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Impact of climate change on agriculture and strategies for its Reduction

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Abstract

Climate change is considered as one of the major environmental problems in the 21st century and which has become an important scientific and political issue. Inter-Governmental Panel on Climate Change has shown that the earth temperature has increased by 0.74°C between 1906 and 2005 due to increase in anthropogenic emissions of greenhouse gases. It is caused due to both external influences such as changes in solar radiation and volcanism and anthropogenic activities which greatly contributes to changes in the atmosphere that began with the industrial revolution. These changes may culminate in adverse impact on human health and the biosphere on which we depend. The multi-faceted interactions among the humans, microbes and the rest of the biosphere, have started reflecting an increase in the concentration of greenhouse gases (GHGs) i.e. CO₂, CH₄ and N₂O, causing warming across the globe along with other cascading consequences in the form of shift in rainfall pattern, melting of ice, rise in sea level etc. Agriculture is likely to suffer due to increased temperature, drought, erratic weather, pests and diseases, etc. The only way to combat these anticipated changes is through adaptation and mitigation. Adaptation can help minimize negative impacts to some extent, however, mitigation should be the long-term strategy of combating climate change.

Keywords: Anthropogenic, climate, impact, radiation, volcanism

Introduction

Climate change is considered as one of the major environmental problems of the 21st century and today's major scientific and political issue. Climate is changing naturally at its own pace, since the beginning of the evolution of earth, 4–5 billion years ago, but presently, it has gained momentum due to inadvertent anthropogenic disturbances. These changes may culminate in adverse impact on human health and the biosphere on which we depend. The multi-faceted interactions among the humans, microbes and the rest of the biosphere have started reflecting an increase in the concentration of greenhouse gases (GHGs). Some external influences, such as changes in solar radiation and volcanism, occur naturally and contribute to the total natural variability of the climate system. Other external changes, such as change in composition of the atmosphere that began with the industrial revolution, are the result of human activities (IPCC, 2007) [7]. Research on the impact of climate change and vulnerability on agriculture is a high priority in India as the impact, if it follows the predictions, is expected to be widespread and severe. Developing the ability to confidently estimate the impacts of climate change on agriculture is critically important. If ever achieved, it could provide the global information needed to help farmers develop their own long-range response to climate change. Fortunately, we are very near to having such a capability,

and it may take 5–7 years to substantially improve the resolution and accuracy of the climate model and evaluate the implications for agriculture.

Climate change: Current trends: According to IPCC (2007) [7], global temperature has increased 0.9 °C (1.62 F) since the 19th century. Oceans are warming at the rate of 0.4 °F, glaciers are retreating at the rate of 3.5 to 4% per decade in the arctic. Moreover, ice sheets have been shrinking with Greenland losing 286 billion tons of ice per year between 1993 and 2016 and Antarctica losing 127 billion tons of ice. Extreme climatic events have resulted in over 725,000 victims, economic costs of US\$700 billion and insured costs of US\$125 billion (Munich Re, 2002) [14]. Sea level has been rising at the rate of 3 mm per year from 1993-2003 which may lead to various countries to disappear, especially the Island nations such as:

- **Maldives:** It lies 4.2 feet above sea level, west of India
- **Tuvalu:** Located in the Pacific Ocean
- **Federated States of Micronesia:** East of the Philippines
- **Kiribati:** Located in the Pacific Ocean
- **Nauru:** Central Pacific Ocean
- **Palau:** Southeast of the Philippines
- **Seychelles:** Western Indian Ocean
- **Tongo:** Southern Pacific Ocean
- **Comoros:** Between Madagascar and Mozambique

The frequency of heavy precipitation events has increased over most land areas - consistent with warming and increases of atmospheric water vapor while more intense and longer droughts have been observed since the 1970s, particularly in the tropics and subtropics.

In Himachal Pradesh 449 sq km (21%) glacier has disappeared between 1962 to 2001 (Chenab, Parbati and Baspa) according to Space Application Centre, Ahmedabad. The overall reduction in glacier area was 21 per cent and it shrunk from 2,077 sqmt in 1962 to 1,628 sqmt in 2001, said the report which was presented in a workshop on 'Snow and Glaciers and the Himalayan River System' organised by State Centre on Climate Change here today. Geological Survey of India has estimated retreat in three glaciers in Satluj basin, six in Chenab, five in Beas and two in Ravi basin. Melting of glaciers leads to formation of small lakes which causes a threat to the downstream areas. In 1880 a glacial lake outburst in Chenab smashed bridges beyond national borders. Snow cover reduction in 2015-16 as compared to 2010-14 are 37% in Ravi basin, Satluj (12%), Chenab (5%) and Beas (20%). There was increase in moraine-dammed lakes from 596 to 1107 from 2013-2017.

So, what is causing all these?

1. Natural causes: changes in solar radiation and volcanism.

2. Anthropogenic sources: Industrial emissions, fossil fuel combustion, deforestation, burning of biomass, land use and land management practices.

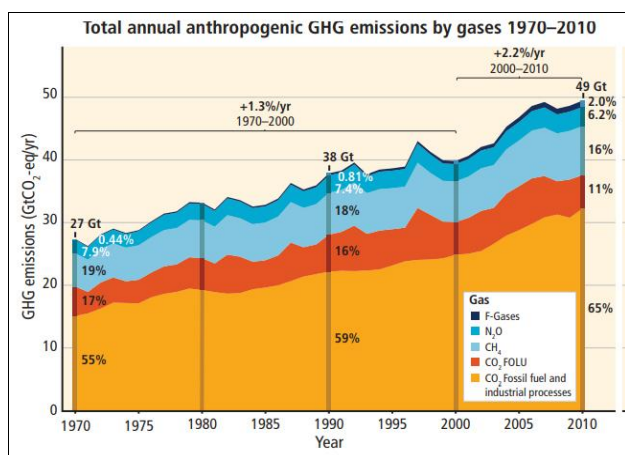


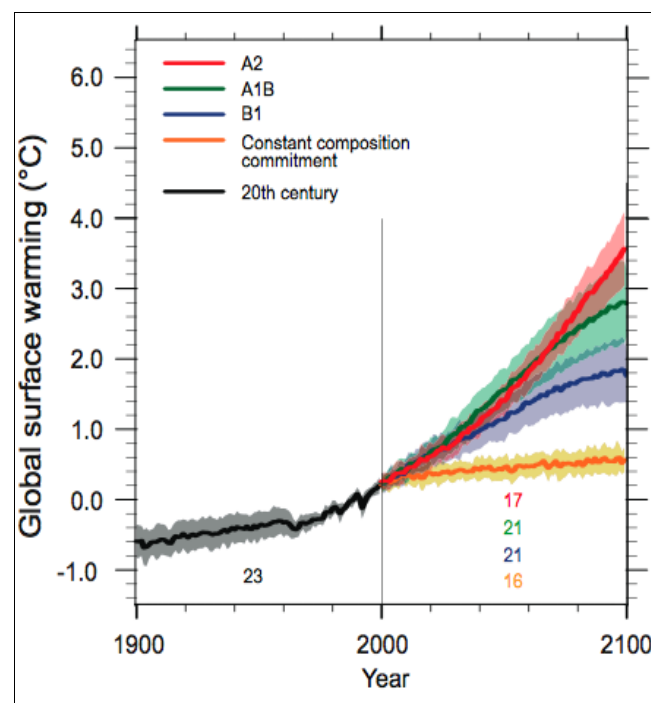
Fig 1: Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO₂-equivalent per year, GtCO₂-eq/yr) for the period 1970 to 2010. Source: IPCC, 2007 ^[7]

Indian scenario

Agriculture sector in India contributes to greenhouse to greenhouse affect primarily through the emission of GHGs such as CH₄, N₂O and CO₂. Of the several sectors of agriculture, enteric fermentation contributes 211,429 Gg (51%), Paddy cultivation contributes 74,360 Gg (21%) and an emission from soil contributes 57,810 Gg (16%). Other sources are burning of crops residues and manure heaps (NATCOM, 2012) ^[15].

Climate change: Future projections

Although there is considerable uncertainty about future, all climate models indicate a rising trend in temperature. By 2100 a rise of 1.8 to 4 °C is expected



Source: IPCC, 2007 ^[7]

Table 1: Climate change scenarios for South Asia (Source: IPCC, 2007) ^[7]

Period	Temperature (°C)		Precipitation (%)	
	Rabi	Kharif	Rabi	Kharif
2010-2039	1.17	0.54	-3	5
2040-2069	3.16	1.71	0	13
2070-2099	5.44	3.14	-16	26

Table 2: Climate change scenario in India (Source: Joshi and Amal, 2009) ^[9]

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

Climate change effects: water

Global water use has increased by a factor of six over the past years (Wada *et al.*, 2016) ^[21]. The global demand for water has been increasing at a rate of about 1% per year over the past decades as a function of population growth, economic development and changing consumption patterns, among other factors, and it will continue to grow significantly over the foreseeable future. Industrial and domestic demand for water will increase much faster than agricultural demand, although agriculture will remain the largest user overall. The vast majority of the growth in demand for water will occur in countries with developing or emerging economies. At the same time, the global water cycle is intensifying due to climate change, with wetter regions generally becoming wetter and drier regions becoming even drier. Other global changes (e.g., urbanisation, de-forestation, intensification of agriculture) add to these challenges (United Nations World Water Development Report, 2018) ^[19].

Water scarcity a real global problem since around 700 million people in 43 countries suffer today from water scarcity. By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity.

So how does it affect agriculture?

Agriculture: 70% of global freshwater withdrawals reaching

up to 90% in some fast-growing economies. Irrigation provides 40% of the world's production on less than 20% of the cultivated land and globally, irrigated crop yields are about 2.7 times those of rainfed farming.

Drought situation in India

About 60-70% of India is vulnerable. 5 million springs across India, nearly 3 million in the Himalayan region alone, which are facing the threat of drying up. According to IMD: 283 districts out of the total 640 in the country currently fall in the rain-deficient category, which is over 44 per cent.

Overall, due to climate change the following make take place:

- Average surface temperature may increase by 2 – 4 °C during 2050s.
- Monsoon rainfall: Marginal changes in monsoon months however, there will be large changes during non-monsoon months.
- Number of rainy days: Set to decrease by more than 15 days.
- Intensity of rains: To increase by 1-4 mm/day.
- Cyclonic storms: Increase in frequency & intensity.
- Sea level rise to be 18 - 59 cm.

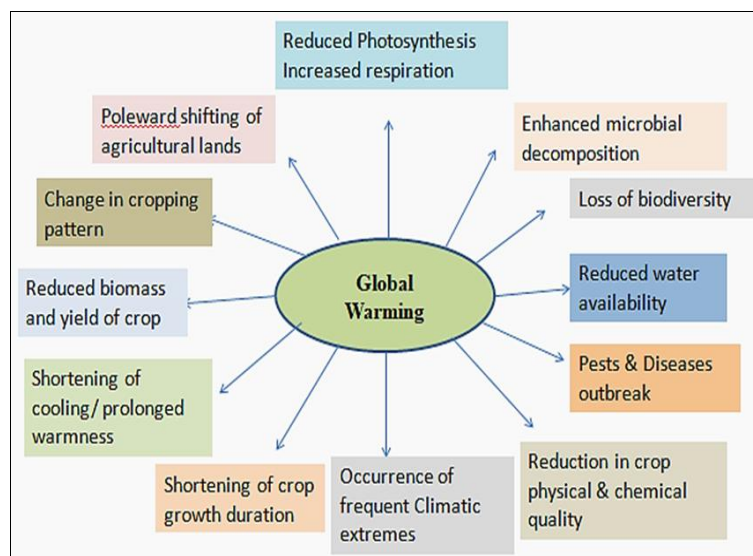


Fig 2: Impact of climate change on agriculture

Productivity of most cereals would decrease due to increase in temperature and decrease in water availability (especially in Indo-Gangetic plains). By mid-century, annual average river runoff and water availability decrease by 10-30% over some dry regions at mid-latitudes. Freshwater availability in Central, South, East and South- East Asia, particularly in large river basins, is projected to decrease which, along with population growth and increasing demand, could adversely affect more than a billion people by the 2050s. Global reports indicate a loss of 10-40% in crop production by 2100 (Aggarwal *et al.*, 2004, IPCC, 2007) ^[1, 7].

Climate change effects on: C₃ and C₄ plants

Photosynthesis increased to some extent in C₃, but no significant response in C₄. Elevated CO₂ increases leaf size,

and this should increase leaf temperatures during heat stress more in C₃ than C₄ species, given the greater average stimulation of growth in elevated CO₂ in C₃ species. With increase in temperature (1°C), yield decreased from 3 - 7% in C₃ plants such as wheat, soybean, mustard, groundnut, potato (Dagar *et al.*, 2012) ^[4]. However, it is usually unaffected up to some extent since optimal temperature needed for C₄ photosynthesis is typically 10 °C greater than that of C₃ photosynthesis, however, Pn is usually inhibited when leaf temperatures exceed about 38 °C in maize

Climate change effects on: Soil

- Soil moisture stress enhanced due to evapotranspiration.

- Erosion in areas where winter rainfall becomes heavier.
- Drier soil will suppress both root growth and decomposition of organic matter.
- High temperature could increase the rate of microbial decomposition of organic matter adversely affecting soil fertility in the long run.
- Nutrient loss due to heavy rainfall in regions those are already moist.

Climate change effects on: Insects

Insects are cold-blooded organisms, therefore temperature is probably the single most important environmental factor influencing insect behaviour, distribution, development, survival, and reproduction. Plants grown under elevated CO₂ are less nutritious to insect herbivores, which can affect their behaviour and performance. As a consequence, insects have a more difficult time converting the food they eat into biomass. In order to mitigate the effects of less nutritious food, insect herbivores often consume more.

- In case of aphids a 2 °C temperatures increase causes one to five additional life cycles per season. (Yamamura and Kiritani, 1998) ^[22]
- Winter mortality of adults of *Nezara viridula* (a) and *Halyomorpha halys* (b) is predicted to be reduced by 15% by each rise of 1°C and in *Chilo suppressalis* (c) two generation per year after 2°C warming. (Kiritani, 2006) ^[11]
- Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains, this consideration is important when choosing management options for onion thrips. (Reiners and Petzoldt, 2005)
- The egg predator (*Cyrtorhinus lividipennis*) had increased instantaneous attack rates and decreased handling times with increasing temperatures until 32 °C. At 35 °C the attack rate and handling time decreased drastically. This implies that predator activity

is likely to increase with increasing temperatures up to a critical temperature of about 35 °C. In addition to affecting biological characters, global warming may cause temporal asynchrony between interacting populations. (Song and Heong, 1997) ^[18].

Climate change effects on Diseases

Generally high moisture and temperature favours and initiate disease development, as well as germination and proliferation of fungal spores of diverse pathogens (Agrios, 2005) ^[2]. Cereal crops become more susceptible to rust diseases because of temperature influence. Oat stem rust resistance genes Pg3 and Pg4 fail at temperature above 20 °C. Climate change is also reported to cause shift in the geographical distribution of host pathogens. Increase in temperature and UV radiation and decrease in moisture may render natural plant products, entomo-pathogenic viruses, fungi, bacteria and synthetic pesticides are less effective.

High moisture favours foliar diseases and some soil borne pathogens such *Phytophthora*, *Pythium*, *R. solani* and *Sclerotium rolfsii*. Drought stress affects the incidence and severity of viruses such as Maize dwarf mosaic virus (MDMV) and Beet yellows virus (BYV) (Clover *et al.*, 1999) ^[3]. Dense canopy encouraged by higher CO₂ levels favours the incidence of rust, powdery mildew, *Alternaria blight*, *Stemphylium blight* and *Anthraxnose diseases*. Moreover, higher CO₂ concentrations induce greater fungal spore production.

Table 3: Reduction in yield due to increase in temperature. (Hundal and Kaur, 1996) ^[6]

Crop	Temperature 1°C	Temperature 2°C	Temperature 3°C
Wheat	8.1%	18.7%	25.7%
Rice	5.4%	7.4%	25.1%
Maize	10.4%	14.6%	21.4%

Table 4: Yield and yield attributes of basmati rice varieties under elevated temperature and low light (+3°C and 64 Klux light) in a glasshouse as compared to normal temperature under open condition (80 Klux light). (Johnson *et al.*, 2011) ^[8]

Variety	Productive Tillers (%)				No. of Panicles/pot				No. of Spikelets/panicle				No. of Grains/panicle				Spikelet sterility (%)			
	T ₀	T ₁	T ₂	T ₃	T ₀	T ₁	T ₂	T ₃	T ₀	T ₁	T ₂	T ₃	T ₀	T ₁	T ₂	T ₃	T ₀	T ₁	T ₂	T ₃
Basmati-370	70	85	78	71	22	19	20	18	103	100	85	100	97	23	71	94	11	16	20	18
Taraori Basmati	78	91	74	88	22	20	18	27	99	104	97	106	92	40	83	44	11	15	55	41
Basmati-386	81	87	73	64	16	14	19	14	94	92	91	100	79	36	47	36	15	22	50	64
Pusa Sugandh-2	76	75	82	84	24	16	24	24	95	75	64	58	74	32	44	58	22	27	32	27
Pusa Basmati-1	85	80	74	76	22	22	20	20	88	105	107	97	85	50	48	50	8	24	41	47
Mean	78	79	80	74	22	20	19	22	92	76	69	89	71	34	47	70	24	39	34	21
LSD at 5%	T=NS, V=5, TxV=6				T=2.5, V=2.8, TxV=5.6				T=9.6, V=10.8, TxV=21.1				T=9, V=10, TxV=20				T=7, V=8, TxV=15			

Five basmati rice varieties were subjected to high thermal and low light stress (3°C higher than ambient temperature and 20% reduction in light intensity) during various growth phases to assess the effect of high temperature and low radiation on growth, yield and yield attributes of these varieties. High thermal and low light stress throughout the entire growth period (Tillering to maturity) caused highest reduction in grain yield followed by plant exposure to such

stress from tillering to anthesis, while heat and low light stress from anthesis to maturity did not show any detrimental effect on grain yield. The reduction in grain yield was mainly due to significant reduction in grains/panicle owing to marked increase in spikelet sterility under high temperature and low light stress as the number of panicles/pot and 1000 grain weight were least affected by such stress.

Table 5: Rice crop responses to variations in temperature (CERES RICE model). (Mathauda, 2000) ^[13]

Yield and Yield Attributes							
Climate Temperature Scenarios Change	Crop Duration (Days)	Grain Yield (kg ha ⁻¹)	Grains (m ⁻²)	Grains (Ear ⁻¹)	Max (LAI)	Biomass (kg ha ⁻¹)	Straw (kg ha ⁻¹)
(% deviation over normal scenario)							
Extreme warm +2.0 °C	-3.3	-8.4	-8.4	-12.4	-3.9	-7.4	-6.4
Greater warm +1.5 °C	-2.6	-8.2	-8.2	-8.3	-3.9	-6.5	-4.7
Moderate warm +1.0 °C	-2.0	-4.9	-4.9	-6.1	-2.4	-3.6	-2.2
Slight warm +0.5 °C	-1.3	-3.2	-3.2	-2.4	-1.1	-1.3	-0.7
Normal weather Normal	153	6136	18846	494	6.2	10220	4943

Saseedran *et al.*, (2000) reported that duration of rice crop decreased in climate change scenario as compared to baseline climate (control). Rana *et al.*, (2011) reported delaying of snowfall in Himachal Pradesh. It may lead to decrease in yield of apple crop.

Solution?

- **Adaptation:** Adjustments in human and natural systems, in response to actual or expected climate stimuli or their effects that moderate harm or exploit beneficial opportunities.
- **Mitigation:** An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.

Adaptations: Agro-techniques for adaptation to climate change

- Primary and secondary tillage
- Choice of crops and cultivars
- Relocation of crops in alternative areas
- Resilient cropping systems
- Seed rates and spacing
- Sowing time
- Contingency planning
- Water management
- Nutrient management

Agro-techniques for adaptation to climate change: Tillage

Primary tillage/secondary tillage practices/Minimum tillage, reduced or conservation tillage practices, in combination with planting of cover crops and green manure crops revert existing soil organic matter, soil moisture, soil erosion and nutrient loss and help to combat further loss due to climate change.

Table 6: Agro-techniques for adaptation to climate change: Choice of crops and cultivars

Location	Crop	Variety	Duration
Varanasi	Pigeonpea	T-21	153
Anantapur	Groundnut	Vemana	105-110
Indore	Soybean	JS-90-41	87-98
Akola	Cotton	AKH-081	150-160
Bijapur	Sunflower	KBSH-1	90-95
Solapur	Sorghum	Mauli	105-110

Deepwater (floating) rice has three special adaptations

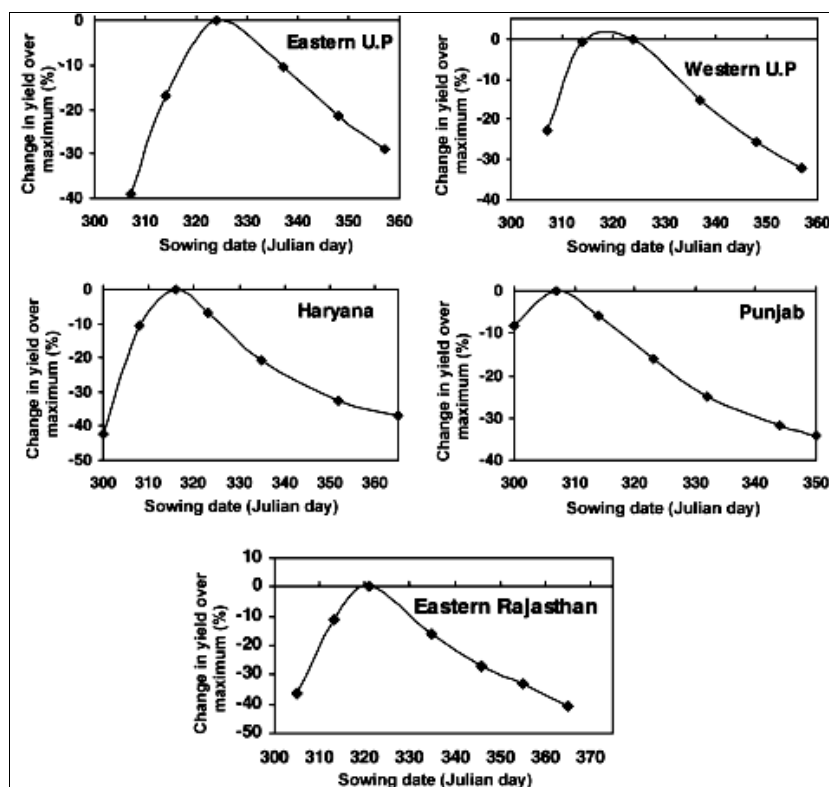
- Ability to elongate with the rise of water levels.
- The upward bending of the terminal part of the plant called 'kneeing' that keeps the reproductive parts above.
- Develop nodal tillers and roots from the upper nodes in the water.

Table 7: Agro-techniques for adaptation to climate change: Relocation of crops in alternative areas. (Lane and Jarvis 2007) ^[12]

Crop	Species	Change in suitable area HADCM3 (%)
Strawberry	<i>Fragaria spp.</i>	-39.25
Sugar Cane	<i>Saccharum officinarum L.</i>	-3.64
Sunflower	<i>Helianthus annuus L v macro</i>	16.20
Sweet Potato	<i>Ipomoea batatas (L.) Lam.</i>	-0.44
Tannia	<i>Xanthosoma sagittifolium L.</i>	-5.80
Wheat	<i>Triticum aestivum L.</i>	-30.86
Yam	<i>Dioscorea spp.</i>	-2.01
Pearl millet	<i>Pennisetum glaucum (L.) R.Br</i>	31.28
Soya bean	<i>Glycine max (L.) Merrill</i>	13.31

Agro-techniques for adaptation to climate change: Seed rates and spacing

- Intra and inter plant competition should be avoided by optimization.
- Reduction of 10-30% seed rate if low soil moisture is anticipated.
- Optimizing spacing to decrease bare soil evaporation.



Agro-techniques for adaptation to climate change: Planting time (Source: Kalra *et al.*, 2008) ^[10]

Agro-techniques for adaptation to climate change: Contingency planning

1. **Early season drought:** Thinning, intercultural practices, mulching, avoid top dressing of fertilizers, opening conservation furrows, ridge and furrow
2. **Mid-season drought:** top dressing and supplemental irrigation, foliar spray of 2% KNO₃ and 2% urea.
3. **Late season drought:** provide lifesaving irrigation, harvesting crop at physiological maturity and harvest for fodder.
4. **High intensity rainfall:** spray hormones to avoid flower drop, plant-protection measures using prophylactic sprays, nutrient foliar sprays.
5. **High rainfall areas:** decreasing the velocity of water down the slope is very critical since doubling velocity can increase the erosive power four times, the carrying (sediment) capacity by 32 times and size of particles transported by 64 times.

Agro-techniques for adaptation to climate change: water management

1. **Methods of application of water:** Drip irrigation (surface sub-surface), sprinkler and surge irrigation, surface irrigation in fields levelled by laser land leveller, smart irrigation systems (15–51%).
2. **Scheduling irrigation:** Critical stages, IW/CPE ratio, Available moisture depletion methods.

Smart irrigation systems on WUE on wheat crop

Ghobari and Marazky (2014) ^[5] reported that in sprinkler irrigation systems, using smart irrigation system increases

water use efficiency by 8.48%-15.76% over conventional sprinkler irrigation systems.

Effect of irrigation regimes at different crop stages on yield of wheat crop

Sharma *et al.*, (1990) ^[17] observed that there was 166% increase in yield when wheat crop was irrigated at crown root initiation (CRI) stage over un-irrigated in 1986-87. Moreover, there was 571% increase when it was irrigated in all the 5 critical stages to that of un-irrigated.

Agro-techniques for adaptation to climate change: Nutrient management

Usman (2013) ^[20] reported the interactive effects of phosphorus (P) and irrigation levels on water use efficiency (WUE) in rice. Significant and the highest mean water use efficiency (13.3 kg ha⁻¹ mm⁻¹) could be achieved when phosphorus was applied @150 kg ha⁻¹ with 8 irrigations. However, there was declining trend for WUE under different of P level with increasing irrigation level. Interactions between different phosphorus levels and different irrigations regimes revealed that WUE increased with increase in P up to 150 kg ha⁻¹ and diminished with further P supply under different of irrigation level.

Agro-techniques for adaptation to climate change: crop management

1. Legume based cropping system: to reduce reliance on fertilizers.
2. Methane mitigation from rice fields: Intermittent irrigation and mid-season drainage can reduce CH₄⁺ flux by 40% but N₂O-N flux may increase by 6%.
3. Direct seeded rice and SRI methods of cultivation are best options available.

Agro-techniques for mitigation to climate change: Nutrient management

- Site-specific nutrient management
- Use of slow release N fertilizers
- Nitrification inhibitor
- LCC (Land Capability Classifications)
- Organic farming
- INM (Integrated Nutrient Management)

Agro-techniques for mitigation to climate change: Tillage

Reduced tillage → Less decomposition → Carbon gain

Agro-techniques for mitigation to climate change: Soil carbon management strategies

- Carbon sequestration: The key to mitigate climate change
- Normal rates of soil organic carbon sequestration on agricultural soils are 200-500 kg C/ha/year
- Management practices: crop residue as surface mulch, crop rotations, INM, SSNM.

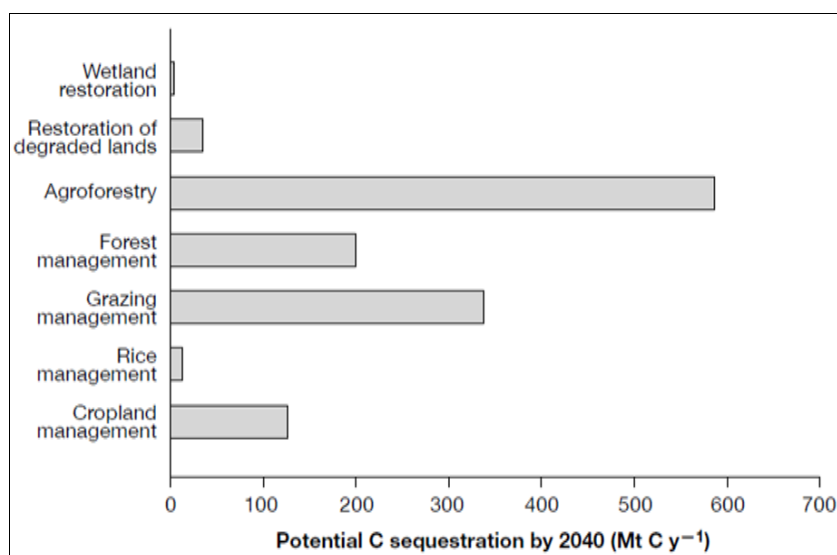
Agro-techniques for mitigation to climate change: Agri-silviculture systems**Table 8:** Carbon storage (Mg/ha/year) in different Agri-silvicultural systems

Location	System	Carbon Sequestration (Mg/ha/year)
Raipur (Swami and Puri, 2005)	Gmelina-based system	2.96*
Chandigarh (Mittal and Singh, 1989)	Leucaena-based system	0.87
Jhansi (Rai <i>et al.</i> , 2002)	Anogeissus based system	1.36
Coimbatore (Viswanath <i>et al.</i> , 2004)	Casuarina-based system	1.45
Saharanpur (Rizvi <i>et al.</i> , 2011)	Poplar based system	11.87

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

Table 9: Carbon storage (Mg/ha/year) in different Silvi-pastoral systems

Location	System	Carbon Sequestration (Mg/ha/year)
Karnal (Kaur <i>et al.</i> , 2002)	Prosopis-based system	2.36
	Acacia based system	1.29
	Dalbergia sissoo based system	1.68
Jhansi (Rai <i>et al.</i> , 2000)	Leucaena-based system	1.82
	Terminalia-based system	1.11
	Neem-based system	0.80
	Albizia procera-based system	2.01
	Dalbergia sissoo-based system	2.90


Carbon (C) sequestration potential (in millions of tonnes per year) of different land use and management options
Summary

- Climate change is a reality. Magnitude of impacts varies greatly by region.
- Agriculture is likely to suffer due to increased temperature, drought, erratic weather, pests and diseases, etc
- Adaptation can help minimize negative impacts to some

extent, however, mitigation should be the long term strategy of combating climate change.

Future thrusts

- A common platform is required to bring researchers, governmental and non-governmental agencies for a common goal.
- Impact assessment modelling has to be taken up on region specific basis but with higher accuracy on spatial

and temporal scale.

- The vast genetic diversity has to be used as adaptive mechanism to address the changes on thermal front.
- Future scenario vis-à-vis crop pest weather relation for different agroecological regions has to be modeled and the adaptation and mitigation strategies evaluation has to be started early.
- Use of energy has to be clean and non-conventional in farming and in all aspects of human life.

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