have been tried especially in shallow and porous red soils regions. However, these options are too expensive for a farmer to invest. In the absence of public assistance this option did not find acceptance. In the black soil regions generally the water stays for longer, as the fine clay particles act as natural sealants. Despite this, farm ponds did not take off in a big way even in these regions. In fact, black soil regions with rainfall around 800 mm are ideal for rainwater harvesting and reuse. Keeping this in mind, an attempt was made in Seethagondi cluster of Adilabad district to impound large quantity of rainwater by digging huge size (20m x 20m x 4.5m) farm ponds which were double the recommended size (10m x 10m x 2 m). Initially, it took a lot of persuasion to convince farmers to part a piece of their land for digging a farm pond. Finally, one farmer by name Mr.Namdev reluctantly agreed to our experimentation. The farm pond was not only a big success but also able to pull out Namdev from debt trap. This success was featured as a lead story on the ICAR website for a long time.

This generated a lot of interest among farmers as well as line departments in the district. Mr.Namdev who was till then not known to many became a household name in the surrounding villages. Several farmers who were earlier reluctant to agree for digging farm pond in their fields, started approaching the project staff. This was due to a systematic awareness programme undertaken by the project. The programme included inviting key officials of the development departments and encouraging them to arrange for farmer exposure visits to the site of farm pond in Garkhampet in the cluster. This success story was widely shared with the media and posted on project as well as ICAR website and shared during many discussions, meetings and seminars. This effort resulted in many more farmers showing willingness to adopt farm ponds on their fields. Taking advantage of the changed attitude of farmers towards farm ponds, a detailed ground survey was carried out in all villages of the Seethagondi cluster and a proposal was prepared identifying 30 suitable sites for farm ponds. The proposal was later submitted to the nodal agency (District Water Management Agency; DWMA) that processed NREGS works through Gram Panchayat. The proposal was closely monitored by the project staff and the community, which was favourably considered and 30 farm ponds worth Rs.20.00 lakhs were approved by DWMA.

Under the NREGS, most of the work is carried out manually and farm ponds of 10 m x 10 m x 2.5 m are generally dug by labour. But the experience of the project has shown that there is a better rainfall potential in the district and hence the ponds need to be almost double the size prescribed under NREGS. However, manual labour is inadequate to dig the farm ponds of bigger size (say 17 m x 17 m x 4 m). This matter was dealt in a separate proposal seeking permission to enlarge the manually dug farm ponds to the desired size by using machines. After obtaining the permission to use machines, 5 farm ponds were enlarged into bigger ponds of 17 m x 17 m x 4 m so as to harvest more rainwater. Once this was successfully demonstrated, the DWMA was once again approached with a proposal to permit use of machines for enlarging all the remaining 25 farm ponds and sanction funds for the same.

Box-2: Increasing groundwater use efficiency through social regulation

The project, right from the beginning, is committed to judicious use of scarce resources such as groundwater by investing in technology as well as community capacity. The efforts in this direction started in the Ibrahimpur cluster, Rangareddy district as soon as the project began. It involved a series of consultations with the bore well owning farmers and the neighbouring ones who did not have water source to irrigate their lands. Initially, the two tube well owning farmers did not like the idea at all. The project then got a defunct bore well repaired as a goodwill gesture and again approached the farmers who had mellowed down by then and agreed to share water, provided the project assisted the community for digging a few more bore wells so that there was enough water to share it across a large area. This time, the project contacted NABARD for assistance who came forward with financing the digging of two tube wells in that area under their comprehensive land development programme (CLDP). This raised the hopes of several farmers including those who owned bore wells initially because with the pooling of water they could now irrigate other patches of their dry fields where they could not have reached water. Thus, the one-year long negotiations with the community to implement social regulations for groundwater usage finally yielded results. Over 60 acres of land belonging to 18 households was brought under protective irrigation by laying out a network of pipelines and bore wells at Malkaipet thanda in Ibrahimpur cluster, Rangareddy district. The entire group of farmers has agreed not to cultivate rabi paddy but to share bore water among themselves for growing ID crops.

Box-3: Farmers build aqueduct to augment water availability

Bheemavaram tank in Tummalacheruvu cluster (Khammam) serves as a source of irrigation for about 120 acres. However, the excess water that flows out of the tank every year during the rainy season goes as waste since it flows down into a drain without becoming accessible to the fields downstream. Therefore, one of the first demands of the community when the project team interacted with them through PRA was construction of aqueduct across the *Bandlavaagu* drain. In order to make this dream come true, project team along with a group of consulting engineers took up the issue and started planning for a low cost aqueduct across the drain to help farmers utilize the over flowing tank water.

The group after careful study, recommended for construction of an aqueduct across the stream and discussed with the farmers if they could take the responsibility of laying the aqueduct under the guidance of project staff and engineers. Since the area is very remote and generally no contractor takes up work in such a hinterland, the farmers agreed to take up the laying of aqueduct on their own. The farmers were encouraged to formulate a user group and open a joint account in the bank so that financial assistance could be directly delivered to the group without much delay. The farmers contributed labour and a committee of the user group and project staff monitored the construction of aqueduct under the guidance of engineers. This approach involved empowering user group to take up construction of assets required by the community under expert guidance with the financial support of the project. Besides, the construction also involved latest low cost technology involving continuous HDPE pipes supported by steel columns instead of cement pipes and RCC columns, which brought down the cost almost by 40%. Since the rainfall during the kharif this year was inadequate, the Bheemavaram tank did not overflow. As a result, the efficacy of the structure could not be ascertained during the year. The farmers however, are upbeat and are working to dig distribution channels downstream so that the entire potential of the overflowing water could be harnessed.

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CDM STRATEGIES FOR LIVESTOCK SECTOR IN INDIA

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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 CH4. 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 CH4 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

Social well-being: 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.

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

Environmental well-being: 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;

Technological well-being: 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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VULNERABILITY ASSESSMENT AND IMPACT OF 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^oC in temperature could decrease the rice yield by about 0.75 ton/ha in the high yield areas; and a 0.5^oC 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^oC 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) $3^{o}C$ warmer than the other, one would be able to infer the *willingness to pay* in agriculture to avoid a $3^{o}C$ 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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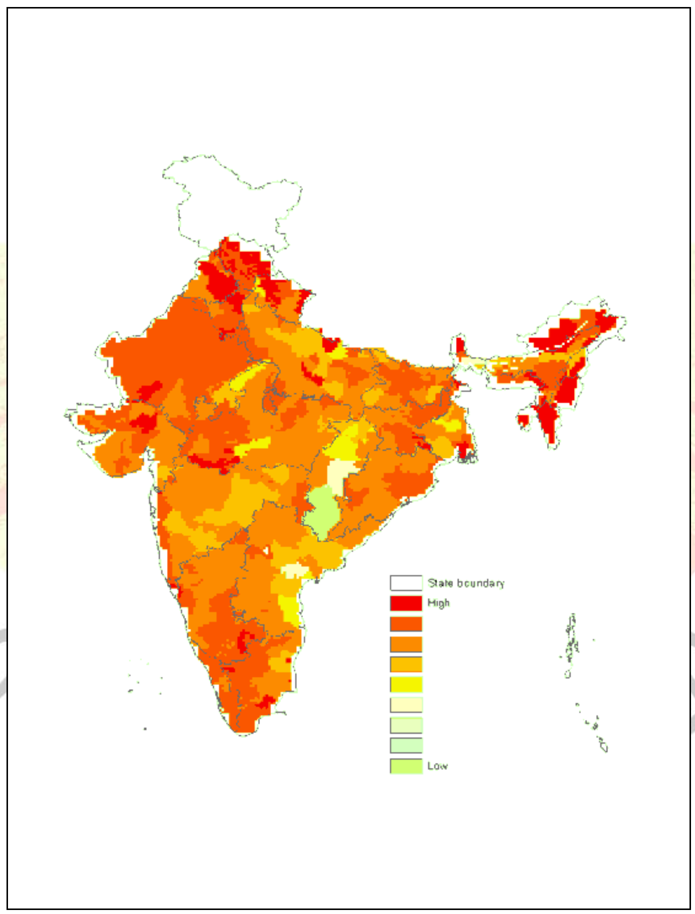
Table 1. Ricardian estimates of effect of climate change on net revenues

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



FARMERS' KNOWLEDGE, PERCEPTION AND ADAPTATION MEASURES TOWARDS CLIMATE VARIABILITY

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Weather extremes and climatic variability are principal sources of fluctuations in the productivity and price fluctuations of agricultural commodities.

Incorporating indigenous knowledge can add value to the development of sustainable climate change mitigation and adaptation strategies that are rich in local content, and planned in conjunction with local people. Indigenous strategies still remain the most reliable and sustainable forms of coping with extreme climate events such as floods and droughts. Indigenous knowledge for adaptation to climate change may be described as knowledge unique to a given culture or society, acquired through accumulation of experiences of local people through informal experiments and intimate understanding of the natural systems stressed by climate change and socio-economic development. Perception results on climate change showed that a significant number of farmers believe that temperature has already increased and that precipitation has declined.

Some examples:

1. Improvement of housing conditions like taking shelter in elevated grounds; selling land; fuel shortage; storing dry foods; diet changes; reducing food intake; banana plantation and bamboo propagation to be used as floating platforms and rafts for movements; growing catkin in sandy loams to prevent erosion.
2. Mixed cropping, inter cropping, delayed sowing.
3. Sesbania + betelvine cuttings to diffuse sunlight.
4. Jackfruit leaves, sugarcane tops as fodder.
5. Local knowledge for animal fattening in summer and accustoming them to winter cold.

Features of Indigenous knowledge:

Multi-level and multisector; site specific; dynamic; systematic observation and experience.

Adaptation Measures

Broadly measures are physical, agricultural, and socioeconomic. Crop diversification, using different crop varieties, changing planting and harvesting dates, increased use of irrigation and increased use of soil and water conservation techniques, and diversification to non-farm enterprises. Other strategies include strengthening community resilience, local institutions and structures, awareness creation and advocacy, research on better varieties, and favourable policy. Field Practices followed by farmers are zero tillage to conserve C in soil, forestry plantations for C sequestration and storing, community forestry, fallow lands, weather forecasting (to know time of planting and cropping pattern), sheep and goat rearing (feed requirement less than livestock)

Extension strategies include field days, farmer-farmer exchange visits, folk songs, dramas and participatory demonstration of adaptation options in farmer's fields.

Criteria in choosing Adaptation Measures

- Cost-effectiveness
- Simplicity
- Responsiveness
- Flexibility
- Reliability
- Location specificity

How to integrate in climate change adaptation policy?

Documentation – Awareness and observation- perception of solution – Motivation – Experimentation – validation – Evaluation – utilization and integration- Dissemination and popularization.

For ensuring sustainability linkages between adaptation options and mainstream development under an enabling environment should be established.

Spatial framework for integration:

Historical matrix-elders brainstorming, years of extremes- GPS for positional readings. Textual form by software ICONS developed by IUCN. ICONS, window-based, spreadsheet with records, sub-records in form format. Then GIS software like ArcView can be linked to ICONS for conducting spatial analysis. Indigenous knowledge is qualitative and for interpretative analysis. Like that for individual, community, regional and national levels it has to be downscaled.

Conclusion:

The overall goal of facilitating adaptation to climate variability is to promote sustainable development through reducing vulnerability and facilitating the resilience of people. Climate change is global, where as adaptation is site-specific. Indigenous knowledge systems were considered inferior and neglected due to centralized decision-making. They are culturally appropriate, holistic and integrative. Identification of successful adaptation measures helps in reducing pressure on resources and environmental risks. *Ensuring the relevance of adaptation measures to the vulnerable populations should be the goal. Identification of successful adaptation measures helps in stabilizing food security in the face of anticipated changes in climatic conditions.*

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CONSERVATION AGRICULTURE SCOPE IN RAINFED AREAS

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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 south-east 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.

IMPACT OF ELEVATED CARBON DIOXIDE AND TEMPERATURE ON INSECT-PLANT 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
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

Insect		**Family**	**Host plant**		**CO_2 conc.**	**Effect on host plants**	**Impact on insects**	**Reference**
Common name	**Scientific name**		**Common name**	**Scientific name**				
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
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
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

Insect		Family	Host plant		CO_2 conc.	Effect on host plants	Impact on insects	Reference
Common name	**Scientific name**		**Common name**	**Scientific name**				
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
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
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

CLIMATE CHANGE VULNERABILITY ASSESSMENT USING CROP MODELS

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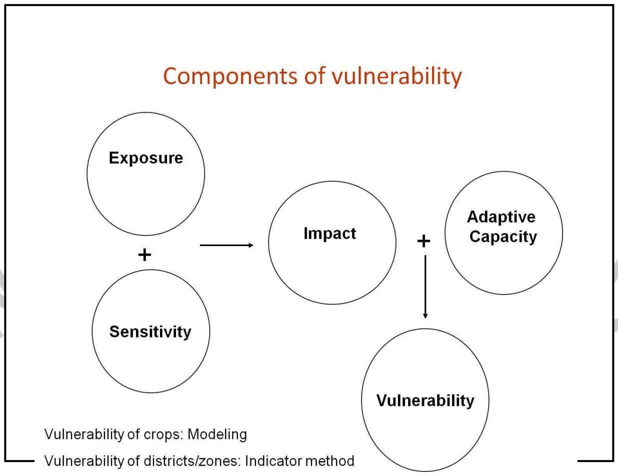
Agricultural communities around the world have always looked for ways and means to cope with climate variability including the use of various traditional indicators to predict the seasonal climate behaviour.Increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance have implications for future food availability. The developing world already contends with chronic food problems. Climate change presents yet another significant challenge to be met. Vulnerability is an emerging concept for climate science and policy. Vulnerability assessment is a key aspect of anchoring assessments of climate change impacts to present development planning. Assessing vulnerability is an important component of human dimensions of climate change research. Vulnerability research find out opportunities to reduce vulnerability and enhance adaptive capacity to current and future climate risks. This information can assist policy makers in developing adaptation plans and to mainstream climate change adaptation into other policy- and decision-making processes. Decreasing the vulnerability of agriculture to natural climate variability through a more informed choice of policies, practices and technologies will, reduce its long-term vulnerability to climate change. In this paper how vulnerability is assessed using the crop models is discussed.

INTRODUCTION:

The rising temperatures and carbon dioxide, and uncertainties in rainfall associated with global climatic change may further impact food production (IPCC, 2007 and Aggarwal, 2003). Climate models indicate continued and accelerated climate change in the future, with temperatures increasing at rates unprecedented in recent human history. Climate change vulnerability research has often focused on modeling the impacts of climate change for natural and human exposure units using simulations produced by global circulation models (GCMs). The starting point here is climate change itself, with vulnerability the endpoint in the analysis, a function of the residual of negative impacts moderated by assumed adaptations. The purpose of these studies has been to assess vulnerability outcomes under different green-house-gas (GHG) scenarios and hypothetical adaptation interventions. Questions typically asked by such research include: What are optimal GHG targets for minimizing vulnerability? Which regions are most vulnerable? Impacts-driven vulnerability research can provide vital information on the potential implications of climate change, and has been widely utilized in vulnerability assessments at national to local levels. Crop growth simulation model play important role to provide key inputs in the assessment of vulnerability.

The IPCC Third Assessment Report (TAR) describes vulnerability as "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 variation to which a system is exposed, its

Sensitivity and its adaptive capacity" (IPCC, 2001). Components of vulnerability are shown in the following figure;



The methodology used for the assessment of the vulnerability of the agricultural resources to a change in climate. The main methodological steps include:

- Identification of sensitive crops (highly climate- dependent) in the region
- Definition of zones
- Definition and collection of information
- Model validation (DSSAT 3.0, INFOCROP,WOFOST, etc.)
- Simulations of crop growth models for impact and adaptation assessment
- Estimation of vulnerability

VULNERABILITY ASSESSMENT USING CROP GROWTH SIMULATION MODELS

Much research to date has provided estimates of the impacts of climate change on food systems. This has demonstrated the importance of changes in seasonal mean weather, and of short-term extremes such as drought and high temperatures, on the productivity of crops. A common approach has been to simulate the impacts of human-induced climate change on crop productivity using crop simulation models driven by weather data downscaled from General Circulation Models (GCMs). Most crop models are designed to run at small spatial scales. A more integrated modelling approach may reduce uncertainties in predictions of crop productivity over regions, and so perhaps provide better estimates of the vulnerability of crops to climate change. For example crop models utilized for decide the sowing window under future projections. For example sowing date is simulated by applying an intelligent planting routine to a given sowing window. The crop is planted when soil moisture exceeds a threshold value. If no such event occurs within the window then crisis planting is simulated on the final day of the sowing window. Farmers can be advised best optimum sowing window under the future climatic projections.

Full integration of crop and climate models is the logical progression of the work described so far.

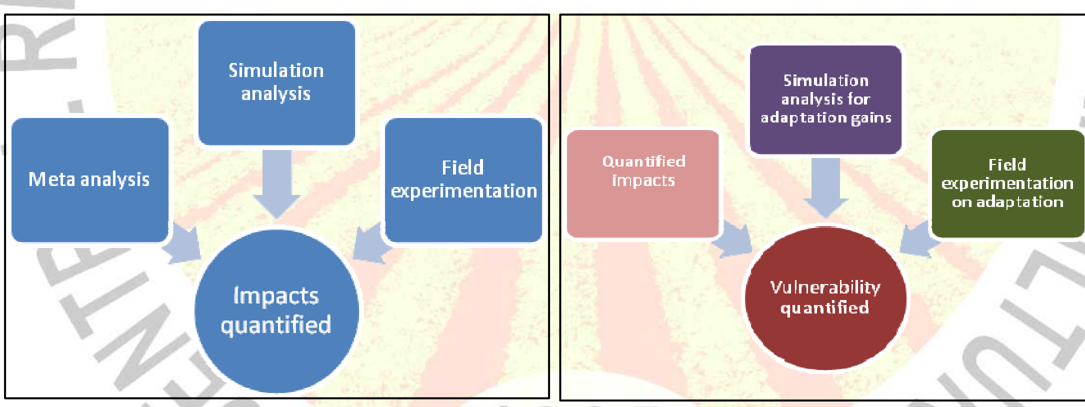
Advantages of a fully coupled crop-climate model include:

- Resolution of the diurnal cycle would enable more accurate simulation of temperature threshold exceedance
- Feedbacks between the crop and its environment can be simulated. This may have a significant impact on yield of the crops.
- Integration of management decisions such as sowing date allows an assessment of the vulnerability of farming systems to changes in the mean and variability of yield and of growing seasons.

Quantification of impacts, adaptation and net crop vulnerability

Vulnerability assessment approaches are different for different sectors. Crop vulenarability can be assessed using crop growth simulation models. To quantify net vulnerability need to quantify impact and adaptation (Fig.1.). The initially Meta analysis should carried out for quantification of impacts, adaptation. In Meta analysis process includes collection various sources data like weather, crop and soil and projected scenario data and arranges in crop growth simulation model format. Impacts, adaptation can be asses with the support of crop growth simulation model studies.

Fig .1. Impacts, adaptation using simulation studies



Indentifying targets

For assessing the vulnerability one must identify the target area and Collect the State, agro-climatic zone wise information. Identify the major crops in each agroclimatic zone along with major variety/hybrid grown under each crop, production and productivity in irrigated and rainfed conditions. Major soil type in each agro-climatic zone under which each crop is grown. Find out the locations representing each agroclimatic zone. Data and information on hazards that the location prone to need to be identified.

Colleting / compiling data base

Simulation models require several datasets and information for location and crop specific calibration and validation. The following list of information needed for simulating a crop model.

soil characteristics for representative locations, daily weather data (Tmin, Tmax, RF, Solar radiation, WS and VP) for baseline period (1960-1990) .Extraction of scenarios data for the location wise, Collection of varietal coefficients and performance indicators phenology, radiation use efficiency (RUE), specific leaf area (SLA), Total dry matter (TDM) and yield. Collection of crop management practices- normal date of sowing, irrigation, fertilizers amount and schedule

approach for simulating baseline yields:
Every scenario is compared with the baseline data in climate change studies. Therefore there is a need to simulate the model with baseline weather data. Select any simulation model- InfoCrop/ DSSAT. Calibrate the model- (location, variety, management, year) using results from detailed experiments. Validate the model for different locations in same/different agro-climatic zones and using specific soil characteristics and weather. Use validated model for simulating baseline yields for past years.

Simulating impacts:
Climate scenario weather data sets are available in the internet provided by IPCC or many scientific organizations in the grid format. These data sets incorporate the changes that are projected in temperature, rainfall and CO_2 for analysing the impacts matrix. Extract scenario data, couple the differences to observed weather during baseline period (1960-1990) and use them for scenario analysis (eg. HadCM3 scenarios 2020, 2050 and 2080 and PRECIS scenarios)

Simulating adaptation capabilities:

After simulating the base line and projected scenarios, there may be a difference in yields due to the change in weather variables in future. Now, identify most promising adaptation technologies ex. Change in variety, planting date, etc. Adapt the matrix used for simulating impacts and run that for change in sowing date and variety. Choose the best yields obtained from array of combinations .Workout the adaptation gains by calculating relative change in yields from baseline yield

Vulnerability assessment

Now with the above results, you have impact and adaptation assessment in your hand. So the net vulnerability any crop can be quantifies as even after adaptation in respective scenario was obtained as net vulnerability given in the equation below ;

Yield loss %, even after adaptation, from baseline = Yield after adaptation (%) - Impact (yield due to climate change (%))

Conclusions

The integrated approach to crop-climate modelling provides tools for the estimation of vulnerability of food systems to climate variability and change. In particular, fully coupled simulations allow simultaneous estimation of the impact of climate change on farming practices and on yield with adaptation and vulnerability to improve the policy decisions.

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ECOLOGICAL FARMING AS A MITIGATION STRATEGY FOR CHANGING CLIMATE

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Introduction

Modern intensive agriculture relies on expensive non-renewable and artificial resources (fossil fuels, agrochemicals and genetically engineered crops) that damage the basic natural resources needed for food production. It pollutes nature with synthetic fertilizers and toxic chemicals that strip the soil of its fertility, harm biodiversity and destroy nature's capacity to keep pests and disease under control. It spreads genetically engineered varieties that threaten the biodiversity of our crop plants which have withstood local conditions for thousands of years and thus risk our ability to produce food under changing conditions. It threatens food security, giving a handful of chemical companies global control over food produced worldwide. It endangers the future of our soils, our water, our climate and our forests, and it is based on the indiscriminate exploitation of natural resources and often on artificial monocultures. It is a major source of global human-induced climate change gas emissions. Direct emissions from agriculture come mainly as methane from livestock and nitrous oxide from fertilized soils. Climate change will profoundly affect food production worldwide.

Fossil fuels: In the most industrialized countries, agriculture requires up to 20 percent of the total fossil fuel used in each nation (Pimentel et al., 2008). Chemical fertilizers, mostly made of natural gas but also of coal and heavy fuels in some countries, require the highest share of this oil energy (about 1.5 percent, but more than 3 percent in countries like India). Diesel needed for irrigation and to power machines and the petroleum needed for pesticide production, combined represent about 1 percent of the total fuel used (Bellarby et al., 2008). As a consequence of this fossil fuel dependence, current grain price movements reflect almost exactly the roller-coaster fluctuations of the oil market.

Agrochemicals: Use of synthetic nitrogen fertilizers has increased globally by more than 8-fold from 1961 to 2006, while grain yields increased globally by 1.5-fold in the same period (FAO stats, 2009). Use of chemical insecticide increased in the United States by 10-fold between 1945 and 2000, while there was a doubling of crop losses from insect damage. The cost of this chemical intensity is an estimated 1 million to 5 million cases of pesticide poisonings per year (UNEP 2004). The worsening of most insect pest problems, and thus dependence on chemical inputs, is increasingly linked to the expansion of crop monocultures and losses in crop diversity (Letourneau and Bothwell, 2008).

Groundwater contamination, fishery losses, loss of natural enemies and increases in pesticide resistance are only a few of the problems arising from agriculture's addiction to pesticides. Pesticides have also been linked to global biodiversity loss and amphibian decline (Rohr et al., 2008).

A recent study has shown that pesticides represent a further threat to farming. Some pesticides are found to disrupt the natural mechanism of nitrogen fixation in legumes, which translates into an estimated loss by one-third of plant yields per growing season and rendering legume crop rotations less effective for maintaining soil fertility (Fox et al., 2007). Chemical fertilizers cause soil degradation and loss of soil fertility in farmlands, plus pollution and dead zones in lakes, rivers and oceans (Carpenter, 2008). Nitrogen fertilizers are also responsible for emissions of the potent green house gas, nitrous oxide (N_2O) (Bellarby et al., 2008). Phosphorus fertilizer is a non-renewable resource and approximately 50-100 years remain of current known reserves (Cordell et al., 2009).

There is an urgent need to develop more ecological agricultural practices which will able to preserve soil fertility, reduce the consumption of non-renewable natural resources and integrated with local biodiversity and landscape. In the last decades, a number of alternate agricultural production systems such as ecological farming, organic farming, permaculture, etc. have been proposed and implemented in order to meet for a more sustainable agriculture.

Ecological farming both relies on and protects nature by taking advantage of nature's goods and services, such as biodiversity, nutrient cycling, soil regeneration and natural enemies of pests, and integrating these natural goods into agro ecological systems that ensure food for all today and tomorrow.

Organic farming/agriculture is one among the broad spectrum of production methods that are supportive of the clean environment. Organic production systems are based on specific standards precisely formulated for food production and aim at achieving agro ecosystems, which are socially and ecologically sustainable. It is based on minimizing the use of external inputs through the use of on-farm resources efficiently compared to intensive agriculture involving the use of synthetic fertilizers and pesticides.

Permaculture puts the emphasis on management design and on the integration of the elements in a landscape, considering the evolution of landscape over time. The goal of permaculture is to produce an efficient, low-input integrated culture of plants, animals, people and structure and integration that is applied at all scales from home garden to large farm.

The benefits of ecological farming

1. Ecological farming provides the ability of communities to feed themselves and ensures a future of healthy farming and healthy food to all people.
2. Ecological farming protects soils from erosion and degradation, increases soil fertility, conserves water and natural habitats and reduces emission of greenhouse gases.
3. Ecological farming is both a climate change mitigation and adaptation strategy. Ecological farming can provide large-scale carbon sinks and offer many other options for mitigation of climate change. In addition, farming with biodiversity is the most effective strategy to adapt agriculture to future climatic conditions. A

mix of different crops and varieties in one field is a proven and highly reliable farming method to increase resilience to erratic weather changes.

4. Ecological farming both relies on and protects nature by taking advantage of natural goods and services, such as biodiversity, nutrient cycling, soil regeneration and natural enemies of pests, and integrating these natural goods into agro ecological systems that ensure food for all today and tomorrow.

Biodiversity

Diversity farming is the single most important modern technology to achieve food security in a changing climate. Scientists have shown that diversity provides a natural insurance policy against major ecosystem changes, be it in the wild or in agriculture (Chapin et al., 2000). A mix of different crops and varieties in one field is a proven and highly reliable farming method to increase resilience to erratic weather changes. And, the best ways to increase stress tolerance in single varieties are modern breeding technologies that do not entail genetic engineering, such as Marker Assisted Selection (MAS). In contrast, there is no evidence that genetically engineered (GE) plants can ever play any role to increase food security in a changing climate. This diversification strategy is backed by a wealth of recent scientific data, for example:• In the United States, agronomists compared corn yields over three years between fields planted as monocultures and those with various levels of intercropping in Michigan. They found the yields in fields with the highest diversity (three crops, plus three cover crops) were over 100 percent higher than those cropped in continuous monocultures. Crop diversity improved soil fertility, reducing the need to use chemical inputs while maintaining high yields (Smith et al., 2008).

• In rainfed wheat fields in Italy, high genetic diversity within fields reduces risk of crop failure during dry conditions. In a model scenario where rainfall declines by 20 percent, the wheat yield would fall sharply. But when diversity is increased, this decline is reversed and yields are larger than average (Di Falco and Chavas, 2006).

Agro-ecological soil fertility

Growing legumes and/or adding compost, animal dung or green manures are some smart ways to increase organic matter and fertility of the soil. Natural nutrient cycling and nitrogen fixation can provide fertility without synthetic fertilizers, and at the same time cut farmers' expenses on artificial inputs and provide a healthier soil, rich in organic matter, better able to hold water and less prone to erosion.

The use of organic fertilizers, generally cheap and locally available, makes ecological farming more secure and less vulnerable to external inputs' accessibility and price fluctuation. Sequestration of carbon in farming soils can also significantly contribute to climate change mitigation.

Ecological farming makes the best possible use of inputs, aiming to build up natural soil fertility and improve efficiency. Organic fertilizers, as well as biopesticides, can be overused; ecological farming aims at the best efficient use of any type of input.

- A recent meta-analysis of data from 77 published studies suggest that nitrogen-fixing legumes used as green manures can provide enough biologically fixed nitrogen to replace the entire amount of synthetic nitrogen fertilizer currently in use, without losses in food production (Badgley et al., 2007).
- In a 21-year-long study on European farms, soils that were fertilized organically showed better soil stability, enhanced soil fertility and higher biodiversity, including activity of microbes and earthworms, than soils fertilized synthetically (Mäder et al., 2002).
- In apple orchards in the US, fertilization with manure (compared to fertilization with chemical fertilizers) increases the amount of carbon stored in the soil, increases the diversity and activity of soil microbes, and decreases the losses of nitrates to water bodies while keeping nitrous oxide losses to atmosphere similar (Kramer et al., 2006).
- Organic farming methods can help reverse the trend of declining soil fertility that many farmers in developing countries are facing. Problems like soil erosion, acidification and organic matter depletion can benefit from agro-ecological practices that nurture soil fertility and biodiversity (Eyhorn, 2007).

Pest protection without chemical pesticides

Ecological farming can achieve pest protection in crop fields without relying on pesticides, by making croplands more resilient to pests. Farmers can find long-term solutions to pest problems by designing diverse crop fields and using low-input technologies locally available. Ecological pest protection is based on enhancing the "immunity" of the agro-ecosystem and promoting healthy soils and healthy plants (Altieri and Nicholls, 2005). By designing agro-ecosystems that on the one side work against the pests' performance and on the other are less vulnerable to pest invasion, farmers can substantially reduce pest numbers. Despite the mainstream research agenda being focused on chemical pest control for the last decades, many studies have found successful agro-ecological ways to regulate specific pest problems.

Some examples are:

• In a unique cooperation project among Chinese scientists and farmers in Yunnan during 1998 and 1999, researchers demonstrated the benefits of biodiversity in fighting rice blast, the major disease of rice, caused by a fungus (Zhu et al. 2000). By growing a simple mixture of rice varieties across thousands of farms in China, they showed that disease-susceptible rice varieties inter-planted with resistant varieties had an 89 percent greater yield and 94 percent less disease incidence than when they were grown in a monoculture. Fungicidal sprays were no longer applied by the end of the two year programme. This approach is a calculated reversal of the extreme monoculture that is spreading throughout agriculture.

• In Africa, scientists at the International Centre of Insect Physiology and Ecology (ICIPE) developed the push-pull system to fight maize stem borers without use of chemicals. Grasses planted on the borders of maize fields (Napier grass and Sudan grass) attract insect pests away from maize – the pull, and two plants intercropped with maize (molasses grass and the legume silverleaf) repel the insect pests from the crop – the push (Hassanali et al., 2008). The push-pull system has been tested by over 4000 farmers in Kenya and about 500 farmers in Uganda and Tanzania, with impressive positive outcomes. Farms using push-pull systems showed between 40 and 90 percent less attack of stemborers and, on average, 50 percent higher yields of maize than monocrop farms. In addition, in the semiarid Suba district, for example, plagued by both stemborers and Striga, milk production is also going up, with farmers now being able to support increased numbers of dairy cows on the fodder produced. Economically, across 4 districts in Kenya over 7 years, the average economic return per hectare was 74 percent higher for push-pull farmers than for monocrop farmers (Hassanali et al., 2008).

• In the state of Andhra Pradesh in India, a pesticide-free farming revolution has taken place in the last few years. A non-pesticide approach to farming, based on locally available resources and traditional practices supplemented with modern science, has brought ecological and economic benefits to the farmers. Under such practices, damages to a crop can be reduced by 10-15 per cent without using chemical pesticides so that the cost of plant protection is low. The small success from a few villages has been scaled up into more than 1.5 million hectares, benefiting more than 350 thousand farmers from 1800 villages in eighteen districts of the state; 50 villages have become pesticide-free and 7 villages have gone completely organic (Ramanjaneyulu et al., 2008). Another example of this success is the performance of nonpesticide management in genetically engineered Bt cotton2 and non-Bt cotton, studied by the Central Research Institute of Dryland Agricuture (CRIDA). This study showed that non-pesticide management in non-Bt cotton is more economical compared to Bt cotton with or without pesticide use (Prasad and Rao, 2006).

Economic success of ecological farming

Ecological farming with practices based on biodiversity and without use of synthetic fertilizers or pesticides, can produce as much food per hectare as the conventional agriculture systems, and even increase yields, especially in developing countries. A recent meta-analysis showed that globally, ecological farming can produce, on average, about 30 percent more food per hectare than conventional agriculture, and in developing countries organic farming can produce about 80 percent more food per hectare (Badgley et al 2007).

Ecological farming is the most promising, realistic and economically feasible solution to the current destructive agriculture model. In a recent UN study, in depth analysis of 15 organic farming examples in Africa have shown increases in per-hectare productivity for food crops, increased farmer incomes, environmental benefits, strengthened communities and enhanced human capital. Organic agriculture can increase agricultural productivity and can raise incomes with low-cost, locally available and appropriate technologies, without causing environmental damage (UNEP and UNCTAD, 2008).

Ecological farming is a profitable farming system. Across Europe, for example, a region-wide analysis indicates that profits on organic farms are on average comparable to those on conventional farms (Offermann and Nieberg, 2000). In apple orchards in the west of the US, when compared with the conventional and integrated farms, the organic farms produced sweeter and less tart apples, higher profitability and greater energy efficiency (Reganold et al., 2001).

In a decade long study in Wisconsin (USA), scientists have shown that farming with high diversity and with no pesticides or chemical fertilizers is more profitable than farming with monocultures and chemicals (Chavas et al., 2009).

An example of economic benefits of ecological farming is the success of the Non-Pesticide Management program in Andhra Pradesh (India) in reducing the costs of cultivation and increasing the net incomes of the farmers. The cost of cultivation was brought down significantly, with savings on chemical pesticides ranging between 600 and 6000 Indian Rupees (US$ 15 - 150) per hectare without affecting the yields (Ramanjaneyulu et al., 2008).

Ecological farming practices are ideally suited for poor and smallholder farmers, as they require minimal or no external inputs, use locally and naturally available materials to produce high-quality products, and encourage a whole systemic approach to farming that is more diverse and resistant to stress (UNEP and UNCTAD, 2008).

Can ecological farming help fight climate change?

Modern intensive agriculture model is one of the largest sources of global greenhouse gas emissions. Ecological farming is both a climate change mitigation and adaptation strategy:

- Efficient ecological farming practices that reduce synthetic fertilizer use and promote fertile soils rich in carbon could mitigate up to 70 percent of global agriculture emissions.
- Key to ecological farming for climate change mitigation is to build up a healthy, carbon-rich soil. This will provide a major carbon sink and at the same time will be the basis for a non-chemical, biodiverse and healthy agriculture.
- Significant emission reductions can be achieved by eliminating fertilizer overuse, which is a triple win: farmers save money by using only the amount of fertilizer used by the plant, emissions are significantly reduced, and nitrate contamination of lakes, rivers, oceans and groundwater is reduced. Growing legumes and/or adding compost, animal dung or green manures, natural nutrient cycling and nitrogen fixation can provide fertility without synthetic fertilizers, and at the same time cut farmers' expenses on artificial inputs and provide a healthier soil, rich in organic matter, better able to hold water and less prone to erosion.

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