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Climate Change and Its Impact on Agricultural Productivity in India: A Review

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ABSTRACT

Productivity is the most important aspect in Indian agriculture that we are most concerned about because of the increasing demand of total food grain production with the disadvantageous decreasing total agricultural land area. Basically, productivity is a result of combined effect of genotype of crop and environment. The environmental part is mostly controlled by climate. So the importance of climate is very important in the diversified Indian continent for boosting our agriculture productivity. But it is very challenging to boost the productivity amidst the changing climatic scenario.

Keywords Climate change, Agriculture, Greenhouse gases.

INTRODUCTION

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC 2007). At present climate change is one of the greatest concerns of everyone as it poses potential threat to environment and agricultural activities throughout the world. As agriculture is a climate - sensitive sector, besides ecological, technological and socioeconomic drivers, crop growth and yields are largely determined by weather conditions of the growing season. Climate change and agriculture are intensely interrelated global processes and therefore a change in climate affects agriculture production (IPCC 2007). Data from NASA's GRACE satellites show that the land ice sheets in both Antarctica and Greenland are losing mass. The continent of Antarctica has been losing about 134 giga tonnes of ice per year since 2002, while the Greenland ice sheet has been losing an estimated 287 giga tonnes per year (Source: GRACE satellite data). Arctic sea ice reaches its minimum each September. September Arctic sea ice is now declining at a rate of 13.3% per decade, relative to the 1981 to 2010 average. The 2012 extent is the lowest in the satellite record. The 10 warmest years in the 136-year record all have occurred since 2000, with the exception of 1998. The year 2015 ranks as the warmest on record and the every month of 2016 has been recorded as the hottest month (Source: NASA / GISS). IPCC has shown that earth temperature has increased by 0.74ºC between 1906 and 2005 due to anthropogenic emission of greenhouse gases. Also if we see in the Indian context, there have been several instances like Earthquake in Gujrat in 2001, Tsunami in S-E Asia, Mumbai flood, Uttarakhand flood and drought in Maharastra in 2015

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Table 1. Greenhouse gases and their contribution to global warming (IPCC 2007).

Greenhouse gases	Atmospheric concentration (PPM)	GWP (relative to CO_2)	Sources
CO_2	379	1	Fossil fuel combustion, deforestation, changes
CH_4	1.72	32	Biomass decomposition, wetland paddies, swamps, marshes, peat lands
N_2O	0.31	150	Fertilizer use, fossil fuel combustion, biomass burning, flooded soil
CFCs	<0.0005	10,000	Aerosols, refrigerator

are some live examples of climate change. Climate change is a result of mainly due to two factors i.e. natural causes (volcanic eruption, the earth's tilt, ocean currents), anthropogenic causes (increase in greenhouse gases).

Greenhouse gas

A greenhouse gas is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone. The highest contribution of greenhouse gas is from the energy sector (61%). Agriculture sector contributes around 28% ; and in the coming years, it has been predicted that contribution from agriculture sector will decline because of more investment and growth in energy and industrial sector (Source: India's Initial National Communication on Climate Change) (Table 1).

Greenhouse gases are the main source of global warming on earth surface due to the increase in temperature caused by the absorption of heat that has been reflected from the earth surface. Although they main source of global warming but we can't say that they are completely disadvantageous because the earth's temperature would have been –18ºC if all the greenhouse gases are completely absent from the earth surface (IPCC 2007) which means there would have been no life forms except some cryogenic life and CO_2 which is the main source of photosynthesis for plans is also a greenhouse gas. So we can't say that greenhouse gases are totally disadvantageous but excess of it obviously dangerous which is the most threatening situation now-a-days.

Impact on crop production

High temperature

Positive impact: Reduced cold and frost events, Total crop growing period increases in temperate areas.

Negative impact : Yield reduction due to shorter grain filling period.

According to the growing degree day concept (GDD), a crop require a fixed number of heat units for completion of the life cycle. Due to increase in temperature, more no. of heat units will be available per day. So, the total no. of heat units required for completion of whole life cycle will be achieved in shorter interval which reduces grain filling period (Arnold 1959). Increased respiration, Increased extreme weather conditions i.e. drought, heat wave, Increase evaporative loss.

High carbon dioxide (CO_2)

WUE is generally high with elevated CO_2 concentration

Water use of crop plants is a physiological process but it is mediated by crop physiological and morphological characteristics (Kimball et al. 2007). It can be described by Penman - Monteith equation, whose form was recently standardized (Allen and Gillooly 2005). The equation reveals several mechanisms by which the climate change parameters temperature, CO_2 and O_3 can affect water use. Elevated CO_2 causes partial stomatal closure, which decreases conductance, and reduces loss of water vapors from leaves to atmosphere. Review of the effect of elevated CO_2 on stomatal conductance from chamber-based

Table 2. Rice crop response (%) to change in temperature.

Temperatures change	Crop duration (days)	Grain yield (%)	Maximum LAI (%)
+2.0ºC	− 3.3	− 8.4	− 3.9
+1.5ºC	− 2.6	− 8.2	− 3.9
+1.0ºC	− 2.0	− 4.9	− 2.4
+0.5ºC	− 1.3	− 3.2	− 1.1
Normal	153	6136	6.2
–0.5ºC	0	+ 0.3	+ 0.2
−1.0ºC	+ 1.3	+ 2.7	+ 0.5
−1.5ºC	+ 2.0	+ 4.6	+ 1.1
−2.0ºC	+ 13.1	+ 21.7	+ 13.6

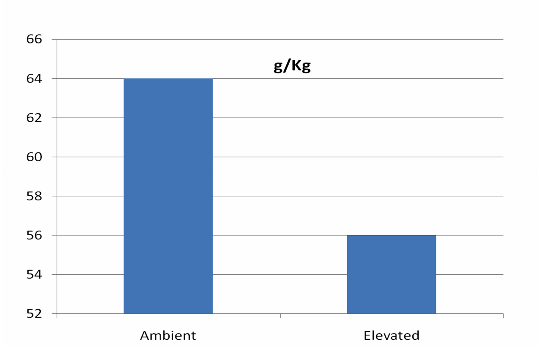

Fig. 1. Elevated CO_2 influences total protein in rice.

studies have reported that, on average, a doubling of CO_2 (from about 340 to 680 ppm reduces stomatal conductance about 34%). There is average reduction of about 40%, with no difference between C_3 and C_4 species (Morrison 1987).

C_3 plants shows significant results as compared to C_4 plants

Doubling CO_2 concentration will increase photosynthesis of C_3 crop species by 30–50% (Table 2). The more increase in photosynthesis in C_3 plants than C_4 plants because there is more increase in CO_2 concentration near (Rubisco) which is more pronounced to oxidation rather than carboxylation if it not optimally surrounded by CO_2 concentration around it. Review of the early enclosure CO_2 studies indicate a 33% increase in average yield for many C_3 crops under doubling CO_2 scenario (Kimball 1983) because of increased numbers of tillers-branches, panicle-pods, number of seeds with minimal effect on seed size while, there is only increase in yield of 10% in C_4 species (Kimball 1983).

Increase atmospheric CO_2 concentrations have a direct effect on the growth rate of crop plants and weed

This experiment was conducted by Bhardwaj et al. (2006) at New Delhi and observed the daily temperature, yield, LAI and put these values in Ceres rice model and predicted the yield, crop duration and LAI by increasing or decreasing 0.5ºC upto 2ºC. It shows that yield increases with decreasing temperature and goes on increasing with further decreasing. Crop duration also increases with the decreasing temperature as per the GDDs concept which also in turn increase the grain filling period and further increment in yield which is well justified to it. The exact opposite occurs when we goes on increasing the temperature (Fig. 1).

From a nutrition point of view, rice protein is an excellent plant protein source for humans and plays a significant role in determining the nutritional quality of rice. Lower total protein concentrations of C_3 crops under elevated CO_2 have been well recognized, which may pose a threat to human nutrition by causing hidden hunger. In agreement with previous reports, elevated CO_2 decreased total protein concentration. In addition, we found that different protein fractions responded differently to elevated CO_2, with the biggest reduction in albumin concentration (−34%), followed by prolamine (−21%), glutelin (–17%) and globulin (−16%). Decreased protein concentration in rice grains exposed to elevated CO_2 has been attributed to a dilution effect, because the protein content in grains is diluted by extra starch accumulated under high-CO_2 conditions. Studies on other C_3 species suggested that the reduction in photorespiration under high CO_2 caused a decrease in nitrate assimilation. This process and other mechanisms were thought to be responsible for the decrease in grain protein concentration under elevated CO_2.

Kaur and Hundal (2006), had followed up the same method for wheat as of rice that we have just

Table 3. Wheat crop response to variation in temperature.

Tem-pera-tures change (°C)	Crop dura-tion (days)	Maxi-mum LAI (% ch.)	Grain yield (% ch.)	Bio-mass yield (% ch.)
+3.0	− 7.7	−38.90	−27.03	−32.35
+2.0	− 5.6	−29.19	−18.02	−22.87
+1.0	− 3.5	−18.38	−9.87	−13.76
+0.5	− 0.7	−5.94	−2.75	−4.60
Normal	143	3.70	49.32 q/ha	133.04 q/ha
−0.5	+ 3.5	+5.14	+6.26	+4.11
−1.0	+ 6.3	+11.62	+7.16	+9.12
−2.0	+ 7.7	+27.84	+7.38	+16.07
−3.0	+ 11.2	+41.08	+9.85	+20.84

discussed. The same trend followed for increment or decreament of temperature. But one thing we can found that there is reduction in yield about 9.87% while in the same case, the yield reduction in rice was of only 4.9% which shows that how sensitive the wheat crop to that of rice with the increase in temperature (Tables 3 and 4).

Earlier workers conducted experiments and found that the maximum yield and LAI has been achieved in (Ambient temperature+Elevated CO_2) treatment while the maximum crude protein content in (Ambient temperature+3.0ºC+Ambient CO_2) treatment. Elevated CO_2 increased grain yield (53.7%), biological yield (51.6%), stover yield (50.5%), harvest index (2.9%), cob diameter (6.7%) and cob length (8.5%). Elevated temperature reduced yield and yield attributes except harvest index. The mean values calculated for two years data revealed that plant height, cob length, cob diameter and number of grains / cob declined by 0.5–5.6% under elevated CO_2 and elevated temperature of 1.5 (T_5) and 3.0 (T_6) compared to ambient conditions (treatment T_1). With elevated CO_2, grain yield increased by 45.7% at ambient + 1.5 (T_5) and by 0.5% at ambient + 3.0 (T_6) temperature compared to ambient conditions. A similar pattern was observed for 100 grain weight, stover yield and biological yield. In general, yield and yield components of maize increased with elevated CO_2 by 2.9–53.7% and with elevated CO_2 and elevated temperature of 1.5 by 9.4–45.7%. Elevated

Table 4. Effect of elevated atmospheric CO_2 and temperature on grain yield, crude protein content and LAI of maize (OTC).

Treatments	Grain yield (t/ha)	Crude pro-tein con-tent (%)	LAI
Ambient temp+Ambient CO_2	4.44	8.83	3.2
(Ambient temp+1.5)+ Ambient CO_2	3.78	9.13	3.1
(Ambient temp+3.0)+ Ambient CO_2	3.58	9.36	3.0
Ambient temp+Elevated CO_2	7.20	7.89	3.8
(Ambient temp+1.5)+ Elevated CO_2	6.47	8.09	3.6
(Ambient temp+3.0)+ Elevated CO_2	4.46	8.45	3.3
SEm ±	0.01	0.06	0.2
CD (p = 0.05)	0.03	0.20	0.7

CO_2 and elevated temperature of 3.0 (T_6) did not affect grain yield but increased number of grains row, grain weight and HI and decreased biological yield. The increment of number of grains row, grain weight cob and HI with elevated CO_2 and elevated temperature of 3.0 (T_6) indicated the dominance effect of elevated CO_2 over temperature effect. Moreover, elevated CO_2 slightly increased number of grains but greatly increased grain weight / cob (43%) and 100 grain weight (29%), hence grain weight was the major contributing factor for yield increment. The above results showed elevated CO_2 concentration significantly increased maize yield as reported previously (Leakey et al. 2004, Sharma and Behera 2009, Kim et al. 2007, Prins et al. 2007). Cure and Acock (1986) reported yield increase by 27% with doubling CO_2 concentration. Meng et al. (2014) observed increased yield by 22.9% when CO_2 level increased up to 700 ppm and Long et al. (2004) reported that grain yield of maize and sorghum increased by an average of 18% when CO_2 were elevated to 550 ppm. On the contrary, Ziska et al. (2006) reported that C_4 plants do not benefit from elevated CO_2 concentration. In the current experiment elevated CO_2 increased number of grains and grain weight. Ziska et al. (2006) reported that increased CO_2 affected reproduction, which in turn increased the number of

Table 5. Impact of climate change factors (temperature, CO_2 and rainfall) on seed yield of chickpea by Cropgro chickpea model.

Year	Climatic scenario	Hisar Yield	Hisar % ch	Indore Yield	Indore % ch	Nandhyal Yield	Nandhyal % ch
Base line		1322		1813		1181	
2030	T	1390	5	1810	0	1001	– 15
2030	T + CO_2	1528	16	1997	10	1136	– 04
2030	T + CO_2 + R	1414	7	2017	11	1135	– 04
2050	T	1440	9	1749	– 4	794	– 33
2050	T + CO_2	1698	28	2095	16	982	– 17
2050	T + CO_2 + R	1547	17	2115	17	994	– 16
CD (p = 0.05)		60		35		30	

flowers, pollen formation, number of grains and grain weight. Recently, Vanaja et al. (2015) observed that elevated CO_2 by 550 ppm enhanced biomass of maize by 32–47%, grain yield by 46–127%, grain number by 25–72%, 100-grain weight by 8–60% and HI by 11–68% in three genotypes of maize in semi - arid tropical climate of India.

Elevated CO_2 caused about 11.0% decrease in N and crude protein contents. Nitrogen and crude protein contents also declined by about 8.5% and 4.3% with elevation of CO_2 and temperature by 1.5 C and 3.0 C, respectively, compared to ambient conditions. The reduction in grain N and crude protein contents may be because of dilution effect as a result of greater carbohydrate accumulation (Rogers et al. 1999, Hogy et al. 2009). Photosynthetic rate was enhanced by 23.49% under elevated CO_2 condition in our study data not shown. Thomas et al. (2009) reported that crops grown with elevated CO_2 concentration are likely to produce poor quality grains and lack in some essential nutrients. The results are in agreement with Jablonski et al. (2002) who reported that seed N content of plants grown under elevated CO_2 reduced by 15%. We observed an 11.0% reduction in N and crude protein contents with elevated CO_2. This reduction may be due to increased carbohydrate concentration and with elevated CO_2 uptake of N may also be reduced. Our results also indicated that elevated CO_2 along with elevated temperature by +1.5 and + 3.0 C increased grain N and crude protein contents by 3.0 and 6.5%, respectively. This showed that elevated temperature could reduce the negative effects of elevated CO_2 on grain N and crude protein contents. Randall and Moss (1990) observed that reduction of N and protein in plant with elevated CO_2 could be partially or fully balanced because of increased temperature, which enhances grain protein content (Table 5).

Singh et al. (2013) planted chickpea in 3 different zones of India in 2011 and he put these values in cropgro model and found that with different combination of temperature, CO_2 and rainfall that had been predicted for 2030 and 2050. Putting these values in this model, we can predict the yield level in future.

If we only consider the temperature level in 2030 and putting other factors remain same as that of base period, we found that there has been increase in yield in Hisar while there is decrease in yield in Nandhyal and there is no effect in yield level in Indore condition. This may ascribed that the temperature in Hisar condition is less than optimum temperature required for Chickpea. So with increased temperature in 2030, there is more increase in yield as it move closer to the optimum level. In Indore condition, the temperature zone is already in the optimum zone and the increased temperature moves in the zone of optimum temperature, so there is no change in yield level in Indore condition. In Nandhyal condition the temperature is already higher than the optimum temperature. So, further increase in temperature will further reduce the yield in Nandhyal condition. If we add the CO_2 effect with the temperature effect, then its effect will either complement or supplement the adverse and good effect of temperature respectively which is clearly seen on the yield level. So, we can point out that increasing temperature doesn't always decrease the yield. It actually depends upon the type of crop and the place upon which we are growing the crop.

Mitigation

We could follow some mitigation statergy to combat the changing climatic scenario. Reforestation, Changing planting dates, Carbon sequestration, Reduce tillage practices, Improve land management.

Methane emission in rice field

Methane emission occurs in anaerobic condition by some methanogenic bacteria by utilizing organic carbon resent in the soil through the plant itself or through the submerged water to the atmosphere. Here are some techniques for reducing methane emission in rice: Breeding rice cultivars with low CH_4 emission, Alternate wetting and drying, Use of sulfate containing fertilizers, Use of methanotrophic bacteria, Controlling soil pH, Adopt SRI and aerobic method.

CONCLUSION

Increased CO_2 levels are expected to favor growth and increase crop yields. Rice and wheat will going to lose about 4.9% and 9.87% of food grain production with increase in 1ºC temperature. Productivity of *rabi* pulses will going to increase in North and Central Indian condition while reverse occurs in Southern Indian condition. Application of sufficient quantity of sulfur and phosphorus and methanotrophic bacteria will reduce methane emission in submerged rice.

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