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Climate Change Impact on Salt-affected Soils and Their Crop Productivity

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Min. of Earth Science
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FOREWORD

Climate change is an undisputed fact, so is the anthropogenic influence which has expedited this phenomenon by alteration of atmospheric gases and indiscriminate exploitation of natural resources. With a formidable task of feeding 17.5% of global human population with only 2.3% of land and 4% of water resources, for country like India, impacts of climate change on natural resources is an important subject, which needs critical examination. Worldwide assessments have indicated that developing countries like India will face additional ecological and socioeconomic stresses due to climate change. Greater seasonal variation in temperature, with more warming in the winter than summer and warmer temperatures at night and hotter days, are some of the trends which have been consistently noted across the country.

During the last decade India experienced a quick succession of droughts with most recent one in 2009 affecting *kharif* crops adversely. In contrast unusual summer rains and floods were experienced in many parts of India recently. The spatial distribution of surface warming suggests a mean annual rise in surface temperatures in North India by 3 °C or more by 2050. The surface mean air temperature could rise by 3 °C in Northern and Central parts, while it would rise by 2 °C in Southern parts during the same period. Globally, year 2003 experienced unprecedented heat and cold waves. Occurrence of higher temperatures in March 2004 adversely affected crops like wheat, apple, potato, and 2005 witnessed destructive hurricanes/cyclones. These changes in climate also play an important role for soil productivity. Expert assessments reveal that despite rise in CO_2 levels globally, during last one decade global primary productivity has decreased due to increased droughts and less availability of water in soil. While the productivity of land is declining due to climate anomalies, the agricultural area is shrinking due to several reasons including spread of marginal saline and sodic areas all over the country. It is due to the movement of salts into productive lands accelerated by increased temperatures, irrigation mismanagement and climatic shifts. High concentration of salts in the root zone limits the productivity of nearly 6.73 Mha of land in India. Similarly, 25% of the groundwater resources in the country are saline and brackish. With respect to climate change these marginally productive land and water resources not only pose challenge but also provide key opportunity of sequestering carbon into existing low carbon soil profile.

Researches are carried out to understand the climate change and its impact on production systems with due emphasis on precious natural resources. Many organizations nationally and globally are committed to take up the issue on priority. Ministry of Earth Sciences, Government of India has made climate change a focal theme, which is already here and striving hard to prepare for future threats, which might be even more adverse. It gives me immense pleasure to note that the Central Soil Salinity Research Institute, Karnal in association with the Ministry of Earth Sciences has organized a Brainstorming Session on ***'Climate Change Impacts on Salty Soils and Its Productivity'***, with the involvement of scientists, farmers and students. Present publication is a quality compilation of the deliberations made during the Brainstorming Session. I congratulate the entire team and the Institute for coming up with valuable recommendations on climate change for future use.

Dated: 30 July, 2013

(A.K. Sikka)

Health and quality of salt affected soils of India in changing climate scenario

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The nature has provided the mankind with four basic resources of climate, water, soil and biodiversity to meet the survival needs. Rational use of these natural resources to meet the needs will determine the longevity of civilizations. During the last more four decades, these resources have been stretched and over exploited to meet food, fibre and shelter requirements of burgeoning human and livestock populations. Over exploitation of water, soil and biodiversity has resulted in their degradation in terms of quality and availability. The food grain production in the country is revolving around 210 to 215 million tonnes since 2001-2002 owing to the adverse impact of weather abnormalities despite the advanced technology. Anthropogenic emissions of green house gasses have considerably increased due to faulty agricultural practices and has resulted in climate change and global warming of the planet (Swaminathan, 2002; Ramakrishna, 2007). Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluoro-carbons (HFCs), perfluoro-carbons (PFCs) and sulphur hexafluoride (SF5) are the six important gases which are responsible for the current global warming. It has been reported that increase in CO_2 concentration in the atmosphere during last 50 years has almost surpassed the increases reported during last 1000 years. The mean global annual temperatures increased between 0.4 to 0.7°C during the last century. The year 2005 has been reported the warmest year so far. Almost all the years in the current decade recorded extreme weather events, and the year 2007 has also been declared as one of the warmest years. Since last several years the wheat production in the country remained stagnated due to increase in temperature during reproductive phase of the crop across the wheat growing regions. As per FAO records, the wheat stocks have exhausted to its lowest level since 1980. The reasons attributed for such a shortfall include abnormal weather conditions in Australia, Ukraine, Argentina and Russia. Melting of glaciers, see level rise, submergence of islands/coastal areas and change in rainfall and temperature pattern over the next century are predicted. This change is bound to affect water availability, bio-diversity pattern, demand a new set of land use pattern including enterprises, commodities, crops and varieties. Global warming related ozone depletion has also been reported which may lead to increased UV radiation with far reaching adverse impact on earth's environment and human as well as livestock populations including microbial communities. Such effects of climate change have already started impacting agricultural productivity in several agroclimatic regions and sub-regions of India. The country experienced one of the severest droughts of the last century during 2002 that lowered food grain production by more than 29 million tons. The cold waves of 2002-2003, 2005-2006, and 2007-2008 caused significant damage to winter crops in the states of Punjab, Haryana and Western UP. The heat wave of March, 2004 in northern states coincided with the reproductive phase of wheat slowed down the translocation of photosynthetic assimilates from vegetative parts to grains and lowered the production by more than 4 million tons. Unexpected heavy rainfall (about 20 cm in 48 hours) during February, 2007 caused extensive damage to wheat and other Rabi crops in Haryana. The monsoon behaviour in 2007 over Kerala was totally different to that of previous years and very heavy rains were observed between June and September leading to severe flooding in low lying areas. Like several past years May, 2008 has also experienced low temperature and monsoon like weather conditions. Predicted spatial redistribution of precipitation, droughts, floods, heat waves, cold waves and water balance will change the land use pattern, cropping systems, pests and diseases.

Net impact on the productivity will be the resultant of contrasting effects of increased temperature and carbon dioxide concentration depending upon C_3 or C_4 plant and their cultivation in temperate or tropical region. These concerns are likely to provide ample opportunities to the agronomists to plan and execute research to deal with future scenarios of climate to sustain agricultural productivity and food and nutritional security in 21st century.

Impact of Climate Change on Agriculture

The climate change will effect crop yields and cropping pattern due to direct effects of changes in atmospheric concentrations of green house gases in general and CO_2 in particular (Aggarwal and Sinha, 1993). Carbon dioxide is a perfect example of a change that could have both positive and negative effects. Carbon dioxide is expected to have positive physiological effects through increased photosynthesis. This impact should be higher on C_3 crops such as wheat and rice than on C_4 plants like maize and grasses. It has been reported that under optimum conditions of temperature and humidity, the biomass increase could reach nearly 36% for a doubling of CO_2. This clearly indicates that the direct effects of changes will be through the change in temperature, precipitation and radiation. However, indirect effects will bring changes in soil moisture and infestation by pests and diseases because of rising temperature and relative humidity. The direct effects of increased carbon dioxide concentrations in the atmosphere are considered to have promoting effect on the growth and productivity of crops as explained earlier. The indirect effects through the increase in temperature will reduce crop duration, increase crop respiration rates, increase evapo-transpiration, decrease fertilizer use efficiencies and enhanced pest infestation. Possible impact of climate change on wheat production in India has been worked out by the climate scientists for the period between 2000 to 2070 (Fig.1). There are general consensus that the yield of main season (*kharif*) crop will increase due to the effect of higher carbon dioxide levels (Aggarwal and Mall, 2002). However, large yield decreases are predicted for the *rabi* crops because of increased temperatures. One of the potential effects of climate change on agriculture will be the shifts in the sowing time and length of growing seasons, which would alter sowing and harvesting dates of plants, crops and varieties. High temperature induced higher evapo-transpiration would call for much greater efficiency of water and nutrients. Changed weed flora and pests would require special methods of management and control, a challenge for agronomy and plant protection community. There may be a shift in climatic zones due to increased temperatures. In mid-latitudes, the shift is expected to 200-300 kms for every 1°C rise in temperature (IUCC, 1992); Morey and Sadhaphal (1981) reported a decrease of wheat yield by 400 kg ha^{-1} for a unit increase of 1°C temperature and 0.5 hour sunshine. Similar observations were recorded by Hundal and Parabhjot Kaur (2007) under Punjab conditions. Their analysis revealed that an increase of temperature from normal can decrease the wheat yields in the following order:

- Temperature increase in 4th week of January decreased the grain yield by 0.99, 0.66, and 0.70 per cent per degree centigrade for wheat sown in 4th week of October, 1st week of November and 2nd week of November, respectively.
- A decrease in grain yield to the extent of 2.88 and 1.87 per cent per degree increase in temperature occurred when wheat was sown in 4th week of October and 1st week of November, respectively.

- Increased temperature during the second fortnight of February decreased wheat yield by 2.40, 3.30, 2.15, 1.26 and 0.69 per cent per degree increase when wheat was sown in fourth week of October, first week, second week, 4th week of November and first week of December, respectively.
- Maximum decrease to the tune of 2.40, 2.10, 2.98, 3.51 and 3.15% occurred when temperature rose during first fortnight of March in case of wheat sown in fourth week of October, first week, second week, fourth week of November and first week of December, respectively.
- A yield loss of 1.24, 2.15 and 3.40% occurred in wheat sown in second week, fourth week of November and first week of December, respectively when temperature increased during 2nd fortnight of March.

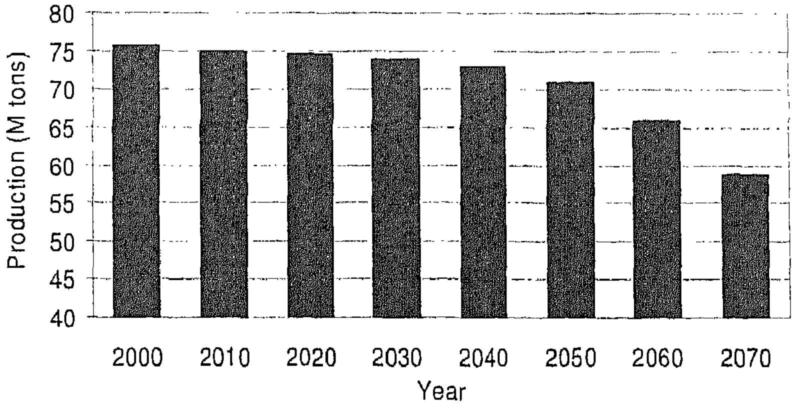

Fig. 1. Possible Impact of Climate Change on Wheat Production in India

Vijay Cuddeford (2002) reported that the area under rice may show a declining trend because several current rice varieties may not set grain under enhanced temperature conditions. There will also be less water for rice cultivation which may necessitate the need of adoption of water saving techniques such as Systems of Rice Intensification (SRI), arobic rice, direct seeded rice etc. The effect will be more pronounced in the drought prone areas where rice is cultivated as *rainfed* crop. Samra and Singh (2002), however, have suggested several strategies and contingent crop plans to negate/moderate the impact of sub-dued rainfall/drought in different agro-meteorological sub divisions of the country. Large scale impacts of climate change on the oceans will include; increase in sea level, increase in sea surface temperature, decreases in sea-ice cover, changes in salinity/alkalinity, wave climate and ocean circulation. Further, with global warming and associated sea level rise, many coastal systems will experience: increased levels of inundation and storm flooding, accelerated coastal erosion, sea water intrusion into fresh ground water, encroachment of tidal waters into estuaries and river systems, elevated sea surface and ground temperatures. Further, change in climate is expected to increase both the evaporation and precipitation. If rate of evaporation exceeds the rate of precipitation, soil becomes drier, lake levels will drop and rivers will carry less water. Warm water in lakes and reservoirs will likely to increase the blue-green algae and other nuisance lower plants that may reduce the levels of dissolved oxygen and adversely affect the fish productivity. With rise in temperature many fish species will try to shift to find out the cooler regions, either they move upstream of river or in the greater depths. Researchers forecast substantial shift in fish habitats, disrupt pattern of aquatic plant and animal distribution and alter the fundamental eco-system process that will result in major ecological change. Kumar and Parikh (1998) worked out economic loss between 9 to 25% for a temperature rise of 2 to 3.5°C. Similarly, Sanghi *et al.* (1998) predicted a loss of about 12.3% in net revenues for a rise of 2°C in temperature and 7% increase in rainfall. Coastal regions of Gujarat, Maharashtra and Karnataka are predicted to be most negatively affected. On the other hand, West Bengal, Orissa and Andhra Pradesh are predicted to benefit (to a small extent) from global warming.

Health and quality of salt affected soils:

High concentration of salts in the root zone soil reduces the productivity of nearly 6.73 Mha of otherwise productive lands in India. Similarly, 25% of the ground water resources in the country are saline and brackish. Certain states like Rajasthan and Haryana located in the western part of the country are endowed with 84 and 62% of poor quality ground waters, respectively. Continuous use of such water for irrigation to agricultural crops is bound to increase the problem of salinity and sodicity in India. Introduction of irrigation without making proper provision for drainage is the major cause for the development of salinity in canal commands. The projections indicate that the country will have 11.7 m ha area affected by salinity and sodicity by 2025. From reclamation and management point of view, the salt affected soils in India are broadly placed into two categories; 1) alkali or sodic soils and 2) saline soils. The alkali soils in general are characterized by high soil pH (upto 10.8), high exchangeable sodium percent (ESP) upto 90, low organic carbon, poor infiltration and poor fertility status. These soils are dominated by sodium carbonate and sodium bi-carbonate salts. Presence of excess amount of Na makes the soils deflocculated resulting in poor physical condition. On the other hand, the saline soils have higher electrical conductivity (> 4 dS/m), low ESP (<15%) and low pH (<8.5). The dominant salts in saline soils include chlorides and sulphates of Na, Ca and Mg. Most of these salts are soluble in nature and can be leached out from the soil profile, if sufficient quantity of water is available for leaching. The Central Soil Salinity Research Institute was established at Karnal in 1969 to develop strategies for reclamation and management of salt affected soils and judicious use of poor quality ground water resources. During last about 38 years of its existence, the institute has developed and standardized several location specific technologies for reclamation and management of saline and alkali soils. A brief account of these technologies is discussed in this paper.

Different sources quote different figures of area under salt affected soils in India. Depending upon the methodology used in estimation of salt affected soils, the quoted figures vary from 4 Mha to 26 Mha. However, in the recent past, the figure of area under salt affected soils in India has been reconciled in a joint consultation of CSSRI, Karnal, National Bureau of Soil Survey and Land Use Planning, Nagpur, National Remote Sensing Agency & State Remote Sensing Agencies. As per reconciled figures, there are 6.73 Mha salt affected soils in India. Sodic soils and saline soils constitute 3.77 and 2.96 Mha, respectively. The state wise area is given in Table 1.

In case the present trend of degradation continued, the projections are that India will have 11.7 m ha area affected by soil salinity and alkalinity. About 25 per cent of the ground water resources are saline and sodic and as such are not suitable for irrigation of field crops. Present use of poor quality waters in different states is given in Table 2.

Table 1: State wise area under Salt-affected Soils in India

State	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Island	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468

Projections by 2025 : 11.7 million ha

Table 2: Percentage use of poor quality water in different states

State	Percentage (estimated values)
Andhra Pradesh	32
Gujarat	30
Haryana	62
Karnataka	38
Madhya Pradesh	25
Rajasthan	84
Uttar Pradesh	47

Health and quality of alkali soils

Alkali soils contain excessive concentration of sodium carbonate and bio-carbonate, which are insoluble in nature. These salts need to be replaced with salts like calcium from the exchange complex. Several amendments like gypsum, pyrite, press mud, farm yard manure, sulfuric acid etc. were tried for reclamation of alkali soils. Based upon efficiency, cost and easy availability, gypsum ($CaSO_4.2H_2O$) has been identified as the most efficient and promising amendment for reclamation of alkali soils (Abrol and Bhumbla, 1979). Application of 15 tonnes of gypsum per ha, its mixing in upper 10 cm soil, followed by water application to facilitate gypsum dissolution and reaction is recommended for reclamation of soils having original pH_2 of 10.4. After gypsum application, rice-wheat crop rotation is followed for three to four years. Cultivation of *Sesbania* as green manure crop after wheat harvest hastens the reclamation process. After 3-4 years of rice-wheat cultivation, several other diversified crops like barseem (*Trifolium alexendrium*), shaftal (*Trifolium resupinatum*), mustard and pulses can be successfully grown.

By adopting this technology about 1.85 M ha alkali lands in the States of Punjab, Haryana and Uttar Pradesh have been reclaimed. The reclaimed area is contributing nearly

10-12 million tones of additional food grains to the central pool and about 175 million mandays of employment has been generated per year.

Health and quality of saline waterlogged soils

Introduction of irrigation in arid and semi arid areas without adequate provision for drainage of excess water, a sizeable area has gone under waterlogging and salinity. The workers at CSSRI standardized sub-surface drainage design criteria for different kinds of soils in the country to lower the water table and remove salts from the crop zone soil profile (Rao and Harrison, 1991). The sub surface drainage (SSD) technology involves laying of PVC pipes at about 1.2 to 1.4 m depth to take out excess water from the soil. Several pilot projects undertaken in different regions of the country proved that waterlogged saline soils can be successfully reclaimed through this technology. Strategies for the disposal of drainage effluent have also been standardized. The state wise drainage area covered is given in Table 3.

Table 3: State wise drainage area covered

State	Irrigation command	Area covered, ha*
Rajasthan	Chambal	15,700
	Indira Gandhi Nahar Priyojana	500
Haryana	Western Jamuna Canal	1450+3000*
	Bhakra Canal	1300+1000*
Punjab	South West Punjab	30+2000*
Karnataka	Uppeer Krishna	30
	Tungabhadra	200
	Malparbha/Ghatparbha	20
Andhra Pradesh	Nagarjuna Sagar	50
	Krishana Western Delta	50
Madhya Pradesh	Unspecified	50
Maharashtra	Uncommanded/ Neera Canal Command /others	1000+1000*
Gujarat	Mahi-Kadana	150
	Ukai-Kakrapar	80
Kerala	Acid sulphate soils	30
Assam	Tea gardens	15

(*Under Implementation/Approved Projects)

The perusal of the data in Table 3 indicates that average increase in productivity by 45% in paddy, 111% in wheat and 215% in cotton can be achieved. Increase in cropping intensity under different sub-surface drainage projects undertaken in the country is given in Table 4.

Table 4: Change in Cropping Intensity

Place	Before drainage	After drainage	Increase (%)
Sampla	0	200	-
Ismaila	73	148	103
Gohana	117	175	50
Konanaki	70	90	29
Uppugunduru	130	165	27
Islampur (Karnataka)			
ORP	0	200	-
Phase II	88	156	77

Some of the significant impacts of this technology includes i)large scale adoption in states like Haryana, Rajasthan and Maharashtra covering an area of about 60000 ha, ii) generation of additional 128 mandays per ha per year, iii) threefold increase in income. iv) minimum flood hazards and v) livelihood security of the rural population. However, high financial investment [about Rs.50,000 (US $ 1250) per ha], difficulty in maintenance of the drainage system, high skill involved in installation and maintenance of sub-surface drainage system, need of community participation, environmental problems associated with disposal of drainage effluents, energy and money requirement to pump the drainage water and social conflicts associated with diversified cropping options in the drainage area are some of the limitations of this technology.

Health and quality of salt affected Vertisols

A sizeable area under Vertisols in the States of Maharastra, Madhya Pradesh, Gujarat, Karnataka, and Tamil Nadu is affected by salinity and sodicity. These soils are heavy textured containing clay content more than 50% and are also underlain with saline/brackish ground water resources. Because of high clay content, these are subject to periodic drying and wetting cycles resulting in deep cracks. Reclamation of such soils, ones the salinity is developed is a difficult task. The exchangeable sodium percentage in these soils has more detrimental effects on soil physico-chemical characteristics and crops. It is generally believed that an ESP of about 8% is as detriment to the crops as an ESP of 15-20 per cent in sandy loam alluvial soils. Bio-saline agriculture has tremendous scope for reclamation and management of Vertisols. A number of salt tolerant plants having economic value have been identified for sustainable management of Vertisols. *Salvadora persica L* (Meswak), a salt tolerant facultative halophyte is identified as a potential source for non-edible oil. It tolerates salinity upto 50 dS/m and also responds well to saline water irrigation. The saplings can be raised using saline water of 15 dS/m. *Salvadora* seeds are good source of non-edible seed oil rich in C-12 and C-14 fatty acids having immense application in soap and detergent industry. Its cost of cultivation under field conditions including raising of nursery has been worked out as Rs.2760/- (US $ about 70) in the first year. The plant after 5 years yield oil about 1800 kg per ha which gives a net return of Rs.8400/- (US $ 210) per year. Dill (*Anethum graveolens*) is an another crop identified for cultivation in moderately saline black soils. This non-conventional seed spice crop gives fairly good yield on saline black soils having salinity 4-6 dS/m. Irrigating this crop with saline ground water in conjunction with best available surface water boosts up crop yields. The studies indicated that if surface water is available for one irrigation, it should be applied at seed formation stage and saline water at the vegetative/flowering stages. Its cost of cultivation in moderately saline soils comes to about Rs.6000/ha (US $ 150) and the crop yields net returns of Rs.16,500 (US $ 413) per ha. Its benefit cost ratio has been worked out at 2.75. This crop also offers an opportunity to the farmers for raising a successful crop in the *rabi* season on saline soils hitherto remain fallow due to water and salinity constraints. Similarly, other crops like wheat and safflower can be grown with cyclic use of good and poor quality ground water. In case of safflower branching and flowering stages are sensitive for saline water irrigation. If surface water is available for one irrigation, it should be applied at branching stage and saline water at vegetative and flowering stages. On the other hand, if surface water is available for two irrigations, it should be applied at branching and flowering stages and saline water at vegetative stage. For highly saline black soils underlain by highly saline ground water, use of halophytic grasses like *Aeluropus lagopoides* and *Eragrostis* have been found ideal for bio-saline agriculture. These grasses can be successfully grown using saline water of EC 30-40 dS/m. *Dichanthium annulatum* was found suitable for cultivation in saline soils having salinity upto 12 dS/m.

Similarly, *Matricaria chemomilla* and *Plantago ovata* medicinal crops can be grown in soils having pH_2 upto 9.5 and salinity in the range of 6-8 dS/m.

Health and quality of Coastal Saline Soils

Major problems associated with the coastal areas include excess water during *kharif* and no water for summer/*rabi* crops, high soil salinity, saline ground water at shallow depth, heavy soil texture, poor drainage condition, adverse climatic condition of cyclones, high acidity of soils at places, low efficiency of plant nutrients and non-availability of suitable variety of crops to suit the climate and the soil. As a result, the coastal area is mostly mono cropped with traditional rice varieties. Several options have been developed for sustainable use of coastal saline soils. Dorouv technology has been developed for skimming fresh rain water floating over saline ground water. This has resulted in almost doubling productivity in coastal areas of Andhra Pradesh. The salt tolerant varieties of rice identified include CSR1, CSR2, CSR3, CSR4, CSR7-1, Canning 7 and Sumati for coastal saline soils. Sapota and guava have been identified as promising fruit crops. Cultivation of *Ajola* in rice fields improves rice productivity significantly. Similarly, rice-fish system proved highly useful to increase farmer's income. Application of 3-4 tonnes per ha of lime in acid sulphate soils improved the rice productivity markedly. Rain water harvesting in dug-out farm pond for undertaking multi-enterprise agriculture with major emphasis on saline aquaculture has tremendous scope to sustain livelihood in coastal saline areas.

Some of the strategies to negate/moderate the impacts of climate change on health and quality of soils are summarized below:

- Developing new plant genotypes for drought, heat and cold tolerance adapted to climatic variability and ranges. There is a strong case to screen and document the already existing germplasm of crops, trees, animals and even microbes about their location specific response to such changes. Based upon this screening, location specific crop/variety calendars for application according to changed situation needs to be developed.
- Devising agronomic practices which may moderate/negate the impact of predicted climate changes and promotion of conservation agriculture practices such as zero tillage, bed planting, residue management and crop rotation.
- There is a need to develop contingency plans to coup-up with weather related abrasions such as cold and heat wave and drought prone regions. These contingent plans should be such that can be practically implemented on a short notice/warning.
- Developing precision and accurate forewarning mechanisms to reduce production risks and for undertaking preventive measures. There is a strong case now to go for developing and upgrading medium and long range forecasting systems (15-20 days in advance) so that farmers have reasonable time to respond to risks.
- Identification of genes for tolerance to moisture, heat and cold stresses and developing a canvas of transgenic having tolerances to abiotic stresses. Biotechnological approaches such as pyramiding of genes should be a priority area of future research in climate change.
- Reducing green house gas emissions through carbon sequestration in different land use systems with major emphasis on raising tree plantations on degraded soils. Research on bio-diesel /petro-crops such as *Jatropha* and *Pongamia* which have potential to substitute fossil fuels needs strengthening. Since India cannot afford to divert cultivable area from grain crops to ethanol/bio-diesel production, our priority should be to extend cultivation of such plants on degraded lands which constitute an area of about 107 Mha.

- Curtailing losses of methane and nitrous oxide from cultivated fields by increasing use efficiency of water, nutrients, energy and other agronomic manipulations.

- Manipulation of crop micro climate by means such as use of wind breaks, tunnels or green houses to reduce the effects of climate change.

- Genetic engineering/biotechnological tools which can convert C_3 plants into C_4 mode of photosynthesis to top the increased CO_2 in the environment for higher biomass production. .

- Develop knowledge based decision support systems for translating weather information into operational management practices at district, block and village Panchayat level.

- Benchmarking of areas prone to climate change impacts on agriculture and livestock and periodic monitoring to initiate timely preventive action.

- Establishment of automatic weather stations in all the 127 NARP zones to provide value added agromet advisory service to the farmers. There is also a need to establish climate monitoring towers/climatic control facilities at select places in the country for periodic monitoring of water, energy, gases and salt fluxes. These facilities should be used for designing location specific cropping/farming systems

- Promoting multi-enterprise agriculture to reduce risk and for assured livelihood security in areas prone to weather/climate abrasions. Nearly 50% of the farmers in India cultivate less than one ha land. Integrated farming system is a promising proposition for such small holding

- Improved management of livestock populations including poultry through better management of feeding and livestock housing. Animal sector is the major contributor for methane to the environment.

- Improving the efficiency of energy use in agriculture by using better designed efficient machinery and implements.

- There is a need to develop crop insurance and early warning systems to reduce/negate the impact of climate change and achieving stability in production. There is also a need to develop weather-crop-livestock relationships and weather-crop modelling for forecasting pest infestations.

- There is a strong case to intensify efforts for increasing climate literacy among all stakeholders of agriculture and allied sectors, students, researchers, policy planners, science managers, industry and farmers.

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Effect of climate change on soil properties

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While climate change is a global phenomenon, arid, semi-arid and coastal regions are especially vulnerable to climate change. Increased human induced activities have accelerated the process of climate change in the recent past and increased the mean global surface temperature by 0.6 °C over 100 years, a phenomenon known as global warming (Singh, 2012). According to intergovernmental panel on climate change (IPCC), the rise in global mean surface temperature with the same rate would be 1.4–5.8 °C by 2100 (IPCC, 2001). The climate change predictions over India indicated that temperature rise is likely to be around 3°C and rainfall increase is expected by 10-20 per cent over central states by 2100 A.D. Uncertainties in the minimum and maximum temperatures which may have adverse impact on agricultural production and productivity. Lal (2001) reported that an annual mean area averaged surface warming over Indian Subcontinent to range between 3.5 to 5.5 °C over the region by 2080. It is reported that a fall in rainfall by 5 to 25% in winter months and an increase of 10 to 15% in summer monsoon in India and the monsoon rainfall is without any trend, being highly random in nature over a long period of time (Mooley and Parthasarathy, 1984). India will also begin to experience greater seasonal variation in temperature, with more warming in the winter than summer (Christensen, 2007). The longevity of heat-waves across India have extended in recent years, leading to warmer temperatures at night and hotter days and this trend is set to continue (Cruz, 2007). Western India is expected to receive higher than normal rainfall as temperatures soar. This change in the amount of rainfall and shifts in the timing will adversely affect agriculture all over. The changes in soil moisture content, pests and weeds brought by climate change will affect the crops. Agriculture in coastal states will be worst affected where agricultural land is susceptible to inundation and salinity.

The extent and severity of soil degradation as well as vulnerability to degradation processes is alarming (Dejoux, 2001). Out of 329 million ha geographical area of the country, about 142 million ha is under cultivation and 120 million ha area is under degraded and waste lands. Salinity and sodicity has degraded about 6.73 million ha otherwise productive area in the country. Out of 6.73 million ha, 2.22 million ha (33% of the total salt affected area of the country) is occupied in Gujarat alone. In Gujarat 0.12 million ha is salt affected black soils covering Bara tract area (Amod, Vagra and Jumbusar taluka of Bharuch district), Bhal area and part of Vadodara, Surat and Ahmedabad districts.

Analysis of rainfall and temperature

Rainfall and temperature are the two parameters likely to be affected by climate change. To study the temporal trends, rainfall data for 36 years (1975–2011) and minimum and maximum temperature data for 18 years (1994-2012) were collected from agro-meteorological station at Navsari Agricultural University, Tancha farm (near Samni) in Bharuch district Gujarat. Its analysis revealed that average annual rainfall over 1975-2011 was 753 mm compared to 895 mm for the period 2000-2011(Table 1). The average annual rainfall during the period 2000-2011 was increased by 19 per cent over long term average (1975-2011). There was notable shifting in monthly rainfall during the monsoon period. Rainfall in the month of June to August during 2000-2011 increased by 11 and 40 per cent while no change in the month of September. The maximum and minimum temperature during 2000-2012 increased by 0.5 °C and 0.7 °C, respectively over the long term average (Table 2). Warmer winters are resulting in the increased incidence of pest attacks in the region. Consequently, farmers are being forced to incur a further burden of higher input/pesticide costs.

It is also observed that the intensity of rainfall was more during later period of monsoon for 2000-2011 as compared to 1975-2011 (Fig. 1). The water balance and length of growing period depends on the amount of rainfall and potential evapo-transpiration. Available water capacity and water holding capacity of soils play important role in determining the length of growing period. It is more affected in salt affected soils as the available water capacity is governed by the osmotic potential of these soils.

Table 1. Changes in average annual rainfall in Bharuch district

	Average annual rainfall for 1975-2011 (mm)	Average annual rainfall for 2000-2011 (mm)	Deviation
Total	753	895	+18.85%
June	159	177	+11.32%
July	232	293	+26.29
August	206	288	+39.80
September	120	120	0

Table 2. Variation in temperature in Bharuch district during 1994-2012 and 2002-2012.

Month	Temperature (°C)					
	Av. Max (1994-2012)	Av. Max (2002-2012)	Deviation	Av. Min (1994-2012)	Av. Min (2002-2012)	Deviation
Jan	29.5	30.0	0.5	12.3	12.5	0.2
Feb	32.5	33.0	0.5	14.3	15.0	0.7
Mar	37.0	37.4	0.4	18.5	18.8	0.3
Apr	39.7	40.2	0.5	23.4	24.0	0.6
May	39.6	39.9	0.3	26.9	27.2	0.2
Jun	36.7	36.8	0.2	27.2	27.3	0.1
Jul	32.8	33.3	0.5	26.1	26.1	0.0
Aug	31.5	31.1	-0.4	25.3	25.3	0.0
Sep	33.6	34.0	0.4	24.8	24.9	0.1
Oct	35.7	36.1	0.3	21.6	21.5	-0.1
Nov	33.9	34.0	0.1	17.1	17.7	0.6
Dec	31.0	31.2	0.2	13.2	13.7	0.4

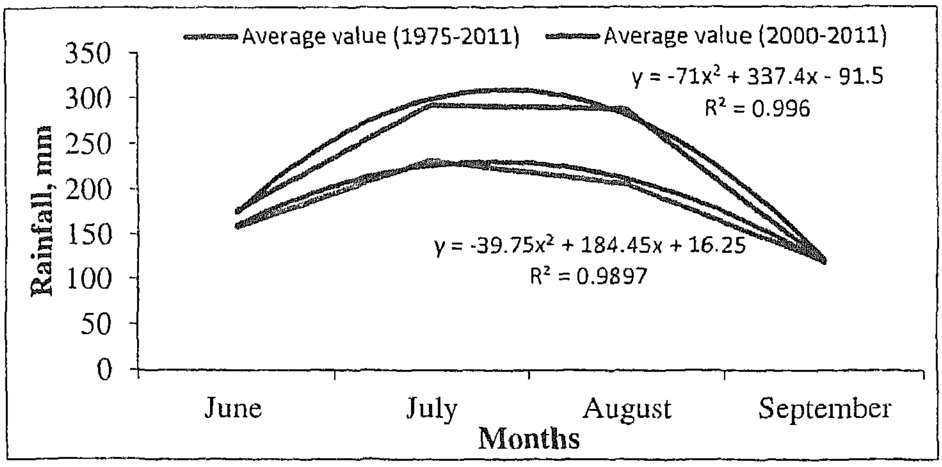

Fig.1. Average annual rainfall during 2000-2011 and 1975-2011

Effect of climate change on soil properties

Change in rainfall patterns and increase in average temperatures brought about by climate change are playing an important role. A rise in global temperature accelerates carbon losses from soils, driving up the concentration of carbon dioxide in the atmosphere. The changes in rainfall patterns will, of course, additionally contribute to an increase in erosion in vulnerable soils, which often already suffer from low organic matter content. Climate change will thus put further pressure on soil quality and will increase the risk of desertification and land degradation, which is already affecting in many areas. Climate change influences the pedogenic properties of soils. The main potential changes in soil-forming factors directly resulting from climate change would be in organic matter supply from biomass, soil temperature regime and soil hydrology, the latter because of shifts in rainfall zones as well as changes in potential evapo-transpiration. Other changes due to climate change (temperature and precipitation) are expected to be relatively well buffered by the mineral composition, the organic matter content or the structural stability of many soils. However, decrease in vegetation/crop cover due to scanty rainfall could lead to soil structure degradation and decreased porosity, as well as increased runoff and erosion on sloping sites and by the concomitant more extensive and rapid sedimentation. In certain fragile soils, the nature of the dominant soil-forming process may change for the worse with increased, decreased or more strongly seasonal rainfall. The changes in temperature but particularly in rainfall to be expected as a result of global warming are subject to major uncertainties for several reasons. In monsoon climates, increased intensities of rainfall events and increased rainfall totals would increase leaching rates in well-drained soils with high infiltration rates, and would cause temporary flooding or water-saturation, particularly in black soils with high clay content. Soils most resilient against such changes would have adequate cation exchange capacity and anion sorption to minimize nutrient loss during leaching flows, and have a high structural stability and a strongly heterogeneous system of continuous macropores to maximize infiltration and rapid bypass flow through the soil during high-intensity rainfall.

Increased microbial activity due to higher CO_2 concentration and temperature produces greater amounts of polysaccharides and other soil stabilizers. Increases in litter or crop residues, root mass and organic matter content tend to stimulate the activity of soil macrofauna, including earthworms, with consequently improved infiltration rate. The greater stability and the faster infiltration increase the resilience of the soil against water erosion and consequent loss of soil fertility.

Higher temperatures, particularly in arid conditions, exhibit a higher evaporative demand. Where there is sufficient soil moisture, for example in irrigated areas, this could lead to soil salinization if land or farm water management, or irrigation scheduling or drainage are inadequate as has been observed in the Sardar Sarovar Canal command area of Gujarat.

The depth of water table over the period (2005-2010) at some benchmark locations in Bara tract area under Sardar Saroval canal command of Gujarat showed a rising trend of groundwater level. In the year 2005, where groundwater depth was between 16-18 m below ground level (bgl) while in the recent years (2010) it raised up and depth was between 14-15 m bgl. It was observed that there was an increase in the groundwater depth over a period of five years (2005 to 2010) to the tune of 1.5 to 2.0 meters estimating a rate of rise of water table was 0.30 to 0.35 meter per annum.

Coastal regions of Gujarat are predicted to be mostly negatively affected. Studies indicated that extremely carbon depleted soils like salt affected soils have quite high potential for sequestering carbon in vegetation and soil if suitable tree and grass species are grown along with best management practices like rain water conservation. In saline Vertisols, the quasi-equilibrium value (QEV) of soil organic carbon (SOC) under the different land use systems showed that the agriculture system at 0-15 cm soil depth had the smallest value of 0.57% as compared to the forest (0.85%) and pasture land use system (0.95%). The QEV of SOC under the pasture was highest as compared to forest and agriculture systems. At this depth the carbon decreased to 0.57% after 8 to 10 years of agricultural practices indicating the decrease of 40%. This indicated that the pasture had the capacity to sequester more SOC than forest and the agriculture system on saline Vertisols. Soil organic matter sustainability under different systems were estimated for the saline Vertisols at various soil depths (0-15, 15-30 and 30-50 cm) under three different land uses comprising of agriculture, woody perennials and pasture based systems. Woody perennials and pasture based systems was found to have higher index than agriculture based system (Chinchmalatpure *et al.*, 2011). Pasture and woody perennials helps in sequestering more carbon than the agriculture systems under climate change scenario.

In Bara tract area of Gujarat, farmers perceived that seasonal cycle for agriculture was no more usual as it was 30 years back, and now climate became highly uncertain. They mentioned that there was an increase in winter temperature and a consequent loss of dew (atmospheric moisture) for the winter crops; irregularity in rainfall; delays in the southwest monsoon and a decline in rains in June; more intense rainfall events, a lot of rain in fewer days; patchiness in rainfall over a region; and a rise in summer temperatures and heat. Weather predictions made by indigenous indicators (flora and faunas) and astrology (*Panchang*) are now not much reliable. Farmers of Bara tract perceived that duration of summer was enlarged and winter was postponed. They say "Earlier, we simply could not sit in the cold, like we are now". They also said that the size of grain of wheat had reduced because of the warmer winters and over the last 4-5 years the weather had been much less cold than necessary for proper growth of wheat crop. Scientific studies confirm that night-time temperatures and maximum winter temperatures are rising. The dew, essential for soil moisture and crop growth on non-irrigated lands, had either lessened or stopped in recent years because of warmer winters. Dew forms and falls at a particular temperature and gets affected if the temperature rises above it. The numbers of rainy days decreased while average intensity of rainfall had increased over the period. The most common complaint was the irregularity in rainfall when the southwest monsoon begins. Three fourth of annual rainfall in Gujarat and in the country as a whole falls in these four months (June to September); hence erratic rainfall behaviour at this time has even weightier consequences. The southwest monsoon used to start on 20 June or thereabouts with reasonable punctuality during years it used to rain well. The Gujarati term itself for the period of the southwest monsoon rains, *chaumasu*, reflects rains over a four-month period. Other irregularities are lot of rain in fewer days and patchiness in rain over a region. Earlier, when the rains came, one would be assured it would rain evenly over a region. Whenever rainfall becomes erratic and intensity of rains increases, the cropping intensity under black cotton soil decreases due to waterlogging. The vulnerability of farmers growing *desi* (indigenous) cotton increased due to its long duration (8-9 months). Due to late cessation of monsoon, about 25 % farmers adapt indigenous varieties of catch crops like *Vigna radiata*, *Cicer arietinum* and *Vigna aconitifolia* to harvest the reserved soil moisture in black cotton soils with objective to increase productivity and multiple cropping index. Heavy heat in daytime and cold nights has resulted in withering away of flowering from fruit trees, and non-formation of seeds in small fruits has become a common feature in many citrus fruits. In Gujarat during 2011 climatic changes have affected yield production to the tune of 50 and 30 per cent in mango and chick, respectively.

Conclusion

Arid, semi-arid and coastal regions are more vulnerable to climate change. Western India is expected to receive higher than normal rainfall as temperatures soar. The average annual rainfall during the period 2000-2011 was increased by 19 per cent over long term average (1975-2011). There was notable shifting in monthly rainfall during the monsoon period. Rainfall in the month of June to August during 2000-2011 increased by 11 and 40 per cent while no change in the month of September. The maximum and minimum temperature during 2000-2012 increased by 0.5 °C and 0.7 °C, respectively over the long term average. Climate change will thus put further pressure on soil quality and will increase the risk of desertification and land degradation, which is already affecting in many areas. Climate change influences the pedogenic properties of soils. Woody perennials and pasture based systems was found to have higher sustainability index than agriculture based system. Pasture and woody perennials helps in sequestering more carbon than the agriculture systems under climate change scenario. So reclamation and management of salt affected soils and waters will help in sustaining food security and also help moderating climate change related risk in near future.

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Climate change: Adaptations and mitigation strategies for Indian Agriculture

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The earth's climate has remained dynamic throughout 4.5 billion years history of the earth, showing changes through a natural cycle periodically. These climate changes in the past geological time had profound influence on sea level, rainfall patterns and temperature related weathering processes. The climate components have changed at different rate and have made certain impact at different time periods. Most of the evidences of past climate change, however, are circumstantial. Comparison of observations with simulations from an energy balance climate balance model indicated that as much as 41-64% of pre-anthropogenic (pre-1850) decadal-scale temperature variations were due to changes in solar irradiation and volcanism (Crowley, 2000). The combination of a unique level of temperature increase in the late 20th century and improved constraints on the role of natural variability provides further evidence that the greenhouse effect has already established itself above the level of natural variability of the last 1000 years and is greater than the best estimate of global temperature change for the last interglacial. The global warming potential of carbon dioxide was estimated by the Sewdish Chemist Svante Arrhenius and by 1938 some other scientists also concluded that human consumption of fossil fuels was already leading to significant increase in atmospheric CO_2 and global average temperature (Callender, 1938). Since Industrial era the contents of Green House Gases (GHGs) particularly of carbon-dioxide has increased many fold (Table 1).

Table 1: Greenhouse gases level since industrial era

Greenhouse gas	Level	
	2005	1750
Carbon dioxide (CO2)	379 ppm	280 ppm
Methane (CH_4)	1774 ppb	715ppb
Nitrous oxide (N_2O)	319 ppb	270ppb

Source: Aggarwal (2008)

Huang *et al.* (2000) have reported that the 20th century to be the warmest of the past five centuries. Later on, Huang (2004) further stated reported that the 20th century warming is a continuation to a long-term warming started before the onset of industrialization, however, the warming appears to have been accelerated towards the present day. The 4th Assessment Report of IPCC (2007a) has stated that the change in earth's climate has been in an unprecedented manner in past 40,000 years, but greatly accelerated during the last century, due to rapid industrialization and indiscriminate destruction of natural environment.

Climate Change as defined by the Inter-governmental Panel of Climate Change (IPCC, 2007a) refers to a change in the state of the climate that can be identified by changes in the mean and /or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. Increasing evidences over the past few decades indicate that significant changes in climate are taking place worldwide as a result of enhanced human activities. The inventions/discoveries made during the last couple of centuries, more so in the last century, have altered the concentration of atmospheric constituents that lead to global warming. 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 a period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agricultural sector as a whole.

Global scenario of climate change

The various assessment reports brought out since 1990s by the Inter-Governmental Panel on Climate Change (IPCC) have reconfirmed that the global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) concentrations in atmosphere were 280 ppm, 715 ppb and 270 ppb in 1750 AD and these values have increased to 379 ppm, 1774 ppb and 319 ppb, respectively in 2005 (Aggarwal, 2008). The increase in green house gases (GHGs) was 70% between 1970 and 2004 and the IPCC has shown through a series of observations and modelling studies that these increases in GHGs have resulted in warming of the climate system by 0.74^0C between 1906 and 2005 (Aggarwal, 2008). The Inter-Governmental Panel on Climate Change (IPCC 2010) has projected that the temperature increase by the end of this century is expected to be in the range of 1.8 – 4.0 ^{0}C and it is also likely that future tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. Increase in the amount of precipitation are likely in high latitudes while decreases are expected in most sub-tropical land regions, continuing observed patterns in recent trends. The projected sea level rise by the end of this century is likely to be 0.18-0.59 m (Aggarwal, 2008). These global climatic changes will affect agriculture through their direct and indirect effects on crops, soils, livestock and pests. Increase in atmospheric CO_2 promotes growth and productivity of plants with C_3 photosynthetic pathway. Increase in temperature, depending on the current ambient temperature, on the other hand, can reduce crop duration, increase crop respiration rates, affect the survival and distribution of pest populations, hasten nutrient mineralization in soils, decrease fertilizer use efficiency and increase evapo-transpiration. Uncertainty in precipitation may cause drought and floods. These environment changes and sea level rise could also affect directly and indirectly the productivity in coastal regions. Further, there may be considerable impact on agricultural land-use due to melting of ice, availability of irrigation, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, decline in arable areas and availability of energy.

Estimating how climate change will affect agriculture adds complexity and uncertainty to already complex climate change models. Amidst this complexity and uncertainty, a fairly consistent pattern of direct agricultural impacts emerges. Agriculture in temperate North America, Europe and Asia is likely to benefit from higher mean temperatures and longer growing seasons, while agriculture in much of the rest of the world will likely suffer declines in productivity. Higher temperatures in already-hot regions will likely reduce crop yields and effectively shorten the growing season by introducing (longer) periods of excessive heat. The best estimates currently available, which combine forecasts from the agronomic and limited economic modeling approaches, suggest that the aggregate impact of these effects will reduce 6% global agricultural production by 2080 (ICTSD, 2010). Climate change will be severe in most of the developing countries thus having deleterious impact on agricultural production.

Indian scenario of climate change

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. Indian agriculture is more venerable to the impacts of climate change in view of high population depending on agriculture and excessive pressure on natural resources. The warming trend in India over the past hundred years (1901 – 2007) was observed to be 0.51^0C with accelerated warming of 0.21^0C per every ten years since 1970 (Kumar, 2009). 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 be almost 30-50% more than the current demand (Paroda and Kumar, 2000) in 2020. With alarming increase in greenhouse gases (GHGs) concentration and its expected impact on climate, meeting the future food requirement is posing a major challenge.

The IPCC has projected $0.5–1.2^0$C rise in temperature by 2020, $0.88-3.16^0$C by 2050 and $1.56–5.44^0$C by 2080 depending upon the scenario of future development in south Asia including India (IPCC, 2007b). Overall the temperature increase is likely to be much higher during *Rabi* season than in rainy *(Kharif)* season. Precipitation is likely to increase almost in all the months except during December-February when it is likely to decrease. Analyses done by the Indian Meteorology Department and the Indian Institute of Tropical Meteorology, Pune, generally show the same trends for temperature, heat waves, glaciers, droughts and floods, and sea level rise as by the Inter-Governmental Panel on Climate (IPCC, 2007b) of United Nations.

Climate change projections made up to 2100 for India indicate an overall increase in temperature by $2-4^0$C (Table 2) with no substantial change in precipitation (Kavikumar, 2010). At all India level, there is no trend in monsoon rainfall during last 100 years, but there are some regional patterns. Areas of increasing trend in monsoon rainfall are found along the west coast, north Andhra Pradesh and adjoining areas, north east India and parts of Gujarat and Kerala (-6 to -8% of normal over 100 years). The spatial distribution of temperature changes indicates a significant warming trend along the west coast, central India, and interior Peninsula and over northeast India. However, cooling trend has been observed in northwest and some parts in southern India. Instrumental records over the past 130 years do not show any significant long-term trend in the frequencies of large-scale droughts or floods in the summer monsoon season. The frequency of cyclonic storms that form over Bay of Bengal has remained almost constant over the period 1887-1997. The magnitude of impact of climate change is likely to vary to vary in different parts of the country. Parts of western Rajasthan, Southern Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh and Southern Bihar are likely to be more vulnerable in terms of extreme events (Mall and Aggarwal, 2002).

Table 2. Projected changes in climate in India (2070-2099)

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

Source: Kavikumar (2010)

Impact of Climate Change on Indian Agriculture

Based on analysis of the Intergovernmental Panel on Climate Change (IPCC), World Development Report (World Bank, 2009) states that agriculture accounts for 14 percent of global GHG emissions directly in CO_2 equivalents and indirectly accounts for an additional 17 percent of emissions when land use and conversion for crops and pasture are included in the calculations. Interestingly, agriculture's share in global GDP is about 4 percent; these figures suggest that agriculture is highly GHG intensive. Developing countries are more vulnerable to climate change because they depend heavily on agriculture as global warming has more impact and they lack capital to invest in adaptation mechanism to encounter the ill effect of climate change. It has been projected that a 2° C increase in average temperatures would reduce world GDP by roughly 1% (Stern, 2007), climate change will ultimately cause a decrease in annual GDP of 4% in Africa and 5% in India without offsetting the innovations for mitigation of impact of climate change (World Bank, 2009). Further, Easterling *et al.*, (2007) reported that food security of most developing countries including India is likely to come vulnerable in the near future with moderate increase in temperature. At the same time, differential impacts of climate change on food production are likely to have consequences on international food prices and trade.

In India, agriculture sector contributes 28% of the total GHGs emissions from India (NATCOM, 2004). The emissions from agriculture are primarily due to methane emission from rice paddies, enteric fermentation in ruminant animals, and nitrous oxides from application of manures and fertilizers to agricultural soils. The emissions from Indian agriculture are likely to increase significantly in future due to our need to increase food production. The latter would require greater emphasis on fertilizers and other inputs which will lead to increased emissions of nitrous oxides and other GHGs. Increase temperatures would lead to higher emissions even at the current level of fertilizers consumption.

The impact of climate change is likely to have a great influence on the agriculture and eventually on the food security and livelihoods of a large section of the rural population in developing countries. Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, and heat waves are known to negatively impact agricultural production and the livelihood of the farmers. Earlier studies conducted in India also generally confirm the trend of agricultural decline with climate change (Lal *et al.*, 1998; Saseendran *et al.*, 2000; Aggarwal and Mall, 2002). Recently, it has been projected there is a probability of 10–40%

loss in crop production in India by 2080–2100 due to global warming (Parry *et al.*, 2004) despite beneficial aspects of increased CO_2, if adaptation mechanism to encounter climate change is not put in place.

Systematic studies on climate change in our country are very few, however, some studies have been published on the quantification of impact on different crops in various parts of country by using several methods including simulation models. Climate scientists depend on models that incorporate sophisticated understanding of the coupled behaviour of the climate system. Apparently, climate models are the main tools available for developing projections of climate change in the future (Houghton *et al.*, 2001). In fact, for such studies, well calibrated and validated crop weather models could be used as an effective tool for assessing the impacts of future changes in climate (Saseendaran *et al.*, 2000). However, the presence of large uncertainties in climate models and future emission scenarios predicting long term changes in certain climate variables, in particular in regional scales, is a challenging task that climate modellers face today (New and Hulme, 2000 and Ghosh and Mujumdar, 2009). While most models used for this purpose have been validated at the plot level, few studies have evaluated them for multiple years at a regional level (Carbone *et al.*, 2003). However, estimates of radiative forcing reveal that gases like CO_2 contribute to warming, whereas aerosol and clouds tend to cool the surface leading to the global warming controversy. It is known that climate models do a reasonable job of capturing the large-scale aspects of current climate, but still contain systemic model errors adding uncertainty to the future projection (Annamalai *et al.*, 2011). Hence, the regional model outputs on temperature and rainfall variations have to be handled with caution while using them for impact assessment.

Early studies indicated that significant changes in climate are observed over different regions of the country during the past 25 years (Sinha *et al.*, 1998a). For example, many parts of northern India show increase in minimum temperature by about 1^0C in *rabi* cropping season. However, mean temperatures are misleading as some of the individual regions could exhibit a larger variation with a larger impact on *rabi* crop production. Sinha and Swaminathan (1991) presented a case study of actual change in temperature in North India. They brought out that while the mean air temperatures over the wheat growing regions were high by 1.7^0C over a period of 15 days (January 16 to February 1), the actual temperature rise was 2.3 to 4.5^0C in the major wheat-producing region of Punjab and Haryana (Sinha *et al.*, 1998b). Through these studies they projected the serious effects of regional temperature on productivity of major crops. They further added that in view of the proportionate production changes in major food crops, viz., rice and wheat, over the years, the dependence on rice and wheat has increased considerably. Therefore, any factor that would influence the productivity through climatic change would affect the food security of the nation, as both these crops are sensitive to temperature variations.

Earlier research results indicate that the productivity of rice crop declines by 41% for 4°C increase in temperature (Lal *et al.*, 1998). However, there are reports indicating that the choice of the variety makes a difference between increase and decrease in the yield while being exposing to climate change scenarios (Challinor *et al.*, 2008). The results of recently published study conducted over the Cauvery basin of Tamil Nadu using PRECIS and RegCM3 regional climate models (RCMs) showed an increasing trend for maximum temperature, minimum temperature (Table 3) and rainfall (Geethalakshmi *et al.*, 2011).

The study further reported yields of rice (ADT 43) simulated by decision support system with CO_2 fertilization/enrichment effect had shown a reduction of 135 kg $ha^{-1}decade^{-1}$ for providing regional climates for impact studies (PRECIS) output, while there was an increase in yield by 24 kg ha^{-1} $decade^{-1}$ for regional climate model system 3 (RegCM3) output, whereas, the yields have shown a reduction of 356 and 217 kg ha^{-1} $decade^{-1}$ for PRECIS and RegCM3 outputs respectively, without considering the CO_2 fertilization effect. Agarwal and Mall (2002) have also reported that 2°C increase in mean temperature has resulted in considerable decrease in grain yield of rice, if there is no adaptation measure taken. Later on Aggarwal (2008) reported that for every 1^0C increase in temperature, yields of wheat, soybean, mustard, groundnut and potato are expected to decline by 3-7%. Similarly, rice yields may decline by 6% for every 1^0C increase in temperature (Saseendran *et al.*, 2000). Recently, IWMI, 2007 estimated that for every 1°C rise in mean temperature, there is a corresponding 7% decline in rice yield; similarly, the International Food Policy Research Institute calculates a 12-14% decline in world rice production by 2050 due to the effects climate change.

Projections indicate the possibility of loss of 4–5 million tonnes in wheat production with every rise of 1°C temperature throughout the growing period with current land use (Aggarwal, 2008). In March 2004, temperatures were higher in the Indo-Gangetic plains by 3–6°C, which is equivalent to almost 1°C per day over the whole crop season. As a result, wheat crop matured earlier by 10–20 days and wheat production dropped by more than 4 million tonnes in the country (Samra and Singh, 2004). Losses were also significant in other crops, such as mustard, peas, tomatoes, onion, garlic and other vegetable and fruit crops (Samra and Singh, 2003). Similarly, the drought of 2002 led to reduced area coverage of more than 15 Mha of the rainy-season crops and resulted in a loss of more than 10% in food production (Samra and Singh, 2002). The projected increase in these events could result in greater instability in food production and threaten livelihood security of farmers. Similarly, increase in temperature also has adverse effect of temperate fruit crops such as apple and other stone fruits. During last decade, it been observed that there was a significant decrease in average productivity of apple particularly in Kullu and Shimla (HP) which was closely correlated with the inadequate chilling hours which is quite crucial for good apple yields. This type of changes can result into shifting of such fruits to higher elevations.

Table 3. Projection of decade mean maximum and minimum temperatures over the Cauvery Basin

Decade	Maximum temperature (^{o}C)		Minimum temperature (^{o}C)	
	PRECIS	REgCM3	PRECIS	REgCM3
1971-1980	34.0	31.9	24.2	21.6
1981-1990	34.5	31.9	24.5	21.7
1991-2000	34.1	32.0	24.3	21.9
2001-2010	35.0	32.1	25.3	22.0
2011-2020	35.0	32.5	25.3	22.3
2021-2030	35.8	32.4	26.1	22.4
2031-2040	35.5	32.7	26.0	22.8
2041-2050	36.6	33.1	26.9	23.2
2051-2060	36.3	33.3	26.8	23.6
2061-2070	37.0	34.1	27.4	24.2
2071-2080	37.6	34.2	28.2	24.5
2081-2090	37.3	34.6	28.0	24.9
2091-2099	37.7	35.0	28.3	25.3
Difference	3.7	3.1	4.2	3.7

Source: Geethalakshmi *et al.* (2011)

Recent simulation analysis projects adverse impacts on maize yields in *kharif* due to rise in atmospheric temperature; but increased rainfall can partly offset those loses. Spatio-temporal variations in projected changes in temperature and rainfall are likely to lead to differential impacts in the different regions (Byjesh *et al.*, 2010). Analysis on sorghum also indicated that the yield loss due to rise in temperature is likely to be offset by projected increase in rainfall. However, CO_2 enrichment/fertilization has clearly demonstrated beneficial effect on productivity particularly in C_3 plants. A recent meta-analysis of CO_2 enrichment experiments in fields has shown that in the field environment, 550 ppm CO_2 leads to a benefit of 8–10% in yield in wheat and rice (Kumar *et al.*, 2011), up to 15% in soybean, and almost negligible in maize and sorghum, but increase in temperature may alter these results. However, complete amelioration of yield loss beyond 2^oC rise may not be attained even after the doubling of rainfall (Srivastava *et al.*, 2010). While the above review indicates gross effects of climate change on crops in India, there are several special ecosystems that are ecologically and economically important, but assessment of impacts on agriculture in these regions has not received adequate attention.

Climate change is expected to accelerate the hydrological cycle, which may result into more precipitation mainly due to reduction of glacier size in long term, thus having contrasting impact on water resources. Trend analysis of past precipitation data in India has not shown any major widespread change in the patterns so far but the results of General Circulation Models (GCMs) show that in future these patterns are likely to change. These changes could be in the seasonal patterns as well as the quantity of precipitation; some areas are likely to receive more precipitation, and others less. This change is termed by some experts as 'wet getting wetter' and 'dry getting drier', whereas these effects are compounded by the sea-level rise in coastal area. The IPCC (2007b) reported a significant increase in runoff in many parts of the world including India. This, however, may not be very beneficial, as the increase was largely in the wet season and the extra water may not be available in the dry season unless storage infrastructure could be vastly expanded. In India, winter precipitation is projected to decline and this is likely to lead to higher need for *rabi* irrigation, lesser storage and increased water stress during the pre-monsoon months. Intensity of rains is projected to increase, which will imply more frequent and severe floods and lesser recharge to groundwater (Jain, 2012).

Further, water for agriculture is becoming increasingly scarce, and climate change-induced higher temperatures will increase crops' water requirements, so shortages will become more serious in coming decades. By 2025, 15–20 million of the world's 79 million hectares of irrigated rice lowlands, which provide three-quarters of the world's rice supply, are expected to suffer some degree of water scarcity (IWMI, 2007). It is also estimated that to eliminate hunger and undernourishment for the world's population by 2025, the additional water requirements may be equivalent to all freshwater withdrawn and used today for agricultural, industrial and domestic purposes (SIWI, 2005). Ways must be found to increase water use efficiency in both irrigated and rain fed agriculture.

Another important threat of climate change is water quality. Since the solubility of gases and rate of biological processes change with temperature, water quality is going to be affected. Changes in water availability may affect concentrations of suspended sediment, nutrients and chemical contaminants in rivers and lakes. Changes in precipitation intensity and frequency will also influence non-point source pollution.

Adaption Strategies to Climate Change

Adaptation strategies should focus on development of new resource use efficient and multiple stress tolerance genotypes, development of new land use systems, evolvement of new agronomic management strategies for climate change scenario, explore opportunities for maintenance/restoration/enhancement of soil properties, popularization of resource conservation technologies, development spatially differentiated operational contingency plans for temperature and rainfall related risks, including supply management through market and non-market interventions in the event of adverse supply changes, value added weather management strategies for reducing production risks, development of knowledge based decision support system for translating weather information into operational management practices and use and explore of opportunities for utilization of indigenous traditional knowledge. We need to identify adaptation strategies that may anyway be needed for sustainable development of agriculture. These adaptations can be at the level of individual farmer, society, farm, village, watershed, or at national level. Some of the possible adaptation options are discussed here.

Alternate land use systems

Agroforestry is a dynamic, ecologically sound, natural resource management practice that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production from increased social, economic and environmental benefits. Approximately 1.2 billion people (20% of the world's population) depend to a large extent on agroforestry products and services for their survival. Incorporating trees into farming systems leads to greater prosperity at the farm level. Trees provide farmers with marketable products-such as lumber, building poles, firewood, animal fodder, fruits, medicines, etc, all of which earn extra income. They improve soil fertility by fixing nitrogen from the air and recycling nutrients from the soil, thereby helping to increase crop yields and helping to ensure stability of future production. Trees on farms also help hold moisture where it is needed, reduce soil erosion and keep valuable topsoil in place, reduce intensity of downstream flooding and maintain watershed building materials. They serve as live fence in semi-arid regions, protecting vegetable and cereal crops that would otherwise be overrun by livestock.

Agroforestry for salt-affected lands

On the basis of experiments conducted on highly alkali soil *Prosopis juliflora, Acacia nilotica, Casuarina equisetifolia, Tamarix articulate, Eucalyptus tereticornis* and *Parkinsonia aculeata* demonstrated a higher tolerance. The biomass of 7 years old *T. articulata, A. nilotica* and *P. juliflora* was 97.3, 69.8 and 51.3 t/ha, respectively. Air-dry biomass from 19.22 to 56.5 t / ha has been obtained from different species raised on high sodic soil. The woody species like *Acacia farnesiana, Parkinsonia aculeata* and *Prosopis juliflora* were rated the most tolerant to waterlogged salinity and could be grown satisfactorily on soils with salinity levels up to 50 dS/m in their root transmission zone. Tree species like *Acacia nilotica, A. tortilis, Casuarina glauca, C. obesa* and *C. equisetifolia* could grow on sites with ECe varying from 10 - 25 dS / m. The biomass of *P. juliflora* and *C. glauca* was the highest (98 and 96 t/ha, respectively) followed by *A. nilotica* (52 - 67 t/ha) and *A. tortilis* (41 t/ha) when planted with sub surface or furrow techniques proving that these are the most suitable species for saline waterlogged soils.

Agroforestry for degraded calcareous soil in dry regions irrigating with saline water

Several trees can be established using saline water up to EC of 10 dS/m. Tree species such as *Tamarix articulate, Azadirachta indica, Acacia nilotica, A. tortilis, A. farnesiana, Cassia siamea, Eucalyptus tereticornis, Feronia limonia, Prosopis juliflora, P. cineraria,* *Pithecellobium dulce, Salvadora persica, S. oleoides* and *Ziziphus mauritiana* are promising. Among tested forage grasses *Panicum laevifolium* produced maximum forage biomass followed by *P. maximum*. Even in the lean period (when people are forced to lead nomadic life along with their herds of cattle) sufficient forage was available from all these perennial grasses. Scheduling the saline irrigation at Diw/CPE ratio of 0.4 improved the yields by about 20% while no further improvement was obtained with enhanced saline irrigation supplies.

Among fruit trees *Carissa carandus, Emblica officinalis, Ziziphus mauritiana* and *Aegle marmelos*) were found promising. In the inter-spaces crops such as pearl millet, cluster bean and sesamum (during *kharif*) and barley and mustard during *rabi* were found highly profitable. Among other non-conventional crops castor (*Ricinus communis*), *Aloe vera*, Dill (*Anethum graveolens*), tara-mira (*Eruca sativa*), Isabgol (*Plantago ovata*) and lemon grass (*Cymbopogon flexuosus*) could be cultivated successfully. *Cassia senna* and *Lepidium sativum* can also be cultivated successfully irrigating with saline water up to 8 dS/m. All these high value crops can successfully be grown as inter-crops with forest or fruit trees at least during initial years of establishment. Ornamental flowers such as *Chrysanthemum, Calendula* and *Matricaria* can also successfully be cultivated irrigating with water of EC up to 5 dS/m. Different cultivars of vetiver could produce 72.6 to 78.7 t/ha shoot biomass and 1.12 to 1.71 t/ha root biomass. The roots are used to extract aromatic oil.

Agroforestry for salty black soils (saline Vertisols) using saline irrigation

Prosopis juliflora and *Azadirachta indica* were most successful species for saline vertisols. Among grasses, *Aeluropus lagopoides, Leptochloa fusca, Brachiaria mutica, Chloris gayana, Dichanthium annulatum, Bothriochloa pertusa* and species of *Eragrostis, Sporobolus* and *Panicum* are most successful. Aromatic grasses such as *Vetiveria zizanioides* and *Cymbopagon martinii* can be grown easily. *Matricaria chamomile* can withstand both high pH and ESP.

Among fruits gooseberry (*Emblica officinalis*) and B*er* (*Ziziyphus mauritiana*) were the most successful plantations for these soils. Oil-yielding bush *Salvadora persica* was grown in combination with *Leptochloa fusca, Eragrostis* spp. and *Dichanthium annulatum* forage grasses on saline vertisol in Gujarat with pH ranging from 7.2 to 8.9 and ECe from 25-70 dS/m. These grasses could produce on an average 3.7, 1.0 and 1.8 t/ha of green forage, respectively. During fourth year the seed yield of *Salvadora persica* ranged from 1.84 to 2.65 t /ha with oil contents ranging from 576-868 kg/ha at different salinity levels.

Combating waterlogging through biodrainage

In waterlogged areas near canals planting cloned *Eucalyptus* on bunds (of ~ one meter height) on farmers field (in two lines in a space of 1m x 1m) each strip separating 66 m (growing crops between two strips), proved very useful, and water table was lowered below 2 m after 5 years of plantations. It not only controlled rise in water table but also helped in revenue generation. Farmers harvested 34 t/ha fresh aerial biomass and 12.3 tones root biomass per ha from 5 years and 4 months old plantation. The strip-plantations sequestered 15.5 t ha^{-1} carbon. After harvest trees could coppice further. Benefit–cost ratio of the first rotation of strip plantations (excluding crop yield) was 3.5: 1 and it would be many folds for next 3 to 4 rotations due to negligible cost of coppiced *Eucalyptus*. Wheat yield in the interspaces of strip-plantations was 3.4 times that in adjacent waterlogged areas without plantation. It was mainly because of lowering of the water table and improvement in soil properties.

Efficient water management techniques

With the increase in demand of water for allied sectors, agriculture must improve water use efficiency generally. Adding climate change to this mix only intensifies the demands on water use in agriculture. With hotter temperatures and changing precipitation patterns, controlling water supplies and improving irrigation access and efficiency will become increasingly important. Climate changes will burden currently irrigated areas and may even outstrip current irrigation capacity due to general water shortages, but farmers with no access to irrigation are clearly most vulnerable to changed scenario. Therefore, there is urgent need of techniques, technologies and investments that improve water use efficiency, access to irrigation or to find ways to improve incomes with less secure and more variable water availability. Popularization of micro-irrigation is the need of hour to maximize the water productivity with each drop of water. Improving the inefficiencies in delivering system also require investment and farmers participation for integrated water management. To discourage injudicious and excess use of water for production, there is need for rational pricing of surface and groundwater can arrest its excessive and injudicious use in overexploited regions like Punjab, Haryana and Tamil Nadu whereas development of infrastructure could create a situation of better utilization of groundwater in the region of less use of ground water like eastern India.

The cultivation methods and practices do influence the water productivity in the changed scenario of climate change. Since rice is the major crop in Indian subcontinent and is the major water consumer among all the crops. Studies conducted with different cultivation methods indicated that the system of rice intensification (SRI) method produced 22% higher grain yield with 24.5% water saving compared to transplanted rice (Geethalakshmi *et al.*, 2011). Water productivity was also maximum under SRI method of rice cultivation (0.58 kg/m^3), followed by alternate wetting and drying method, and aerobic rice cultivation (Table 4). Beside water saving, SRI method of planting significantly reduced the methane emission (Nguyen *et al.*, 2007; Yan *et al.*, 2009) thus indicating that SRI method of cultivation will suit better under future warmer climate in terms of economizing water and increasing the productivity. Efforts should be initiated to develop the package of practices for SRI in different agro-ecological regions and popularization of this technology in the current scenario.

Table 4. Grain yield and water productivity in different rice cultivation systems

System of cultivation	Grain yield (kg/ha)	Water saving over conventional method (%)	Water Productivity (kg/m^3)
Transplanting method (Conventional)	6032^b	-	0.36^c
Direct sowing rice	5175^c	6.2	0.33^d
Alternate Wetting and Drying	5111^c	25.7	0.41^b
System of Rice Intensification (SRI)	7359^a	24.5	0.58^a
Aerobic rice	3582^d	42.3	0.37^c

Means within the column followed by the same letter are not significantly different (LSD at $P = 0.05$)

With dwindling water availability, 'deficit irrigation' can make a substantial difference in productivity in the areas having limited access to irrigation. In *rain-fed* areas, water conservation and water harvesting techniques should be given due consideration for higher productivity. Greater emphasis on water harvesting and improving the efficiency of regional as well as farm water use efficiency could help to face uncertain rainfall. Policies are needed that would encourage farmers to conserve water and use it judiciously. For example financial compensation/incentive/subsidy for increasing the efficiency of irrigation water use through drip and sprinkler methods could encourage farmers to improve soil health, manage with less water, and assist in overall sustainable development.

Since freshwater supplies are limited and has competing uses, and would become even more constrained in changed global climate, we have to start vigorous evaluation of using industrial and sewage wastewater in agriculture. Such effluents, once properly treated can also be a source of nutrients for crops. Since water serves multiple uses and users, effective inter-departmental co-ordination in the Government is needed to develop the location–specific framework of sustainable water management and optimum recycling of water.

Resource conservation technologies

Production techniques may be as important as production technologies in climate change adaptation and mitigation. In the projected scenario of climate change, conservation agriculture holds good as adapting strategy to build up organic matter in soils and create a healthy soil ecosystem by not tilling the soil before each planting. Resource conservation technologies (RCTs) such as zero-tillage and bed planting have been shown to be beneficial in terms of improving soil health, water use, crop productivity and farmers' income (Gupta and Seth, 2007). Zero-tillage is widely adopted by farmers in the Northwestern India, particularly in areas where rice is harvested late. It has been well documented that ZT can save 13–33% water use and 75% fuel consumption (Malik *et al.*, 2002) whereas bed planting has the potential to save water by 30–50% in wheat (Kukal *et al.*, 2005).

In addition, such resource conserving technologies restrict release of soil carbon thus mitigating increase of CO_2 in the atmosphere. By increasing the organic matter in soils, conservation agriculture improves the moisture capacity of the soil and thereby increases water use efficiency. The practice also reduces carbon emissions by reducing tilling, although it also requires more sophisticated pest and disease control because the system is not 're-booted' at each planting. An array of other production management practices and technologies could similarly improve farmers' mitigation and adaptation to climate change, including equipment and information that enables more precise application of inputs, especially fertilizer. The key challenge is to assure that such practices do not reduce yields so that the demand for additional land offsets the benefits from on-field sequestration. Therefore, there is need to frame policies and incentives that would encourage farmers to sequester carbon in the soil and thus improve soil health, and water use and energy more efficiently. Policies to support the diffusion of this information and to help interpret these forecasts in terms of their agronomic and economic implications are required to help farmers in a big way.

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Socio-ecological dynamics and climate change: Sustainable adaptation

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Global climate change is a reality today with negative consequences for human cultures, livelihoods and ecosystems (O'Brien *et al.*, 2004; Adger *et al.*, 2012). Climatic change is being considered as a systemic phenomenon of the environment (Go´mez-Baggethun *et al.*, 2012) with which farming and local communities have historically evolved, adapting their traditional ecological knowledge (TEK) systems and associated institutions to accommodate current shocks (Colding *et al.*, 2003). Observations of traditional communities and rural farmers on local environments and inferences drawn using indigenous bio-meteorology and weather variables (Turner and Clifton, 2009) enable these peoples to develop climate resilient local adaptation strategies (Carter *et al.*, 2007). In recent past, weather advisory has also played a key role to adapt climate change (Singh, 2013). However, farmers' strategies are one of the least understood aspects of broad-scale sustainable adaptation and management of natural resources (Go´mez-Baggethun *et al.*, 2012). Whereas no single stakeholder has immediate and promising solutions to offer in adapting to climatic variables, different stakeholder has different resources (e. g. knowledge, creativity, practices and monitory resources). The key to strengthening agricultural adaptation is to integrate these different resources (SRC, 2012).

Work done elsewhere has shown that mainstreaming farmers' knowledge and perceptions into policy can result in more effective ways of combating climate change (Eriksen *et al.*, 2011) as compared with relying exclusively on externally supported technologies (McIntyre *et al.*, 2008). After 65 years of independence, India's climate change and science policy makers have recognized that farmers' knowledge, experience, and grassroots innovations can be applied at a broader perspective to enhance location specific agricultural adaptations (NAPCC 2008, p5). In the past, Indian scientists and policy makers did not recognize the full potential and dynamic nature of TEK. But, recently some of the TEK have been validated scientifically in adaptation initiative. Thus, with its dynamic potential, TEK has opened the eyes of formal science and policy makers to use it in location specific and convincing agricultural adaptation research (Singh, 2013).

Within the last two decades, high levels of climatic variability in various parts of India have imposed negative consequences on agricultural resources (Pant, 2003; O'Brien *et al.*, 2004). From the year 2009 to 2012, for example, large agricultural areas have experienced abrupt changes in seasonal cycles, high intensity rainfall with reduced number of rainy days, and semi- to severe droughts (Inter Press Service, 2013). The sensitivity of small-scale and marginal farmers to such environmental risks, and associated socio-economic, institutional and policy constraints (a compounded impact) has magnified their agricultural vulnerability, as for example in the drought of 2013 in Maharashtra state (The Hindu, 2013). Such circumstances occurring over the years in many socio-ecological systems of India have forced many of these farmers to draw on and expand their TEK, grassroots creativity, knowledge networks and social capital, other than using appropriate scientific technologies to adapt and sustain their livelihoods. These TEK-led adaptations provide significant insights (Gomez-Baggethun *et al.*, 2012) for their mainstreaming into sustainable adaptation policies, with provisions for participatory learning between TEK holders, planners and policy makers in agriculture (Singh *et al.*, 2011).

Based on the questions and arguments raised above, this study was carried out with aim to (i) study perception and experience of farmers about climate variability in different socio-ecological systems (SES) of India, and (ii) explore traditional ecological knowledge, grassroots innovations and scientific technologies led adaptations in varied SES of India.

Perception about climatic variability

The data in table 1 reveal that, in general farmers from varied socio-ecological systems are experiencing variable climate. Majority over 85.4 % from Haryana and 89.3 % from UP agreed that duration of winter is decreased. Similarly for the occurrence of drought, flood and predictability of weather, farmers from varied socio-ecological systems agreed that they are experiencing problems in agriculture with regards to sowing/transplanting of crops and their management. The similar situations prevail in Arunachal Pradesh also where farmers have very close interaction with not only agriculture but community based forest resources management also. They have noticed changes in phonological behavior of some plant species. For example bioculturally important key stone species, *Gymnocladus burmanicus* and oil seed plant namdung (*Perilla ocymoides*) are threatened. These two species have been the part of food and hunting system of *Adi* tribe. The process of fermented foods prepared from legumes and semi-domesticated species are getting affected as perceived by *Adi* women. Now, the indigenous indicators which have been used in predicting weather have become less reliable in most of the cases as agreed by farmers from Haryana (45.5%) and UP (40.2%).

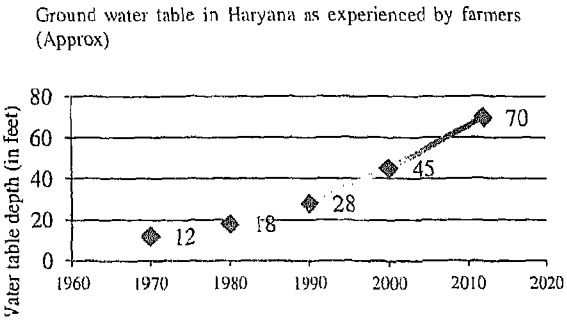

Fig. 1. Farmers' experience on depletion of water table in selected blocks of Haryana

We found that for total number of rainy days and temperature regimes as experienced by farmers, for example in Haryana, the meteorological data have tuned with farmers' experiences (Karnal district), therefore validating the ground truth (CSSRI 2011). Therefore perception of farmers on climatic variability seems to be rational.

Due to erratic rainfall, faulty cropping systems (rice and wheat) and some other anthropogenic factors, farmers for example of Haryana, are experiencing depletion of ground water level (Fig. 1). The similar rate of depletion of ground water was observed by the Central Ground Water Board also (Fig. 2). Therefore, link between farmers' experience on variable climates and its effect on natural resources seems to be rational.

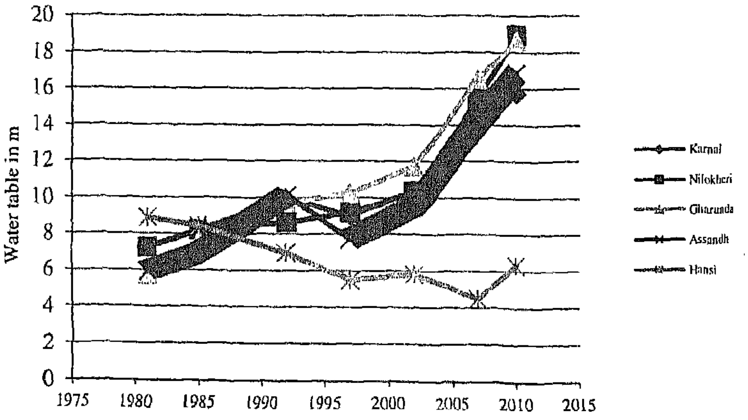

Fig. 2. Actual status of water table in selected developmental blocks of Haryana recorded by Central Ground Water Board

Table 1. Farmers of varied socio-ecological systems and their perception about variable climate

Climatic indicators	Farmers perception																			
	Strongly agree				Agree				Undecided				Disagree				Strongly disagree			
	Ar P	RS	HR	UP	Ar P	RS	HR	UP	Ar P	RS	HR	UP	Ar P	RS	HR	UP	Ar P	RS	HR	UP
Duration of winter is decreased	78.1	90.0	85.4	89.3	21.9	10.0	14.6	10.7	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	
Timing of winter start is postponed	69.2	75.5	80.3	82.3	29.2	24.5	19.7	17.7	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Duration of summer is increased	90.51	94.1	90.2	92.7	09.5	05.9	09.8	07.3	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Timing of summer start is not pre-poned	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	10.0	15.0	00.0	00.0	30.0	15.5	68.3	74.5	60.0	69.5	31.7	25.5
Duration of rainy season is decreased	87.5	95.5	95.2	90.6	12.5	04.5	04.8	09.4	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Number of rainy days are decreased	95.2	92.5	93.5	95.6	04.8	07.5	06.5	04.4	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Event of drought is increased	10.0	30.0	60.4	64.2	30.0	60.0	30.6	25.7	15.0	05.0	09.0	10.1	35.0	05.0	00.0	00.0	10.0	00.0	00.0	00.0
Occurrence of flood is increased over a period of time	10.0	00.0	45.2	52.5	50.0	00.0	25.8	33.8	15.0	35.0	29.0	13.7	20.0	35.0	00.0	00.0	30.0	05.0	00.0	00.0
Weather in general is predictable	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	15.0	25.0	00.0	00.0	40.0	50.0	95.2	90.5	45.0	25.0	04.8	09.5
Types of bio-bio-meteorological indicators (flora and fauna) farmers were using 40 years back are no more effective in predictability	30.5	20.0	45.5	40.2	25.0	25.0	40.5	25.5	20.0	25.0	14.0	00.0	12.3	25.0	34.3	00.0	05.0	12.2	00.0	00.0

Ar. P.= Arunachal Pradesh, RS= Rajasthan, HR= Haryana, UP= Uttar Pradesh

Vulnerability and adaptive capacity of farmers of varied socio-ecological systems

Farming communities of four socio-ecological systems revealed that they have different degree of agricultural risks and adaptive capacity (Table 2). Farmers living in stressed ecology (e.g. Rajasthan) were observed to have more risk in failing agriculture caused by climatic and other socioeconomic factors. It could be learned that the socio-ecological systems which have high degree of risk had low level of adaptive capacity also, as for example in case of Rajasthan and Arunachal Pradesh. Our results found support from the study of O'Brien *et al.* (2004) who reported that degree of agricultural risks in selected areas of Rajasthan and Uttar Pradesh are high with low level of adaptive capacity. Personal work in Arunachal Pradesh also revealed that the types of farming and it associated risk is high with low level of adaptive capacity of farmers as compare to Haryana and similar other developed states of northern India.

Table 2. Vulnerability and adaptive capacity of farmers of varied socio-ecological systems

Varied Socio-ecological systems	Types of climate, agriculture and ecology	Based on primary work		Validity (based on secondary sources)[3]	
		Agricultural risks[1]	Adaptive capacity[2]	Agricultural risks	Adaptive capacity
Arunachal Pradesh	Humid climate, high rainfall, but rainfed agriculture. Ecology rich with native flora, and farmers practice jhum-agriculture with local crop varieties	High	Low to lowest	High to highest	Low tom lowest
Rajasthan	Arid climate, farmers have mostly rainfed land (irrigated with open well), they use mostly improved and few local crop varieties	High to highest	Low to lowest	High to highest	Low to medium
Haryana	Semi-arid and sub-humid climate. Fully irrigated, saline soil and water, rice-wheat based cropping system, intensive agriculture with high inputs	Medium to high	High to highest	Medium to high	High
Uttar Pradesh	Sub-humid climate, subsistence farmers, rice-wheat based cropping system supported with few vegetable and sugarcane crops. Sodic soil, use of mostely improved crop varieties and low level of input use	High to highest	Low to medium	High	Low to medium

[1] Agricultural risks were measured using indicator: degree of sensitivity and exposure towards climatic (variable and extreme events) and socioeconomic (size of land holding, annual income and types of technologies used in agriculture).

[2] Adaptive capacity was measured using indicators: size o land holding, types of agricultural technologies used, viability of technologies in relation to climatic events, subsidiary occupation of farmers, subsidy support, access to various information resources relating to climate and agricultural technology, types of power relation of farmers, socio-cultural capital of famers and institutional diversity in a village.

[3] Validity of primary research data on agricultural risks and adaptive capacity was matched with the work of O'Brien *et al.* 2004.

Compounded climatic vulnerability as experienced by farmers

Other than the climatic factors, there are number of socioeconomic, institutional and policy factors which after compounding with climatic variables make farmers and agriculture more vulnerable (Fig. 3). These variables could be gender, age, rising cost of cultivation of crops, social power structures, and agricultural policies. Therefore, observations provided clue that vulnerability in agriculture is multidimensional rather than only climate caused, and needs sustainable adaptive practices.

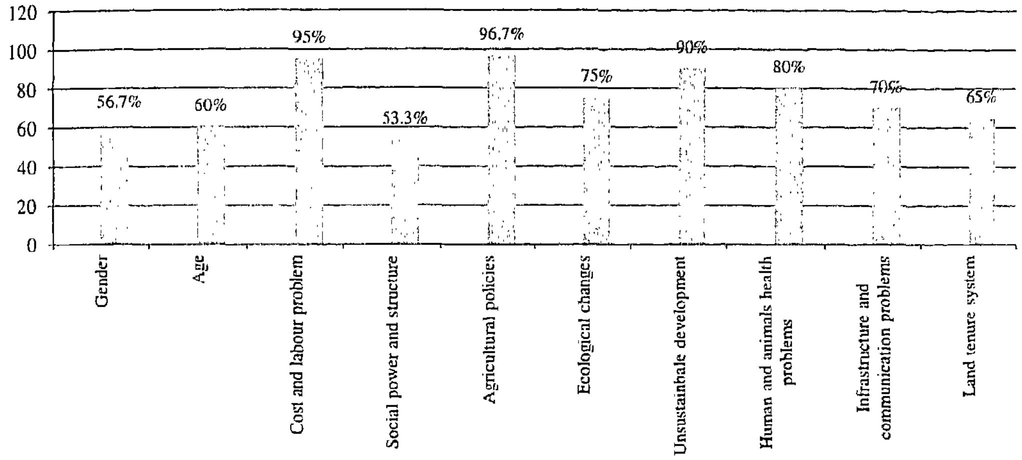

Fig. 3. Factors causing compounded vulnerability with climatic variability in agriculture

Adaptation in agriculture by farmers of Haryana and UP

Farmers of Haryana revealed that, farmers who live in sodic and saline environments of Haryana are following number of adaptive practices which have multiple benefits (Table 3). Some of these adaptive practices are dual purpose wheat, adapting sugarcane as an economic and opportunistic adaption and resources conserving technologies (minimum and zero tillage). First, second and third number of adaptive practices (as mentioned in table 3) are promoted by CGIAR system based CISA project (CSSRI), while other practices are pursued by national line departments. We also observed that other than the recommended and scientific knowledge based practices, there are other adaptive practices which have great role to cope with variable climate or reduce the exploitation of natural resources.

Table 3. Some exemplary adaptations in Haryana led by scientific and co-knowledge

Adaptations	Attributes of adaptations	Adaptation %
Dual purpose wheat with barseem	• Actual benefits: 75-80 quintal fodder yield • This adaptation is experienced to be beneficial in case if temperature is increased during first 50 days after sowing. • It 70-80 quintal yield of wheat and barseem fodder • Wheat crop provides about Rs.160/quintal fodder after 55-60 days. • The net benefit from fodder is Rs. 8000 (cost is Rs. 1200/acre) • This type of cropped wheat further provides about 22 quintal grain yield/acre	2-6

Adaptation of sugarcane in salt affected lands	• Soil pH 8.4 with EC 7.5 • Water table at 3.0 feet and irrigation through canal • Reactive and inclined to fetch market opportunity	8-16
3.Direct seeded rice	• Energy saving (50%) • Labour saving (Rs. 1800/acre) • Water saving (puddling disturbances the field) 25%, weekly irrigation while in transplanted rice need every third day irrigation • Less attack of *Gob ki sundi* (stem borer) • Less infestation • CSR 30 need not to be harvested during growth (Rs. 600/acre) • Early maturity (about 10 days) results into timely sowing of wheat	4-9
Zero-till wheat with rice reside (with happy seeder)	• Zero till with residue saves one irrigation (25-30% water) • In case if of rising temperature during March at grain filling stage) with residue cropped wheat absorb the heat • Soil carbon sustainability index increases 8.84± 0.47% which is 1.48% more than conventional practices (7.34)[1] • Rice residue incorporated in soil adds 200 kg nutrients/ha/yr[1] • Saves energy by 20000 MJ/ha/yr[1] • Reduces carbon foot prints and green house gases emissions equivalent to 1000 kg CO_2/ha/year[1] • In salt affected land, wheat cropped with rice residue helps in increasing water holding capacity • It helps in weed suppression (about 70%) thus reduces cost about Rs. 400/acre • It also helps in reducing crop yellowing • It prologs about 3 days in grain maturity which results into increasing yield (about 1.0 quintal benefit/acre)	2-6

These practices include farmers own knowledge network, their location specific refinement in agricultural practices (e. g. change in sowing time, selection of short duration varieties, manipulation in agronomic practices, farmers' knowledge led green manuring to enhance soil carbon, etc.) which have tremendous potential in sustainable adaptation. Interestingly, in case of delayed monsoon, the rich farmers of Haryana use to purchase paddy nursery from farmers of Western UP for assuring *kharif* season crop.

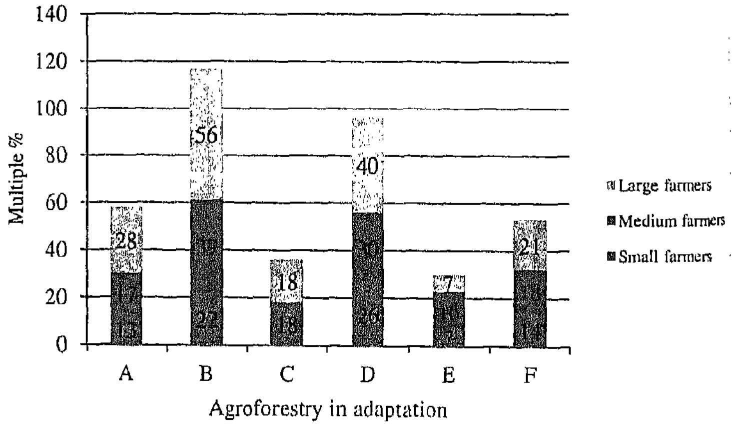

Fig. 4 Agroforestry based adaptation

A= Managing water logged saline soils
B= Diversifying cropping systems
C= Effective management of degraded lands
D= Taking it as an economic adaptation
E= Minimizing environmental risks
F= Improving soil fertility and reducing soil pH

Even the middle class farmers of Haryana have purchased the paddy nursery from rich farmers of same village or neighboring village . Some adaptive practices in Haryana which can be treated as 'economic and opportunistic based adaptation' in the favorable climate supported with congenial market and government policies. For example, in water logged condition (caused by high intensity rainfall and seepage by canal) of Haryana, it was observed that agroforestry (eucalyptus and poplar based) is becoming a popular adaptation among large and small farmers (Fig. 4). Though, it is taken on the bunds only, but marginal farmers do not prefer it much.

In some of the villages, such in the Jind district where soil and water is saline, farmers have started cultivating cotton in upper landscape where soil pH is around 7.84 to 8.4 with EC 1.20. Though, earlier these villages were not known for cotton cultivation. This could be possible because of in 2012, the rain was less (CSSRI 2011), and the cotton price was about 4150/quintal. This attracted farmers to go with cotton. Contrary to this, in 2011 farmers of Hisar were in great loss in cotton crop due to high intensity rainfall and high seepage of canal water with a disloyal market price.

In contrary to Haryana where adaptation were based on mostly scientific knowledge, the farmers of UP were found to adapt contingencies practices in sodic environment. The adaptive practices being followed by farmers are seems to be subsistence in nature, and more of based on the diversification and collective knowledge system (Table 4). It has also been observed that farmers do not apply opportunistic and economic adaptation except few (4-5% farmers) who adapts cash crops such as potato and rice (Mahsuri and Sarju-52 varieties). Exclusively nature dependent community, for example *Bhar*, still dependent about 75 per cent on aquatic resources access from sodic environment to sustain their life support system. Though, in last 20 years due to erratic rainfall and rapid socio-political and economic changes, the vulnerability of *Bhar* community is increased- as production of *tinni* rice (*Oryza ruffipogan*) and indigenous fishes have decreased.

Table 4. Adaptive practices in relation to variable climate of (UP)

Adaptive practices	Adaptation %	Types of weather/climate and other factors
Short duration crops (rice, millet- sama)	07.40	Delayed monsoon and drought
Changes in cultural practices of crops	18.32	Erratic temperature and rainfall
Diversification in farming systems (animals, subsidiary business, etc.)	28.91	Uncertainty in seasonal cycles and climate, and exclusive dependency on natural resources
Relying on integrated practices and knowledge	36.41	Uncertainty in seasonal cycles and climate
Helps from government schemes (watershed) and agricultural inputs (seeds)	05.70	Less rain or drought
Reciprocal learning on adaptive practices	29.70	Risks involved with uncertain climate
Collective risk bearing (social capital)	14.20	Risks involved with uncertain climate
Individual innovation (varieties, management practices)	04.30	General climatic variability
Renting lands to resource-rich farmers	06.40	Failure of tube-wells, less rain and other socioeconomic factors
Scientific practices (varieties and other inputs)	29.87	Climatic stresses
Migration of small farmers and agricultural labors to city in search of job	12.65	Small size of land holding, compounded impact of climatic variability

Hence, there is ample scope to enhance the capacity of farmers in order to access the resources from other sources and agencies which are compatible to their biophysical and socioeconomic conditions. Such efforts can accelerate the decision making capacity and thereby to adapt the other available options by the local farmers.

Adaptations in Rajasthan and Arunachal Pradesh

It could be learned that farmers of Rajasthan were following reactive adaptations such as changing crop varieties (e.g. hybrid during the good rainfall year. Usually after every third year, there is uncertain and prolonged rain) and diversifying their cropping as well as farming systems. In majority of the cases (about 65.0%), farmers were having one or two members of his/her family in cities working as labour or some semi-skilled job to cope-up the climatic challenges and assure food and livelihood security. It is important to mention that historic and natural adaptations, such as community based water conservation are almost being replaced (65.4% cases) with formal knowledge (e.g. varieties, plant protection measures) led adaptation governed by factors such as changing landscape and reduction in livestock and agroforestry practices) (55.5% cases).

In case of Arunachal Pradesh, it has been found that farmers are subsistence in nature (95%) and exclusively dependent on natural resources (jhum agriculture, community based forest resources for ethnic vegetables, and accessing aquatic resources for fish). These farmers have integrated strategies including agriculture, rearing semi-wild animal (*Mithun),* pigs and poultry (75.0%). Therefore, adaptations are diversified and historically established after a long time interaction with humid climate and fragile ecosystem. One attribute of adaption was quite different in the Arunachal Pradesh, and that was social capital which forms backbone of reducing risk and sustaining life support systems even during climatic crisis also. Examples include, formation of *reglep* (informal institution of women to reduce labour cost in agriculture and drudgery) and continuance of *kebang* (an indigenous male dominated institution who collectively manage forest resources). These two institutions assure equitability of common property resources in society and perform agricultural activities even during extreme climatic events to reduce external dependency.

Conclusion and Policy Implications

From foregoing study, I could be concluded that other than climatic factors, multiple socioeconomic, institutional, political and cultural factors affect vulnerability and thereby adaptation. The diversity existing in socio-ecological systems determine types of adaptations, and selectivity of adaptive options. Based on the findings, the following key recommendation emerged:

1. Instead of considering climate change as key driver in agricultural vulnerability; others socioeconomic, cultural, institutional and political stressors should be given due attention while developing plan, practice and policies whether for salt and non-salt affected social-ecological systems;

2. Adaptive practices in problematic and salty environments itself are dynamic in nature and follow '*micro-ecosystem*' approach instead of macro-ecosystem, thus these needs location specific package of practices to enhance farmers' adaptive capacity rather than general recommendations;

3. Especially in salt affected environments, instead of '*Top-to-Bottom*' approach; 'co-management' (grafting and blending of informal and formal knowledge) model is desired;

4. Some of the farmers' practices such as knowledge networking system (e.g. purchase of paddy nursery during variable climate from one state to another) may be adapted in

adaptation packages, while some of the agronomic manipulation led adaptations (change in time of sowing, seeding technology, etc.) need to be screened. If found suitable, they may be included in contingency plan of adaptation, otherwise need to be refined and percolated back to the farmers;

5. Some community based knowledge/strategies led agricultural adaptations (e. g. agroforestry in water logged situations, and community managed forest resources for livelihood) have promising future in sustainable adaptive practices and related research. GIM (Green India Mission- mitigation policy) and sustainable agriculture mission under NAPCC may opt these community based adaptations for not only to combat climate change, but also to ensure multiple outcomes of farmers adaptive practices; and

6. Every socio-ecological system (both normal and salty) needs distinct plan and policies where informal (empirically tested) and formal knowledge are blended/integrated together, along with considering socio-economic, institutional, cultural and global change issues into account

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Climate change effects on salt affected soils: Conceptual framework for meeting the challenge of mitigation and adaptation

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Indo-Gangetic plain (IGP) constitutes about 13% of the total geographical area of India, and it produces about 50% of the total food grains (Pal *et al.*, 2009). This region is one of the most populated areas of world and provides livelihood security for several hundred millions of people (Paroda *et al.*, 1994). This will result in a greater demand for food and it is estimated that the food grain requirement by 2020 in the region will be almost 50% more than at present (Paroda and Kumar, 2000). IGP is environmentally sensitive, socially significant *and economically strategic domain where landscape, hydrology and soil fertility are* threatened by climate warming coupled with anthropogenic pressure. Climate change is having various direct and indirect effects on agriculture production, although these effects may be small to moderate. Despite of various efforts taken to mitigate the adverse effects of climate change, significant effects are highly likely to occur over the next century (IPCC, 2007).

According to intergovernmental panel on climate change (IPCC), the rise in global mean surface temperature with the same rate would be 1.4–5.8 ^{0}C by 2100 (IPCC, 2001). Countries with warmer climate like Africa, India and South America will be more prone to the negative effects of climate change on crop production (Cline, 2007). Developing countries like India will face some additional ecological and socioeconomic stress. Reports reveal that all-India mean annual temperature has shown significant warming trend of 0.05°C/10y during the period 1901 to 2003, however, during 1971 to 2003 it has been accelerated to 0.22°C/10y (Kothawale and Ropakumar, 2005). Increased emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are mainly responsible for this accelerated rate. Modeling for climate scenario shows that India could feel incidences of warm and wet conditions, altered precipitation frequency and intensity resulting due to climate change (Watson *et al.*, 1996). These changes in climate play an important and effective role for soil productivity of the region. A few works also suggest that extent and severity of soil degradation as well as vulnerability to degradation processes is alarming (Dejoux, 2001). These may altogether have impact on soil water content, run off and erosion, salt content, inhabiting biological diversity, carbon and nitrogen balance with effects on water balance components particularly on evapo-transpiration (Aggarwal *et al.*, 2004).

The agricultural area of IGP is shrinking due to the spread of marginal saline areas in Haryana, Punjab and Uttar Pradesh. On the other hand, the productivity of land is also declining due to climate anomalies. About 0.75 t/ha decrease in rice yield with 2^{0}C increase in air temperature in high yielding rice areas and about 0.06 ton/hectare in the low yielding coastal regions has been reported by Sinha and Swaminathan (1991). An increase of 1^{0}C temperature may cause decrease of 8% wheat yield under salt affected areas of Uttar Pradesh (Mishra *et al.*, 2011). It may also reduce wheat crop duration by seven days and reduce yield by 0.45 ton/hectare (Aggarwal *et al.*, 2004). Though the region specific impacts of climate change are uncertain in India, the farmers of marginally productive and *rainfed* lands are going to suffer significant damages.

There is a need to identify region specific problems associated with agricultural activity due to the effects of environmental changes on crop production. Management options to mitigate climate change and its effects also need to be delineated. However, adaptation efforts are now being taken as paired measures with mitigation strategies to uphold soil productivity under the climate change scenario, particularly in developing countries. It should be of utmost priority to consider and prepare for impacts of climate change on food production to ensure food security for the global population (Schmidhuber and Tubiello, 2007). Collaborative efforts which are required to guarantee the practices applied are significant assuming it as a collective responsibility of all sectors at global level.

Anticipated interactions of agriculture with climate change

- ***Land use change impacts global warming***

The potential of greenhouse gases like CO_2, N_2O, CH_4 to warm up the environment is referred to as its global warming potential. It is a relative measure of how much heat a greenhouse gas traps in the atmosphere. The overall balance between the net exchange of gases from a crop production system constitutes the net global warming potential (GWP) of that production system. The common unit is referred to as carbon dioxide equivalent or CO_2e. Increased concentration of greenhouse gases in atmosphere over last 250 years has been primarily attributed to the combustion of fossil fuels, and land use changes including deforestation, biomass burning, draining of wetlands, ploughing and use of fertilizers. It now far exceeds pre-industrial values determined from ice cores spanning many thousands of years (IPCC, 2007). Models predicting an increase of 1°C to 4°C (1.8°F to 7.2°F) over the next century (Wigley, 1999) due to continuous accumulation of GHGs.

- ***Soil emission of the main greenhouse gases (GHG): CO_2, N_2O, CH_4***

According to IPCC (1996), agricultural facilities contribute approximately 20% of the annual increase in anthropogenic GHG emissions. When accounting for the common cropping systems and GHGs, carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) possess top place. Activities like deforestation and intensive agriculture have contributed considerably towards increase in atmospheric CO_2 which before 1970 was contributed more by the agricultural activities than from fossil-fuel burning (Lal *et al.,* 1998). Human activities are responsible for altered carbon cycle. They influence addition of carbon as well release of carbon from natural sinks like soil. According to IPCC (2001), about 75% of total CO_2 emissions have been accredited to burning of fossil fuels and rest to land use changes in the past 20 years. Global concentration of atmospheric CO_2 has been increased from 280 ppm of pre-industrial phase to 379 ppm in 2005 that exceeded by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores (IPCC, 2007).

Agriculture sector is considered as the largest producer of non CO_2 emissions like methane (CH_4) and nitrous oxide (N_2O), contributing about 60% of total emission (WRI, 2008). Globally, 52% of CH_4 and 84% of N_2O emissions was attributed to the agricultural sources such as animal husbandry, manure management and agricultural soils (Smith *et al.,* 2008). Flooded rice cultivation is attributed to be the third largest source (91%) of agricultural emissions, contributing to 11 percent in the form of CH_4 arising from anaerobic decomposition of organic matter. According to USEPA (2006) the emission of methane in highly populated countries like China and South East Asia are expected to increase by 10 and 36%, respectively, by 2020. However, quantification of methane emission from paddy field is difficult as it is dependent on the land in cultivation, fertilizer use, water management, density of rice plants and other agricultural practices (Aydinalp and Cresser, 2008). Animal husbandry (7%) and the burning of agricultural wastes (2%) contribute less significantly to CH_4 emissions.

Agriculture accounts for about 38% of global emission of N_2O. Nitrous oxide emissions contributed to 40–44% of the GWP from *rainfed* sites and contributed 16–33% of GWP in the irrigated system (Mosier *et al.*, 2005). Application of nitrogenous fertilizers, cultivation of nitrogen fixing crops, retention of crop residues and cultivation of soils with high organic carbon content are the main sources. However, volatilization following atmospheric deposition of applied nitrogen, as well as surface runoff and leaching of applied nitrogen into groundwater and surface waters (USEPA, 2006) adds to the indirect sources. Nitrification and denitrification resulting in N_2O production get enhanced when available nitrogen exceeds plant requirements.

- ***Carbon balance: Net ecosystem productivity***

The carbon pool within the soil systems is considered to be the world's largest terrestrial store of carbon (Post *et al.*, 1982) but various anthropogenic activities like changes in land use and land management practices affecting soil carbon stocks and fluxes. Estimates suggest that agriculture production contributes up to 12,000 megatons of carbon dioxide equivalent a year and up to 86% of all food-related anthropogenic greenhouse-gas emissions (Gilbert, 2012). The accumulation of soil organic carbon is proportional to biomass accumulation, and it increases with increasing precipitation (Post *et al.*, 1982) and decreasing temperature (Burke *et al.*, 1989). Therefore, net ecosystem productivity is strongly linked with the climatic conditions.

Net ecosystem productivity (NEP) is used to measure the net exchange of carbon between an ecosystem and the atmosphere; however it is more intricate and difficult to assess. The NEP has been reported to decrease with increase in water stress in forests (Granier *et al.*, 2007). It can be taken as a good indicator of carbon accumulation rate within a system though it is largely dependent on prevailing management practices and climatic conditions. A forest ecosystem adapted to low temperatures tends to the lower rate of photosynthesis and high rate of respiration in high temperature conditions causing a greater reduction in carbon sequestration potential (Huxman *et al.*, 2003). For an ecosystem net primary productivity (NPP) and carbon storage are potentially affected by the changes in atmospheric CO_2 concentration and climate. A positive correlation has been established by researchers between NPP i.e. the total plant growth per unit area per year and climatic conditions. Under climate change scenario crop yield may get positively affected because of CO_2 fertilization under high concentration of CO_2 or may decrease due to rising air temperatures (Rosenzweig and Hillel, 1998) and water stress.

- ***Drought and salt stress***

Drought is defined as a long period with abnormal rainfall affecting growing or living conditions adversely (Allaby, 1989). With the climate change there may be increased incidences of drought. This increase may be upto 13fold over the present scenario (Williams, 1988) leaving the crops for an increased demand of irrigation (Wheaton, 1994). However increased rate of ET and aridity also brings the problem of salinity especially in the areas where ground water table is shallow. Salts along with the capillary water travel to the overlying soil horizons. The availability of water to the plants is influenced by various soil properties viz. porosity, field capacity, plant available water, soil texture etc (Jarvis, 2007; Reynolds *et al.*, 2002). Higher salt content in the soil profile and higher salt concentration in the soil solution alters the osmotic potential of water affecting plant available form. Along with this, high temperatures elevate drier conditions which increase water stress and accentuate demand for water (Fink *et al.*, 2004). Salt affected soils with high pH and presence of certain cation and anion in the soil solution and on exchange sites can have ion specific effects due to change in osmotic potential, and imbalance in plant nutrition (due to deficiency/toxicity of different nutrients). It all may have direct effect on soil biota and plant growth and on the whole on the crop yield (Mengel and Kirkby, 2001).

- ***Water quality and salt movement***

High temperature and high ET has been found to cause accumulation of salts in the upper soil horizon with decreased rate of downward leaching resulting into soil salinization/alkalization even in places that were not found affected earlier (Dregne, 1976). There is also a problem of secondary salinization with increase in canal irrigation. The process of salinization due to lateral movement of water is well explained by Rengasamy (2002). Studies done in four different climatic regions of world *i.e.* Mediterranean, semi-arid, mildly arid and arid, reveal a non-linear relationship between soluble salt concentration and rainfall (Pariente, 2001). Salt affected soil results from changes in water balance collective with excess salt accumulation at some depth in the soil profile following erosion leaving it exposed to atmosphere (West *et al.*, 1994). Plants growing on these soils are susceptible to osmotic stress and specific ion toxicity that overall decrease the quantity (yield) and quality of the crops (Grattan and Grieve, 1999). Salt accumulation negatively affects the soil properties and processes and reduce land potential to be cultivated or for any other use (Várallyay, 1994). High salt content in the soil water associated with impaired uptake of other essential elements like Ca in case of high Na becomes unavailable to plants. Soil water phase of salt affected soils show signs of low nutrient ion activities (Grattan and Grieve, 1999).

Saline and sodic soils in climate change context

Salt affected soils are rich in salts in soil solution as well as exchange complex. They can have several ways of interaction with climate change effects (Figure 1). Climate change is causing increase in soil salinization/sodicity problem. Dregne *et al.* (1991) reported that in 11 countries, about 29.6 Mha area of total 158.7 Mha irrigated area, is affected with high salt content. Increasing salinization of natural resources like soil, land and water is now regarded as serious environmental problem. Changes in hydrology tend to raise the water table and increase the mobilization of salts (Charman and Wooldridge, 2007). Further, accumulation of salts creates other problems and inhibits the growth thus affect the productivity. Also, salt affected soils have poor structure which is a major constraint while using these soils for production.

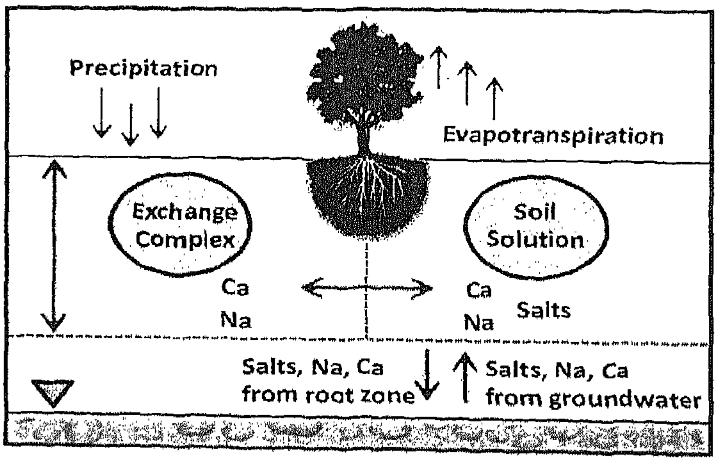

Fig. 1. The salt development mechanisms in soils and their probable interactions with climate change processes.

- ***Challenges for salt affected lands***

Marginal productivity = higher susceptibility to climate impacts

Climate plays an important role in maintaining the soil properties. It can have adverse effects on all type of soils yet can have even more deleterious effects on sodic lands. Increased sodicity affects the soil physical properties like dispersion and slaking, and cause dispersion of aggregates and loss of carbon bound within aggregates and physically protected from decomposition (Tisdall and Oades, 1982). Smith *et al.* (2009) have estimated that agricultural soil would lose upto 62-164 Tg carbon by 2100 with the changed climate scenario using Century Model. Sodic soils with high amount of sodium on exchangeable sites affects the plant growth (Gupta and Abrol, 1990) and climate change may aggravate the problem. Altered pattern of rainfall can affect the capacity of soil to maintain the required level of organic carbon and also the soil structure. Sodic soils suffer from ponding on surface due to their lower infiltration rates. High evapo-transpiration causes rise in salt concentration in soil solution. The soil moisture available to plant is in very low amount and presence of salts in this water raises the osmotic potential of soil solution. Water becomes physiologically unavailable to plants and may generate water stress and other nutrients deficiencies. Nitrogen is an important element for crop growth especially in sodic soils (Curtin and Naidu, 1998), but the rate of loss of N through volatilization increases in soils with high pH and waterlogged conditions (Grattan and Grieve, 1999). Also presence of high level of chloride may also limit the uptake of nitrate (Grattan and Grieve, 1999). All these factors may altogether affects the plant growth, reproduction and senescence by affecting plant's physiological and biochemical functions (Rengasamy *et al.*, 2003).

Low soil stability = higher susceptibility to tillage, irrigation

Soil structure is a very important factor in crop production, controlling cultivation, plant growth, grain yield and quality (Shepherd, 1992). Increasing sodicity may affect the rate of biomass accumulation and carbon emission and thus can alter the carbon dynamics in the soil. Dispersion of soil aggregates causes loss of soil carbon and generates other conditions like compaction. Formation of soil crust can affect various soil processes like water infiltration, run off, erosion and evaporation. Dispersive clays and soils are much more susceptible to dispersion (Bhardwaj *et al.*, 2010). Presence of Na in any clay mineralogical group increases the dispersivity of soil (Bhardwaj *et al.*, 2009). High clay content in the sodic soils develop cracks in soil when dry. Drier climatic conditions will enhance the problem by increasing the frequency and size of cracks (Climate Change Impacts Review Group, 1991). Owing to rigorous structural degradation, presence of high salt content and consequently developed imbalance in water availability limits the biomass production on sodic soils. Climate change will aggravate the degradation of sodic soils by accelerating salt accumulation in susceptible regions.

- ***Opportunities for salt affected areas***

With the increased incidences of climate change and growing demand for food supply, there is a need to increase the area of arable land. Bringing salt affected soils to cultivation require the development and implementation of which are efficient, inexpensive with none or minimal effects on environment (Qadir and Oster, 2002). The amount of carbon stored in salt affected soils is usually very low than in normal soils (Paustian *et al.*, 1998). The level can be raised by using appropriate management practices after reclamation. Sodic soils can be reclaimed using amendments like gypsum a source of calcium in available form to replace the excess of Na on exchangeable sites that may be leached out with addition of water. These soils may then be cropped appropriately to enhance primary productivity and sequestration of carbon which is considered as a mitigating strategy against the elevating concentration of CO_2 in the atmosphere. Locking of atmospheric CO_2 into the soil systems also enhance the soil and water quality, and improve the productivity of land. Land management practices that are favorable to plant growth, soil biota and soil structure are believed to enhance the soil organic matter and will increase the soil carbon density. Management practices such as zero tillage, conservation tillage, change in cropping pattern, use of tolerant varieties, and reduced summer fallowing all complement sequestration of carbon within the soil system. Reduce/conservation tillage rationalizes the undesirable effects of plowing by causing mechanical disturbances to the soil aggregates (Parr *et al.*, 1990). Traditional management practices involves the mineralization of soil organic carbon by enhancing the breakdown of soil aggregates on the other hand conservation agricultural practices decreases this loss by slowing down the breaking of aggregates (West and Post, 2002). The scope of carbon assimilation and sequestration in soil is higher in marginally productive saline and sodic soils which are very low in soil carbon.

Soil carbon sequestration although involves the interaction with other important nutrients/minerals, several experiments have been conducted by workers to evaluate the improvement in carbon content of salt affected soils cultivated using suitable management practice (Gupta and Abrol, 1990; Singh *et al.*, 1997). Several packages of practices have been developed and evaluated. Mishra *et al.* (2010) also reported increased in carbon content in sodic soils under different horticulture crops. Use of crops tolerant to high salt levels and those needing minimum tillage will also be beneficial for cultivation on salt affected lands.

Conclusions and Recommendations

Climate change is having adverse effects on agricultural productivity and the effects are much more adverse for saline and sodic soils. At the same time new areas due to altered rainfall pattern and high temperature are getting affected by salt accumulation and becoming susceptible. Climate change favours development of conditions which enhance salt accumulation in soil profile, their movement to upper horizons and development of osmotic stresses. Agricultural practices like land use change, improper use of fertilizers and cropping patterns with higher emissions of greenhouse gases have also been contributing to climate change phenomena. Water resources are getting contaminated due to excessive use of fertilizers. High temperatures accelerate evapo-transpiration causing upward movement of salt to upper horizons. Salt accumulation in soil solution makes water unavailable to plants, causing decrease in crop yield. This condition is more severe in case of saline and sodic soils that are already affected with high level of salts and have marginal productivity. Salt affected soils constitute a huge extent of area worldwide. Most of recently developed sodic soils are in highly productive regions of world such as Indo-Gangetic plain. Reclamation of these lands and then by putting them under proper management brings great opportunity to increase food supply and livelihood security, especially in developing

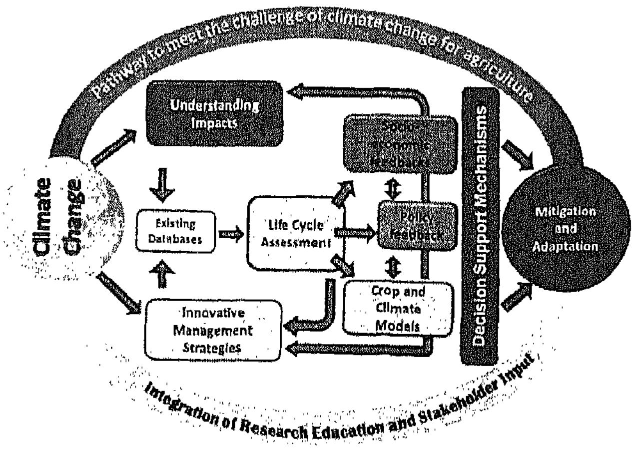

Fig. 2. Conceptual framework to meet the challenge of climate change mitigation and adaptation in agriculture.

countries. On the other hand reclamation and management of salt affected areas can increase primary productivity and helps in sequestering carbon in soil to meet the climate change mitigation goals. These soils represent a great potential to sequester carbon with in the soil system, directly by enhancing their primary productivity by improving the soil physico-chemical properties and indirectly by lowering the emission of CO_2 in to the atmosphere. Adoption of resource conservation technologies like zero tillage, residue application, permaculture, judicious use of fertilizers, salt tolerant varieties will further enhance the potential of these lands to sequester carbon. Thus, not only salt affected soil but other waste lands with low productivity can play important role in the current climate change scenario. The two prolonged strategy of enhanced carbon storage in these lands as well as boosting food security makes salt affected areas strategically very important in terms of policy. Development of efficient reclamation as well as management technologies hold the key, though, to the extent of benefits which can be achieved. In nutshell the immediate challenge is to understand threat and level of impact of climate change, then to identify alternative management practices, their life cycle assessment, inculcating the generated information into crop, climate and socio-economic models and get the feedback to improve the management (Fig. 2) and ultimately feed this information into policy and decision making to meet the challenge of mitigation and adaptation to climate change. Salt affected marginal lands have a strategic role to play in achieving the goals.

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Impact of climatic variability on groundwater resources in fresh ground water region of Haryana

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Scientific evidence has demonstrated that the earth is moving towards a point of no return, where imbalances brought about by climate change will have serious ecological impacts. Climate change is no more an environmental concern. It has emerged as the biggest developmental challenge for the planet. Throughout the 21 century, India and other countries in south-eastern Asia are projected to experience warming above the global mean. India will also begin to experience greater seasonal variation in temperature, with more warming in the winter than summer (Christensen, 2007). The longevity of heat-waves across India have extended in recent years, leading to warmer temperatures at night and hotter days and this trend is set to continue (Cruz, 2007). These heat-waves will lead to increased variability in summer monsoon precipitation, with drastic effects on the agricultural sector in India (Bhadwal, 2003).

Rainfall is a climate parameter that affects the way and manner in which mankind survives. Apart from the beneficial aspects, the rainfall can also be destructive in playing the major role in natural disasters like floods and landslides. Long term trends of Indian monsoon rainfall for the country as well as for smaller regions have been studied by several researchers. It has been reported that the monsoon rainfall is without any trend, being highly random in nature over a long period of time (Mooley and Parthasarathy, 1984). But on a spatial scale, existence of trends was noticed by Parthasarathy (1984) and Rupa Kumar *et al.* (1992). Using the network of 306 stations and for the period 1871-1984, Rupa Kumar *et al.* (1992) identified the areas having decreasing and increasing trends of monsoon rainfall.

Besides rainfall, the key component in the hydrologic cycle is evapo-transpiration. The evaluation of evapo-transpiration is important to study the impact of climate change on water resources, since it is a vital link between the atmosphere, plant and the soil matrix component of hydrologic cycle (Fig. 1).

It is expected that evaporation (E) or evapo-transpiration (ET_0) will increase due to global warming. Some studies reported in the literature show that despite the increase in air temperature, E and/or ET decreased in some regions across the globe (Bandyopadhyay *et al.*, 2009). This shows that in addition to air temperature, there are other climatic parameters, like wind speed, relative humidity, radiation, etc. which may lead to for the observed decreases in E and/or ET, offsetting the influence of temperature.

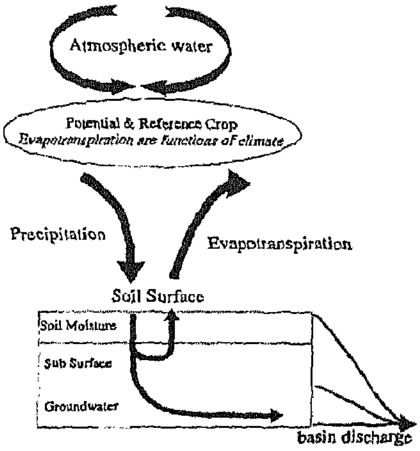

Fig 1: Hydrologic cycle

The change in pan evaporation (E_{pan}) and potential evapo-transpiration (PET) has been observed in recent decades in different