43rd Foundation Day Lecture

delivered by

Dr. Gurbachan Singh

Chairman
Agricultural Scientists Recruitment Board
New Delhi

on

Thursday, the 1st March 2012

Central Soil Salinity Research Institute
KARNAL - 132 001 (Haryana)

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Climate Change and Sustainable Agriculture: Harnessing the Potential of Salt Affected Soils

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1. Introduction

There has been a steady increase in the emission of green house gases like carbon dioxide, methane and nitrous oxide in the environment. Increase in carbon dioxide from 280 ppm to 380 ppm, methane from 700 ppb to 1750 ppb and nitrous oxide from 270 ppb to 316 ppb between 1750 and 2007 has been reported. Agriculture is reported responsible for upto almost half of all methane emissions. Increased human induced developmental activities have further accelerated the process of climate change in the recent past and increased the mean global surface temperature by 0.6°C over the past 100 years, a phenomenon known as global warning. The climate change predictions over India indicate that temperature rise is likely to be around 3°C and rainfall increase is expected by 10-20 per cent over central states of India by 2100 A.D. The climate change triggered frequency of weather related events like floods, droughts, frost, cold and heat waves has considerably increased during last two decades. Continuation of such trends associated with rise in temperature is expected to melt ice, glaciers, re-distribute water flow in rivers, raise sea levels, sub-merge coastal habitats, islands, generate tsunamis and dislocate human and livestock settlements. Predicted spatial redistribution of precipitation, droughts, floods and water balance will change land use, pests, diseases and other ecological parameters. These changes will necessitate the need to devise research strategies to deal with predicted changes to sustain agricultural productivity and to achieve food and nutritional security in 21st century.

Out of 329 million ha geographical area of the country, about 142 million ha is under cultivation and the same is almost constant for last several years. There seems little scope to increase area under cultivation. However, about 120 million ha area is constituted by degraded and wastelands. Development and refinement of appropriate technologies for reclamation and management of degraded lands seems promising option to achieve future food and nutritional security as well as adoption and mitigation strategy to cope with predicted future climate change scenario. Soil salinity and sodicity has degraded about 6.73 million ha otherwise productive area in the country. In the present paper, information has been compiled and discussed how reclamation and management of salt

– affected soils and waters will help sustaining food security and also help moderating/negating climate change related risks in the near future through carbon sequestration in vegetation and soil. The information has been compiled under the sub heads: future climate change scenario in India, climate change and agriculture vulnerability, impact of climate change on agriculture: recent case studies, harnessing salt–affected soils potential and future research and development needs.

2. Future Climate Change Scenario in India

The Central Research Institute for Dryland Agriculture through its All India Coordinated Research projects on Agro-Meteorology and Dryland Agriculture has worked out the trends in maximum and minimum temperature during Kharif and Rabi season for Indian conditions. Their calculations indicate that there may be several location specific uncertainties in the minimum and maximum temperatures which may have adverse impact on agricultural production and productivity. Their calculations for trends in monthly rainfall in various sub-divisions in India indicate that rainfall may be more during December, January and February in case of West Rajasthan, Punjab and Haryana. However, there may be slight decrease in October and November rainfall in several divisions. The analysis was also made about trends of rainfall in India and shift in surplus rainfall for the period 1871 to 1999 and 1960 to 1999. The observations indicate a shift in surplus rainfall from west towards east. Lal (2001) made calculations about the predicted climate change and its impact on agriculture in India and the results are reported in Table 1. He reported an annual mean area averaged surface warming over Indian Subcontinent to range between 3.5 to 5.5 °C over the region by 2080. These projections showed more warming in winter season over summer monsoon. Rise in surface temperature in north India is predicted 3 °C or more by 2050. A marginal increase of 7 to 10% in rainfall is predicted over the subcontinent by 2080. Further, the study revealed a fall in rainfall by 5 to 25% in winter months and an increase of 10 to 15% in summer monsoon rainfall in India. These projected changes will have both beneficial and adverse effects on agriculture, horticulture, environment and socio-economic set-up. To devise strategies to manage such changes and to reduce vulnerability of agriculture, careful analysis of old climate data and linking with weather forecasting and working out eco-years, eco-seasons, eco-months and eco-weeks at each agricultural university and ICAR research institute will be required. Samra and Singh (2002) 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.

Table 1. Climate change projections for India

Year	Season	Temperature change (°C)		Rainfall Change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.17	1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

Source: Lal (2001)

It has been estimated that mountain glaciers in the Himalayas and on the Tibet-Qinghai Plateau are melting and could deprive the major rivers of India and China of the ice melt needed to sustain them during the dry season in the future. Scientists believe that water flows in Yellow river and the Yangtze River basins where irrigated agriculture depends heavily on river will decrease and may have negative impact on food production. However, the scientists at the National Institute of Hydrology (NIH, Roorkee) have studied the glaciers in the Himalayas and their results indicate that situation is not that serious but there has been some decrease in the size of glaciers at some locations. There is a strong need to bench-mark the melting processes and their annual monitoring using GPS and satellite systems.

3. Climate Change and Agriculture Vulnerability

The climate change will affect 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 is said to be higher on C_3 crops such as wheat and rice than on C_4 plants like maize, sorghum, sugarcane 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 C_3 crops as explained earlier. The indirect effects through the increase in temperature will reduce crop duration, increase crop respiration rates, increase evapotranspiration, decrease fertilizer use efficiencies and enhanced pest infestation. 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 evapotranspirtation 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 scientific 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). Significant shift in latitude for apple cultivation has been reported in Himalayas. 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 Kaur (2007) under Punjab conditions.

Climate change effects will be more serious in the coastal regions. 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 like mangroves, passion fruit, coastal badam and other fruit crops 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.

4. Impact of Climate Change on Agriculture: Recent Case Studies

4.1. Drought of 2002 and 2009

The geographical position of India makes it highly vulnerable to different kinds of natural disasters. About 57, 28, 12 and 8% of the geographical area of the country is prone to earthquakes, droughts, floods and cyclones, respectively (Samra *et al.*, 2006). The drought of 2002 was one of the severest droughts of the last century. Overall rainfall deficiency for the country as a whole was 19% and 56% area received deficient rains. Out of 36 meteorological sub-divisions in the country, 21 sub-divisions received deficient and scanty rains. The month of July received 49% less rainfall than the long range average. Water storage in 71 major reservoirs was 33% less than the average of previous years. About 21.5 million ha area was not sown and 47 million ha of sown crop was damaged, with a food grain short fall of more than 29 million tonnes. About 300 million people in 56% of the total geographical area were affected. A loss of 1250 million mandays of employment was reported. Ground water table in drought affected area declined by 2 to 4 m below the normal levels. Everyday about 1.5 billion liters of drinking water was transported by tankers and railways during drought period (Singh, 2006a). Prasada Rao (2008) has studied the impact of droughts on Indian food grains production from 1950-51 to 2007-08 (Fig. 1). The drought of 2009 was also quite severe and lowered the food grain production by about 19 million tonnes. Though the monsoon of 2010 was normal for the country as a whole, but states like Jharkhand, Bihar, West Bengal and Eastern Uttar Pradesh experienced drought like situation. From agricultural production and productivity view point, it is not the total rainfall which matters but its distribution in time and space is highly crucial.

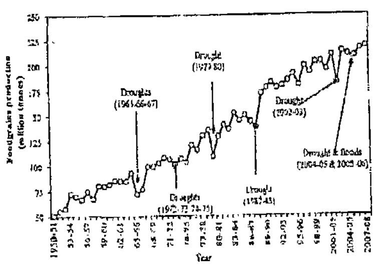

Fig. 1. Impact of droughts on Indian foodgrains production from 1950-51 to 2007-08
Source: Prasada Rao (2008)

4.2. Cold waves

An important weather phenomenon that causes significant impact on agricultural production year after year over the northern and north-eastern regions of India is the 'Western Disturbances'. The intensity/frequency and the aerial extent of these disturbances significantly influence the quantum of rainfall/snow over these regions during the Rabi season, lean season flow of rivers and occurrence of cold wave conditions. In this process, they influence overall hydrology, the daily maximum/ minimum temperatures, range of sunshine hours and humidity. A good example of this is the severe and prolonged cold wave conditions that prevailed over many parts of northern and north-eastern part of India during the winter season of 2002-2003 which had considerably affected the survival and productivity of seasonal and perennial crops (Singh, 2004). Except the southern region of the Indian Peninsula, most of the country, particularly the Indo-Gangetic Plains was affected by freezing and cold days injuries having severe impact on crops, vegetables, fruit trees, fishery, livestock and even human beings. Extreme fluctuations beyond normal variation in temperature due to cosmic events and anthropogenic activities that alter cardinal points of crop growth stages are a major concern in agricultural management and production. During December 2002 to January, 2003 daily maximum and minimum temperatures at several places in north India remained un-usually below the normal continuously for 3-4 weeks. As a consequence of such phenomena, about 600 ha of orchards of mango and litchi were severely damaged in the Shiwalik belt of Punjab (Table 2). The extent of damage varied from 40-100 per cent in mango to 50-80 per cent in litchi with reduced fruit size and poor quality in guava, ber and kinnow (Samra *et al.*, 2002-2003). Crop yields in the cold wave year of 2002-03 were reported lowered by 10 – 42% in wheat, 25 – 30% in gram and 50 – 70% in mustard as compared to previous normal year of 2001-02 at Agra. Early sown winter maize in more than 36000 hectares was adversely affected by cold wave with 70 – 80% loss in seed setting in Bihar. Productivity loss due to cold injury in boro rice of Assam was 10% and crop took 10 to 25 days extra to mature as compared to normal year. In the early sown crop, seedling mortality during the vegetative stage was 37%. Grain sterility across farmers fields varied from 50 – 60%.

Similar damage was also reported during 2005-2006 and 2007-2008 due to cold waves in northern states of India. Excellent crops of tomato, potato, peas, marigold, dahlia, chrysanthemum, papaya and even guava were severely damaged. The mean maximum and minimum temperatures during 2005-06, 2006-07 and 2007-08 at Karnal along with long term average are given in Fig. 2, 3 and 4. There was 100% loss of tomato crop, 72-80% in potato, 30-50% in winter maize and peas, 50% in brinjal, 100% loss to marigold and 30-40% in Dahlia and Chrysanthemum during winter of 2007-08.

Table 2. Effect of cold wave on fruit orchards in selected villages of Hoshiarpur region, Punjab

Name of the farmer and village	Fruit species and age	Area in acres	Yield damage (%)	Damage to plants (%)
Sh. U.S. Chatha Village Mehlawali	Litchi (12 years)	8	100	30-60
Sh. J.S. Lali Bajwa Village Mehlawali	Litchi (15 years)	2	100	30-60
Sh. K.S. Gill Village Kharkan	Mango (15 years)	10	100	60-80
	Litchi (12 years)	5	100	60-80
Sh. Ranjit Singh Village Kantia	Mango (10 years)	45	100	80-100
	Aonla (15 years)	10	100	80-100
Mr. Ramji Das Village Dholwaha	Mango (8-10 years)	30	100	40-60
Sh. J.S. Dhaliwal Village Dholwaha	Mango (8-10 years)	60	100	40-60
Mr. Deepak Puri Village Chohal	Mango (30 years)	5	100	100
Sh. Jaspal Singh Village Mehmowal	Mango (10 years)	6	100	60-80
Village Salimpur	Mango (2-3 years)	5	100	100

Similarly, during 2002-03 cold wave associated mortality rate in papaya ranged from 40-83 per cent in the lower Shiwalik regions, plains of Uttar Pradesh, Bihar and north-east. Likewise, in the Doon Valley of Uttaranchal, plant mortality was nearly

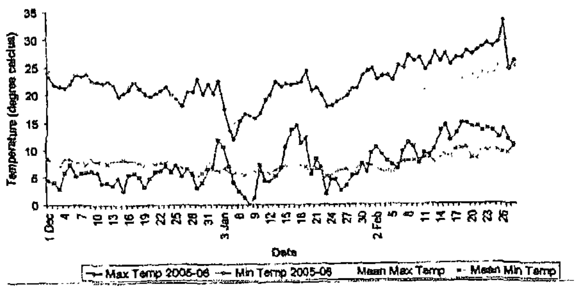

Fig. 2. Variation of maximum and minimum temperatures during Dec., 2005- Feb., 2006

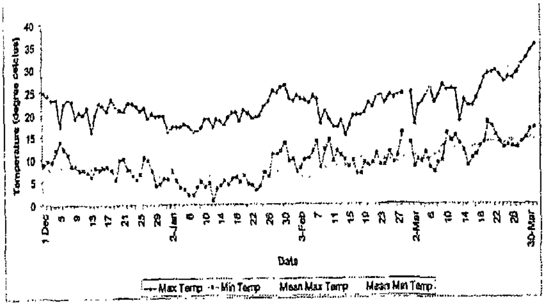

Fig. 3. Variation of maximum and minimum temperatures during Dec., 2006 – March, 2007

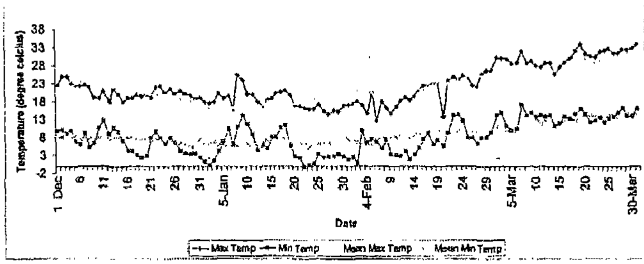

Fig. 4. Variation of maximum and minimum temperatures during Dec., 2007 - March, 2008

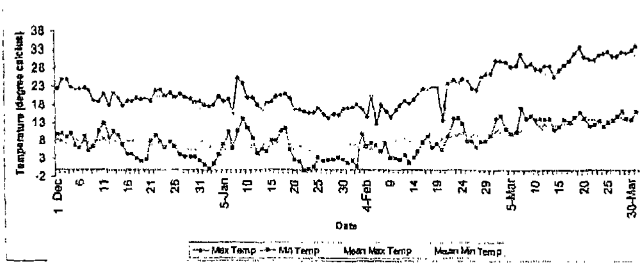

Fig. 5. Daily minimum temperature of 2002-03 and average at Dehradun

80% in less than two years old plantations, 15% in 2-4 year, 10% in more than 4 year old mango plantations and damage of growing tips in matured trees. The effect of cold injury was in the order of mango> papaya> banana> litchi> pomegranate> amla. The mean minimum temperatures at Dehradun during this season and long term average temperatures are shown in Fig. 5.

Temperate fruits like apple, peach, plum, cherry, however gave higher yields due to extended period of chilling in 2003. Cold waves also affected the fish productivity in Pujnab, Haryana and Bihar. In Naubatpur block of Patna, mortality in 4 months old fish was 87% in mirigle, 33% in Rohu, 7% in Catla and 37% in the composite culture. Proper selection of crops and their varieties according to site conditions, providing wind breaks or shelter belts, frequent irrigation, smoking, covering young fruit plants with thatches or plastic sheets, air mixing, maintaining maximum depth of water in fish pond and their aeration are some of the farming manipulations for managing cold wave injury (Singh, 2006).

4.3 Heat Wave of March, 2004

Temperature plays an important role in the growth and productivity of thermo sensitive winter season crops which generally require specific cardinal levels of heat during various stages. Increased frequency of departures from normal temperature and heat wave conditions has raised human causalities and agricultural losses in the recent decade. Samra and Singh (2004) studied the impact of abnormal temperature rise in March, 2004 on several winter crops including wheat, mustard and vegetables. Highest rise from the normal in the daily maximum temperature was observed at Srinagar (3-12 °C) (Fig. 6) followed by Palampur (8-10 °C); Hisar (2-10 °C); Ludhiana (3-6 °C); Jammu (1-6 °C); Uttaranchal (1-5 °C) and Jaipur (1-5 °C). Even minimum temperature during this period was higher than normal in several

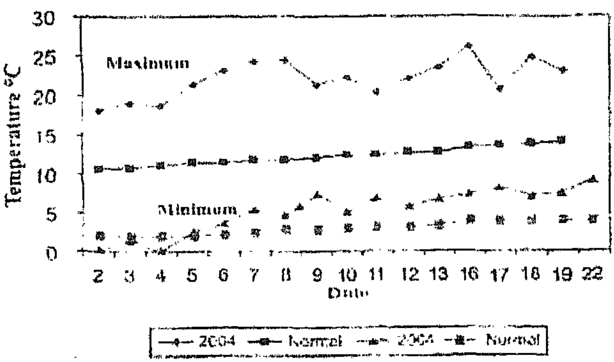

Fig. 6. Maximum and minimum temperatures (Srinagar) during March 2004

places such as Srinagar, Palampur, Ludhiana and Pantnagar. As a result of that wheat production loss of 4.6 million tonnes was very close to the advanced prediction of about 4.4 million tons by modeling techniques (Aggarwal and Singh, 2004). The wheat crop matured 10-20 days in advance of normal period with reduced 1000 grain or test weight. Sowing of peas was advanced by one month due to early melt of snow in Lahul valley, apples flowered 15 days early in Chamba district and there was poor formation and filling of pods of rape seed and mustard in Himachal Pradesh. Linseed yield reduced by 50 per cent, there was abrupt flowering and excessive flower drop in peas, tomatoes, cole crops and fenugreek. Onion and garlic productivity was reduced by 15-25 per cent associated with reduced bulb size. The forced maturity brought down seed productivity of broccoli, carrot, raddish, turnip by 10-15 per cent. Coconut, banana, cardamom, black pepper, cashew etc. were affected in Kerala due to heat waves induced lower humidity and soil moisture. Breeding of thermo insensitive crops/ varieties, frequent irrigation, mulching to maintain high soil moisture and sprinklers are called upon to mitigate adverse effect of heat wave on production (Singh, 2006c). Long distance open grazing of lactating animals may be avoided. Frequent watering and bathing of animals will enhance proper feeding of livestrock.

Some of the weather aberrations are also favourable. For example, during 2007-2008 continuous prolonged low temperature during the month of February and March contributed very significantly in improving productivity of wheat in Punjab, Haryana and Western UP. Both Punjab and Haryana harvested bumper crop and exceeded their procurement targets by big margins due to prolonged continuous cold weather. The yield of early sown wheat was drastically reduced due to low temperature during flowering stage. However, normal and late sown wheat benefited from the prolonged low temperature condition because of better tillering, seed setting and grain filling. Different wheat varieties behaved differently to this season temperature when planted at different dates. For example variety HD2581 yielded much higher when planted during mid November compared to its sowing on November 2, 2008 at CSSRI farm, Karnal. Heat wave conditions during February – March, 2010 in Punjab, Haryana and U.P. lowered wheat production by 2 – 3 million tonnes. Wheat crop matured 10 – 15 days earlier and the harvested crop had 9 – 11% moisture in the grains compared to 12 – 14% in a non-heat wave normal year. Flag leaf which contributes for increased grain weight during maturity phase was dried up 15 – 20 days earlier.

5. Harnessing the Potential of Salt Affected Soils

5.1 Salinity Problem: Global and Indian Scenario

Soil and vegetation represent potential sinks for carbon sequestration and reforestation is considered as a possible means of mitigation of global warming. As per recent estimates nearly 953 million ha area is affected by salinity and sodicity in the world (Table 3). Australia followed by north and central Asia and south America have the maximum problem of high salt concentration in the root zone soil.

Table 3. Distribution of salt affected soils in the world (million ha)

Region	Solonchaks/ Saline	Solonetz/ Sodic	Total
North America	6	10	16
Mexico and Central America	2	-	2
South America	69	60	129
Africa	54	27	81
South and West Asia	83	2	85
South and East Asia	20	-	20
North and Central Asia	92	120	212
Australia	17	340	357
Europe	-	-	51
Total	-	-	953

Statewise area affected by salinity and sodicity in India is given in Table 4. As per reconciled data reported in Table 4, about 6.73 million ha otherwise productive area is constituted by salty lands. Gujarat state followed by UP has maximum area affected by salinity and sodicity. It has been further projected that 11.7 million ha area will be affected by 2025.

Several studies in India (Yadav and Singh, 1970; Gill *et al.*, 1987; Singh *et al.*, 1988) reveal 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.

Nearly 25% of the ground water resources in India are saline and/or brackish. Continuous use of such water for irrigation is bound to increase soil salinity/sodicity. States like Rajasthan and Haryana have 84% and 62%, respectively ground water as saline/sodic. Percentage use of poor quality waters in selected states is given in Table 5.

Introduction of irrigation in canal command areas coupled with over use of water has resulted in rise in ground water. In some of the canal commands water table is rising @ 0.3 to 1.2 meter/annum (Table 6). Nearly 3.55 million ha is already water logged and gone out of cultivation. Statewise extent of water logged area is reported in Table 7.

Table 4. Extent of salt affected soils in India (ha)

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 5: Percentage use of poor quality waters in different states

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

Source: CSSRI, Karnal

Table 6. Rising trend of water table in irrigation commands

Irrigation command	Rise of water table (meter/ annum)
IGNP, Rajasthan	0.29 – 0.88
Western Yamuna and Bhakra canal	0.30 – 1.00
Sharda Sahayak, U.P.	0.68
Nagarjuna Sagar, A.P.	0.32
Malprabha canal command, Karnataka	0.60 – 1.20

Table 7. Extent of water logged areas in India

State	Waterlogged area (m ha)
Andhra Pradesh	0.43
Bihar	0.35
Gujarat	0.17
Haryana	0.23
Karnataka	0.05
Kerala	0.08
Madhya Pradesh	0.06
Maharashtra	0.02
Orissa	0.18
Punjab	0.30
Rajasthan	0.18
Tamil Nadu & Pondicherry	0.61
Uttar Pradesh	0.59
West Bengal	0.29
Total	3.55

Source: Ministry of Agriculture (Draft Report, 1999)

Losses in productivity due to water logging are reported 42% in paddy, 38% in wheat, 77% in cotton and 61% in sugarcane compared to productivity of these crops in normal soils (Table 8).

Table 8: Losses due to water logging and soil salinity

Crop	Normal Lands	Salt affected lands	Waterlogged lands
Paddy	39.9	21.8(45)	23.0(42)
Wheat	26.0	15.8 (40)	18.6 (38)
Cotton	16.3	6.1 (63)	3.7 (77)
Sugarcane	636.8	330.2 (48)	247.5 (61)

5.2 Reclamation and Management Strategies

After the establishment of Central Soil Salinity Research Institute in 1969 at Karnal, several site specific technologies have been developed for reclamation and management of saline and alkali soils. A gist of the relevant technological options is discussed as under:

Sub-surface drainage technology has been developed to reclaim waterlogged saline soils. Statewise drained area covered is given inTable 9. Similarly, change in cropping intensity after installation of the drainage system is reported in Table 10.

Several salt tolerant varieties of rice, wheat and mustard have been developed which can be grown either without or with half the recommended dose of amendments. The promising varieties are listed below:

Rice: CSR 10, CSR 13, CSR 23, CSR 27, CSR 30 and CSR 36

Wheat: KRL 1 - 4, KRL 19, KRL 210 and KRL 213

Mustard: CS 52, CS 54 and CS 56

Besides these, salt tolerant trees, grasses, bushes, biofuel crops have been identified and agro-techniques for their successful cultivation in salty lands standardized. Several multipurpose tree based silvi-agri and agroforestry models have been developed for fuelwood and forage production and bio-amelioration of both sodic and saline soils. An augerhole technique for establishing tree plantations in soils of pH_2 >10.0 was developed. Several village community lands affected by salinity/ sodicity have been planted with trees like *Prosopis juliflora, Acacia nilotica, Eucalyptus tereticornis, Casuarina equisetifolia* and *Tamarix articulata*. The augerhole technique was further improved as pit - augerhole technique which made it possible to grow even fruit trees such as amla, guava, jamun, karaunda, ber and imly in salty lands. Trees and grasses once established in salt lands help reclamation of such soils by root activity and addition of leaf litter.

Table 9: State wise drainage area covered

State	Irrigation Command	Area Covered (ha)
Rajasthan	Chambal	15,700
	Indira Gandhi Nahar Pariyojna	500
Haryana	Eastern Jamuna Canal	1450+3000
	Bhakhra Canal	1300+1000
Punjab	South West Punjab	30+2000
Karnataka	Upper Krishna	30
	Tungabhadra	200
	Malparhba Ghatparbha	20
Andhra Pradesh	Nagarjuna Sagar	50
	Krishna 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

Table 10: 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 (Karnatka)			
ORP	0	200	-
Phase II	88	156	77

Association of salt-tolerant grasses like *Leptochloa fusca* with trees further hastens the reclamation process. The short, medium and long term effects of trees on soil properties in general and carbon sequestration in particular is reported in Tables 11 and 12. The perusual of the data clearly indicates that significant amount of carbon is sequestered in the soil. The extent of carbon build-up depends upon the nature of tree species, planting density, age of plantation and the management practices.

Mechanism of soil reclamation by trees and grasses and processes involved are explained below in figures 7 and 8. The crops grown in the soils reclaimed by trees and trees plus grass mixtures are reported to have much better productivity compared to their productivity in soils reclaimed by amendments (Table 13).

Table 11. Reclaiming effects of *Prosopis juliflora* plantations on village community lands

Village	Depth (cm)	Soil properties			
		pH		Organic carbon (%)	
		Initial	after 8 years	Initial	after 8 years
Shera	0-15	10.0	8.8	0.13	0.48
	15-30	10.1	9.6	0.06	0.21
Sutana	0-15	10.2	8.5	0.20	0.40
	15-30	10.6	9.4	0.07	0.09
Nain	0-15	9.7	8.6	0.08	0.45
	15-30	10.2	9.2	0.10	0.12
Bhalsi	0-15	10.0	8.8	0.22	0.65
	15-30	10.5	10.1	0.08	0.12

Table 12. Ameliorating effects of mesquite and other tree plantations on an alkali soil

Species	Original		After 20 years	
	pH_2	Organic carbon (%)	pH_2	Organic carbon (%)
Eucalyptus tereticornis	10.3	0.12	9.18	0.33
Acacia nilotica	10.3	0.12	9.03	0.55
Albizia lebbek	10.3	0.12	8.67	0.47
Terminalia arjuna	10.3	0.12	8.15	0.47
Prosopis juliflora	10.3	0.12	8.03	0.58

Table13: Straw and grain yields of wheat and oats in soils taken under the 25 years old tree plantations and in the adjacent crop land soil

Tree Plantations	Wheat		Oats	
	Grain ($g\ pot^{-1}$)	Straw ($g\ pot^{-1}$)	Grain ($g\ pot^{-1}$)	Straw ($g\ pot^{-1}$)
Prosopis juliflora	61.7	87.5	87.9	111.1
Terminalia arjuna	44.0	38.5	45.8	62.8
Eucalyptus tereticornis	32.2	25.3	42.7	58.5
Albizia lebbek	45.3	43.5	52.8	66.9
Acacia nilotica	55.7	68.8	61.6	67.5
Crop land	13.3	15.4	24.3	26.7
LSD (p=0.05)	2.8	2.0	7.0	9.4

In general, it is difficult to build organic carbon in soils where summer temperature exceeds 40 - 45 °C. However, integration of trees with crops in a unified agroforestry system helped building appreciable quantity of organic matter in the soil (Table 14).

Fig 7.Silvi-pastoral model for bioamelioration of sodic soils

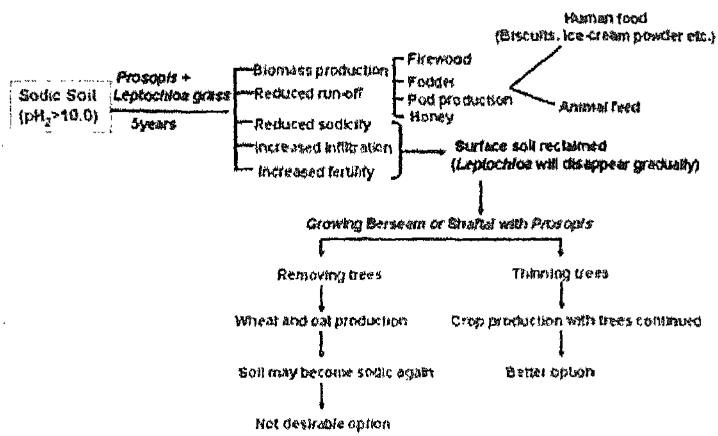

Fig 8. SILVI-AGRICULTURAL MODEL

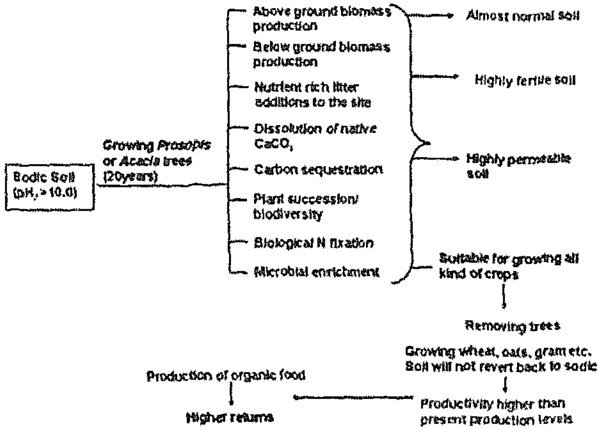

Table 14: Change in soil properties (0-30 cm) under different tree-crop combinations in 5 years

Land use systems	Organic carbon (%)	Available N (kg ha^{-1})
Crop based system	+ 0.07	+ 10
Eucalyptus based	+ 0.12	+21
Acacia based	+ 0.20	+ 31
Populus based	+ 0.17	+ 25

Role of trees having high transpiration rates has been exploited to lower the water table in areas where ground water is showing rising trends. This process is known as bio-drainage. Bio-drainage is defined as the process of removing the excess soil *water through transpiration using bio-energy of the plant and radiation energy* of the sun. It is an option to prevent the development of water logged and saline soils especially in land locked areas where there is no possibility of disposing saline drainage effluent. Also there are large areas which get water stagnation due to seepage from higher elevation, surface disposal of urban and industrial effluents and floods during rains, where due to their topographical locations, conventional system of de-watering through mechanical pumping and surface drainage is not possible. Promising tree species for bio-drainage use include: *Eucalyptus, jamun, shisham*, bamboo, poplar etc.

5.3 Salt Affected Grazing Lands

Salt affected grazing lands are predominant landscapes throughout the country. The biomass production capacity of these lands is relatively low because of poor soil health and management. The above ground biomass of saline communities in peripheral areas of Runns in Rajasthan was reported ranging from 0.6 to 0.8 t ha^{-1} while in saline depressions of Jaisalmer, some grass communities were found to produce from 0.30 to 0.65 t ha^{-1} forage biomass. Major species which contribute significant biomass as fodder in such lands include: *Aeluropus, Atriplex, Bothriochloa, Cenchrus, Chenopodium, Chloris, Cynodon, Dactyloctenium, Dichanthium, Eragrostis, Leptochloa, Kochia, Panicum, Salsola, Suaeda, Tribulus, Salvadora, Prosopis and Ziziphus.* Similarly, the important top feed shrubs and trees include *Ailanthus excelsa, Acacia nilotica, A. catechu, A. leucophloea, A. tortilis, Balanites roxburghii, Prosopis cineraria, P. juliflora, Azadirachta indica, Albizia lebbeck, Leucaena leucocephala, Dalbergia sissoo, Melia azadirach, Hardwickia binata, Grewia ovata, Ficus bengalensis, F. religiosa, Anogeissus pendula, Bauhinia variegata, B. racemosa, Butea monosperma, Cordia dichotoma, Flacourtia indica, Moringa oleifera, Dichrostachys nutans, Morus alba, Ziziphus mauritiana and Z. nummularia.* The leaves of most of these trees are rich in nutrients. This type of fodder becomes more relevant during drought scarcity period.

5.4 Salt Tolerant Halophytic Pastures

Many halophytes grow in natural saline or other arid environments, which are rapidly deteriorating through the process of desertification. It is necessary for plants growing under saline conditions to maintain a high concentration of osmotic substances to successfully overcome the water-relating forces of the surrounding soil. Halophytes growing in saline soil are able to change the osmotic potential of their cell sap whenever required.

The value of certain salt-tolerant shrub and grass species have been recognized by their incorporation in pasture-improvement programmes in many salt-affected dry regions throughout the world. There have been recent advances in selecting species with high biomass and protein levels in combination with their ability to survive a wide range of environmental conditions, including salinity and drought. Considerable success has been achieved in Indian Subcontinent and else where in cultivating halophytic forages such as chenopods, especially *Atriplex* in areas subject to total summer drought on badly salt-affected lands. Grazing animals can meet their requirement of protein and metabolisable energy through mixture of saltland fodders, tops of plantations of halophytic shrubs/trees (providing crude protein) and a minimal understorey cover of forages. Another plant, which has attracted much attention as a fodder plant on soils affected by salinity and waterlogging is kallar grass (*Leptochloa fusca*). In India and Pakistan, this grass has been widely utilized for production in both alkali and saline waterlogged soils. In a silvi-pastoral system with trees such as *Acacia nilotica, Prosopis juliflora* and *Dalbergia sissoo* (the loppings of these could be used as forage) for initial four years. On an average *Leptochloa* could produce 15.6 to 17.4 t ha-1 green forage per annum on highly alkaline soil (pH>10) even during low rainfall years. Species of halophytic forages like *Salicornia, Chenopodium, Kochia, Atriplex, Salsola, Suaeda, Trianthema, Portuleca, Tribulus and Alhagi along with several grasses such as Aeluropus lagopoides, Sporobolus (S. marginatus, S. airoides, S. diander, S. helvolus, S. tramulus), Cynodon dactylon, Dactyloctenium sindicum, Paspalum vaginatum, Chloris gayana, Echinochloa turnerana, E. colonum, Eragrostis tanella, Dichanthium annulatum, Brachiaria mutica, Bathriochloa pertusa* and many others are commonly found grown naturally in both alkali and saline soils and contribute as forage even during drought period.

In many coastal areas (including low rainfall areas of United Arab Emirates and Rann of Kutchh in India) where mangroves occur sporadically and there is scarcity of fodder, the foliage of many mangroves and associated plants such as species of *Avicennia, Ceriops, Bruguiera, Rhizophora, Sonneratia, Kandelia, Terminalia, Pongamia, Barringtonia* and many others, are used as forage for cattle, goats and camel. Among other trees particularly grown on inland salty lands, species of *Acacia, Prosopis, Salvadora, Cordia, Ailanthus, Balanites, and Ziziphus* are traditional fodder plants of drought prone arid regions. Many species of *Acacia (A. cyclopes, bivenosa, ampliceps, halosericea, saligna, salicina, and victoria)* and *Prosopis (P. juliflora, cineraria, chilensis, glandulosa, pallida and tamarugo)* are among the most promising genetic resources to be utilized in developing fodder sources in drought prone areas.

5.5 Trees and Bushes on Field Boundaries and Bunds

Palnting of multipurpose tree species (MPTS) and promising bushes on the boundaries of agricultural fields in drought prone salt affected area is useful as (i) bio-fence protection against wild animals, (ii) as an alternate source of fodder, fuel and income generating products during severe drought, (iii) as vegetative barriers to conserve soil and water, (iv) moderating effects of drought through moderating micro-climate and (v) in some cases act as shelterbelts/wind breaks and carbon sequestration.

Farmers make high bunds on the periphery on their agricultural fields, plant *Saccharum munja* on top and fix thorny bushes/branches of trees to protect their crops from wild animals. Such bio-fencing practices need replacements at shorter intervals and do not generate any product of economic value. The list of species which can be exploited as a live fence and drought moderating option includes: *Capparis decidua, Opuntia ficus-indica, Leucaena leucocephala, Carrisa carandas, Lantana camara, Aloe barbadensis, Prosopis juliflora*, etc.

5.6 Under Utilized Agroforestry Resources

Large number of trees, bushes, shrubs and grasses are naturally growing as wild plants in rainfed regions of the world. Such plants are adapted to rainfed situations and have tremendous potential to be exploited as a food, forage, fuel and / or industrial crops (Singh 2003, Singh and Felker 1998). Some of these plants are already exploited in different parts of the world. For example, edible cactus (*Opuntia ficus indica*) is being extensively used as a fruit, forage, vegetable and medicinal crop in countries like Mexico, Argentina, France, Brazil, Italy, South Africa and even in south western USA. The other uses of cacti in arid and semi-arid areas include: live fence, vegetative barrier for soil and water conservation in sloping land and as a wind break. A summary of *Opuntia* uses is presented in Table 15. The forage quality parameters of this under utilized plant as reported in literature are cited in Table 16.

Table 15:Uses of *Opuntia* species

Food	Fruits and fruit peel, juice, pulp, alcoholic beverages, jam, syrup
Forage	Stems/cladodes, fruits, seeds, cultivated as forage shrub
Energy	Biogas, ethanol, firewood
Medicine	Diarrhoea (stem), diuretic (flower, root), amoebic dysentery (flower), diabetes (stem), hyperlypidemy (stem), obesity (fibres), antiinflamatory (stem)
Cosmetics	Shampoo, cream, soaps, body lotions
Agronomic	Hedges and fences, mulching, soil improver, wind break, organic manure
Others	Adhesives and glues, pectin, fibres for handicrafts, paper (stem), dyes (fruit), rearing of *Dactyloptus occus* on cladodes, antitranspirant, ornamental

Similarly, trees of the genus *Prosopis* are highly tolerant to aridity and salts. *Prosopis juliflora* has the potential to grow greener even during severest drought period. The trees provide livelihood support in terms of firewood, fodder and even pods as human and cattle feed. It has also been exploited economically as timber, firewood and forage tree in countries like Brazil, Argentina, Peru, Mexico, Senegal, South Africa and USA. Comparison of protein content of *Prosopis juliflora* in relation to other important trees as reported in the literature is given in Table 17. The data indicates that the *Prosopis* pods and leaves contain almost similar protein as that found in alfalfa.

Table 16:Range in values for cactus cladode composition for use in animal feed

Moisture content (%)	85-90
Crude protein (%)	5-12
In vitro dry matter digestibility (%)	75
In vitro protein digestivity (%)	72
Crude fibre (%)	43
P (%)	0.08-0.018
Ca (%)	4.2
K (%)	2.3
Mg (%)	1.4
Energy (Meal kg^{-1})	2.6
Carotenoids (mg 100 g^{-1})	29

Table 17:Comparison of protein content of mesquite (*Prosopis juliflora*) products in relation to other products in Brazil

Product	**Protein (%)**
Pods (*Prosopis juliflora*)	12.9
Leaves (*Prosopis juliflora*)	13.6
Maize (*Zea mays*)	6.0
Alfalafa (*Medicago sativa*)	14.1
Guinea grass (*Panicum maximum*)	2.6

To exploit the use of under – utilized plant resources as climate change adoption and mitigation strategy we need to focus on : (a) to prepare an inventory of under – utilized/un-exploited plants and maintain their germplasm for productivity and quality improvement, (b) identification of ecological limits and optimal management practices for promising species and their evaluation as monoculture/ mixed communities or even as under – storey crop with trees, and (c) linking research and developmental issues of under – utilized plants with already existing international networks on such plants and (d) standardization of post harvest processing techniques for value addition and marketing opportunities.

5.7. Shelterbelt

Well designed shelterbelts conserve moisture and soil against wind erosion, neutralize heat wave, cold wave and fruit fall due to wind blowing. In addition to these effects, shelterbelts can also provide a wide range of useful products, from poles and fuelwood to fruits, fodder, fibre and mulch. They have been planted quite extensively along Indira Gandhi Rajasthan Canal, roads, railway lines and around the orchards. Species of *Eucalyptus, Populus, Casuarina, Prosopis, Acacia, Leucaena, Azadirachta, Moringa* and *Gliricidia* are most frequently grown as wind breaks/shelterbelts. These are distinguished from boundary plantations and living fences by their orientation, which must face the wind. Diversifying the species in the shelterbelt can also bring a wider variety of useful products to local users.

6. Conclusion and Future Research and Development Priorities

Adaptations of agriculture to climate change will call upon pro-active or anticipatory research on enterprises, commodities, crops, varieties and farming systems insensitive to cold, heat, disease, pests and moisture stresses. Agronomic manipulations such as improved fertilizer use to reduce emissions of methane and nitrous oxide, irrigation management for minimum methane production and conservation agriculture practices will be highly demanding for achieving desired goals. *Ex-situ* and *in-situ* harvesting and conservation of rainwater, raising horticulture and agro-forestry plantations on all kinds of wastelands to sequester carbon, substitution of fossil fuels with bio-fuels (*Jatropha* and *Pongamia* plantations), weather based forewarning for agricultural practices and operations can play a significant role in moderating climate change. Creating awareness about dangers of predicted climate change and mobilizing community effort will go a long way in tackling climate change at local, regional, national and global scale. Human resource development and capacity building of sensitive communities is called upon. Future projections based upon climatic modeling on likely temperature and rainfall patterns in next 100 years will be mandatory.

To moderate/mitigate climate change impact on agriculture in the future, Govt. of India has initiated several pro-active research, development and policy efforts. National Network on impacts, adoption and vulnerability of Indian agriculture to climate change (NPCC) was launched by ICAR in 2004 at 15 locations which was extended to 23 locations during XI Plan. The project was aimed to quantify the sensitivity of crops, soils, water, fish and livestock to climatic changes. Similarly, several projects related to climate change were launched under the National Agricultural Innovation Project (NAIP) focusing on developing strategies for sustainable management of degraded land and water for enhanced livelihood security of the farming communities. Recently, National Initiative on Climate Change Resilient Agriculture (NICRA) has been launched in January, 2011. This initiative will focus on strategic research, technology demonstration, capacity building and sponsored research covering field crops, horticulture and plantation crops, livestock and fisheries. Demonstration of available climate resilient technologies and farmer's fields in 100 most vulnerable districts of 27 states and union territory of Andaman and Nicobar Islands have been targeted. The Department of Agriculture and Cooperation, Ministry of Agriculture has also launched a mega programme under the Mission on sustainable agriculture to manage climate change related future risk to sustainable food and nutritional security in the country.

All the above initiative of Ministry of Agriculture and other Departments/Ministries of Govt. of India such as Department of Science and Technology, Ministry of Environment and Forests and Ministry of Water Resources etc. will provide much needed funding support for research and development on climate change. Development and refinement of technologies for rehabilitation of 120 million ha degraded/wastelands in general and about 7 million ha salt-affected soils in particular need to be considered on high priority. These carbon depleted soils will provide much needed opportunity to sequester carbon in the soil. Sequestration of carbon will not only imply increasing the amount of carbon entering the soil but also a decline in the amount leaving through rapid decomposition due to high temperature. Several studies in salt-affected soils proved that reclamation of alkali soils with amendment like gypsum application, and of saline soils by drainage installations will help in restoration of vegetation cover and increase of soil organic carbon.

Association of grasses like *Leptochloa fusca* with multipurpose trees like *Prosopis juliflora* and *Acacia nilotica* in a unified agroforestry system in highly sodic soils in 4 to 7 year rotations has yielded biomass of about 24 t ha^{-1}. Our several experiments in different agro-eco regions further proved that carbon content in the soil continued to increase with age of plantation, type of tree and grass species and stocking rate.

Gupta and Rao (1994) calculated carbon stocks of Indian soil covering 328.5 million ha using organic carbon data of 32 benchmark and 16 other sites to the tune of 24.3 Pg of carbon and potential of 34.9 Pg. Their calculations reveal that the difference of 10.6 Pg can be taken as gap which need to be exploited through rehabilitation of degraded lands in general and salt-affected soils in particular. To achieve this target will require massive afforestation and agroforestry programmes to be launched on wastelands using funding support from the climate change related projects of Govt. of India. This seems to one of the promising options to moderate global warming impact on agriculture in the near future. Large scale promotion of biofuel crops and multi-enterprize agriculture practices and rainwater harvesting and re-use will be called upon to moderate/mitigate climate change related risk in agriculture.

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