International Letters of Natural Sciences *Online: 2014-02-27*
ISSN: 2300-9675, Vol. 11, pp 16-29
doi:10.56431/p-28x9v3
CC BY 4.0. Published by Academic Open Access LTD, 2014

Implications of Global Warming on Changing Trends in Crop Productivity – A Review

Shamayita Banerjee, Priya Banerjee, Aniruddha Mukhopadhayay*

Department of Environmental Science, University of Calcutta,
51/2 Hazra Road, Kolkata - 700 019, India

*E-mail address: am_cuenvs@yahoo.co.in

ABSTRACT

Evidence of changes in weather parameters like ambient temperature, precipitation, wind flow, etc., are prominently visible across the world. These changes have been reported to effect global crop yield. This review compiles both direct and indirect effects of climate change on global crop productivity with highlights on existing local and global scenarios. As a conclusion, it may be stated that thorough understanding of agricultural techniques and analysis of global change factors is highly essential for achieving sustainable agricultural yield over the upcoming years.

Keywords: Carbon Dioxide; Global Warming; Crop Productivity; Climate Change

1. INTRODUCTION

It has been stated earlier in several studies that the chief reason behind climate change is the rise in CO_2 level. According to USEPA carbon dioxide is the main greenhouse gas which is usually emitted due to several anthropogenic activities apart from being naturally present in the atmosphere or as a part of the carbon cycle along with other natural processes. Post industrial revolution, increased activities by humans have become chiefly responsible for the increase in the concentration of CO_2 and other greenhouse gases. Carbon dioxide is also added to the atmosphere from a variety of other related sources. Scientists have expressed concern about the possible climatic ramifications of current and future concentrations of carbon dioxide in the atmosphere (IPCC, 1992). The increased carbon dioxide concentrations has been said to be responsible for Global warming, a condition indicating global rise of temperature. Carbon dioxide persists in the atmosphere for a long time owing to its very slow transfer to the ocean sediments (Solomon et al., 2009). Certain physically based, mathematical climate models known as General Circulation Models (GCMs), indicate, that doubling the level of atmospheric carbon dioxide from the level of 350-360 ppm will raise the mean global surface temperature by 1.5 to 4.5 °C (IPCC, 1992). Climate models considering increased greenhouse gases and aerosols project an increase in global mean surface temperature of about 1 to 3.5 °C in the next century (IPCC, 1996)

The concomitant increases in concentration of atmospheric CO_2 and increases in global surface temperature along with certain associated changes in precipitation and other factors may affect the productivity of life-sustaining, crop plants (Allen, 1990; Kimball, 1983; Rogers et al. 1993).

Agricultural systems are in proper sense, managed ecosystems. Thus, there is a typical effect of climate change on production and food supply which has been estimated by scientists. Agricultural systems are dynamic; producers and consumers which are intricately interrelated are continuously responding to changes in crop and livestock yields, food prices, resource availability, and technological change. Keeping in mind these adaptations and adjustments, it is difficult but necessary to measure accurately climate change impacts. Human attempts in adapting to the climate change can be accounted either in the form of short term changes in production and consumption practices or in the long term changes in technology and applications, that can lead to a successful estimation of the potential damage caused by climate change. Agriculture is therefore strongly influenced by weather and climate. Climate change can therefore be expected to impact on agriculture, potentially threatening established aspects of farming systems, their growth and agricultural yield.

The nature of agriculture and farming practices in any particular location are strongly influenced by the long-term mean climate state the experience and infrastructure of local farming communities are generally appropriate to particular types of farming and to a particular group of crops which are known to be productive under the current climate. Higher growing season temperatures can significantly show their impact on agricultural productivity, farm incomes and food security (Battisti et al., 2009).

Moderate levels of climate change may not necessarily confer benefits to agriculture without the producers being adapted to the situation, but an increase in the mean seasonal temperature can bring the harvest time of current varieties of many crops nearby and hence can reduce final yield without any sort of adaptation to a longer growing season. In areas where temperatures have already been close to the physiological temperature maxima for crops, for example in the seasonally arid and tropical regions, higher temperatures can turn out to be more detrimental, increasing the heat stress on crops and water loss by evaporation. Different crops show different sensitivities to warming or rise in temperature. It is therefore important to note the range of uncertainties that can account for changes in crop yield for a given level of warming.

2. SOME IMPORTANT PARAMETERS RESPONSIBLE FOR THE CHANGE IN CROP PATTERN

Climate change and agriculture are interrelated processes, both of which take place on a global scale (IPCC, 2007). Global warming is projected to have significant impacts on certain parameters like temperature, carbon dioxide, glacial run-off, precipitation and the interaction of these elements that can affect agriculture. These conditions determine the carrying capacity of the biosphere to produce enough food for the human population and domesticated animals. The overall effect of climate change on agriculture will depend on the balance of these parameters that would otherwise successfully maintain ecological balance. Henceforth the assessment of the effects of global climate changes and their various parameters on agriculture might help to properly anticipate and adapt farming processes so as to maximize agricultural production (Fraser, 2008). At the same time, agriculture has been shown to produce significant effects on climate change, primarily through the production and release of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, but also by altering the Earth's land cover, which can change its ability to absorb or reflect heat and light. Land use change such as deforestation and desertification, together with use of fossil fuels, are the major anthropogenic sources of carbon dioxide; agriculture itself is the major contributor to increasing methane and nitrous oxide concentrations in Earth's atmosphere (UN Report on Climate Change, 2007).

A study published in Science suggests that, due to climate change, "southern Africa could lose more than 30 % of its main crop, maize, by 2030. In South Asia losses of many regional staples, such as rice, millet and maize could top 10 %" (Lobell et al. 2008; BBC News).

The Intergovernmental Panel on Climate Change (IPCC) has produced several reports that have assessed the scientific literature on climate change. The IPCC Third Assessment Report, published in 2001, concluded that the poorest countries would be hardest hit, with reductions in crop yields in most tropical and sub-tropical regions due to decreased water availability, and new or changed insect pest incidence. In Africa and Latin America many rainfed crops are near their maximum temperature tolerance, so that yields are likely to fall sharply for even small climate changes; falls in agricultural productivity of up to 30 % over the 21st century are projected. Marine life and the fishing industry will also be severely affected in some places. Climate change induced by increasing greenhouse gases is likely to affect crops differently from region to region. For example, average crop yield is expected to drop down to 50 % in Pakistan according to the UKMO scenario whereas corn production in Europe is expected to grow up to 25 % in optimum hydrologic conditions.

In the long run, it was estimated that the climate change could affect agriculture in several ways that are as follows:

- *productivity*, in terms of quantity and quality of crops
- *agricultural practices*, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers
- *environmental effects*, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity
- *rural space*, through the loss and gain of cultivated lands, land speculation, land renunciation, etc..
- *adaptation*, organisms may become more or less competitive, as well as humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of rice.

Small increases in temperature in low latitudes may have a greater impact than in high latitudes, possibly because agriculture in parts of these regions is already marginal. Water is vital to plant growth, so varying precipitation patterns have a significant impact on agriculture. As over 80 per cent of total agriculture is rain-fed, projections of future precipitation changes often influence the magnitude and direction of climate impacts on crop production (Olesen et al. 2002; Reilly et al., 2003; Tubiello et al. 2002). The impact of global warming on regional precipitation is difficult to predict owing to strong dependencies on changes in atmospheric circulation, although there is increasing confidence in projections of a general increase in high-latitude precipitation, especially in winter, and an overall decrease in many parts of the tropics and sub-tropics (IPCC, 2007). The differences in precipitation projections arise for a number of reasons. A key factor is the strong dependence on changes in atmospheric circulation which itself depends on the relative rates of warming in different regions, but there are often a number of factors influencing precipitation change projections in a given location.

Many people especially the agronomists believe that agricultural production is grossly affected by the pace of climate change and its severity. If the change takes place slowly and gradually, then the biota can get enough time for adjustment. Rapid change in climate can harm those places which are already suffering from poor soil profile and unfavourable climatic conditions. In this case less time is available to these places for optimum natural selection and adaptation.

3. DIRECT IMPACT OF CLIMATE CHANGE

Probable climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. Although increase in temperature can have both positive and negative effects on crop yields, generally temperature increases have been found to reduce yields and quality of many crops, most importantly cereal and feed grains.

3. 1. Rises in Temperature

With reference to the IPCC's Fourth Assessment Report (IPCC, 2007), Schneider et al. (2007) gave a projection related to the future effects of climate change on agriculture. They concluded roughly for an increase in global mean temperature for about 1 to 3 °C (by 2100, relative to the 1990-2000 average level) there would be significant decrease in the level of productivity for some cereal crops in the lower latitudes. It has also been predicted that productivity may increase in higher latitudes.

Increase in temperature may lead to higher respiration rates, shorter periods of seed formation and, consequently, lower biomass production. Crop growth cycles are related to temperature and increase in temperature speeds up development. In case of an annual crop, duration between sowing and harvesting season decreases, hence this shortening of growth cycle affects productivity. Also higher temperatures may result in a shorter and insufficient development period; therefore, it may lead to smaller and lighter grains, lower crop yields and perhaps lower grain quality (i.e. lower protein levels). Again, certain weeds, diseases and pests (Ziska et al. 2011) benefit from warming and growth of many microbial (usually fungal infection) is aggravated when warmth and moisture are available. Humidity and temperature can thus favour the growth of fungal infection and damage crops.

In most of the croplands throughout the world, the temperature has risen significantly which has affected growing season of several crops. Apart from rise in temperature, there are few other factors that have also affected crop production directly or indirectly. They are moisture retaining capacity of the soil, hydrological cycles and tropospheric ozone.

Temperature affects agricultural yields through various ways. Higher temperature results in faster development of crops and therefore shorter growing season (Stone, 2001). Thus the duration for which crops last is very short and this may give rise to lower yields. Temperature also affects the rates of photosynthesis, transpiration and respiration. Increase in temperature during day increases photosynthesis (provided the temperature is maintained near the optimal range) whereas an increase in temperature during night raises the rate of respiration (Crafts-Brandner et al 2002). Another factor directly affected by the fluctuation in temperature is humidity. Increase in temperature leads to an increase in saturation vapour pressure of air. Relative humidity has remained roughly constant in recent decades over large spatial scales (Willett, 2007) and is projected to change minimally in the future as well. Increase in temperature to an extreme level can directly damage plant cells.

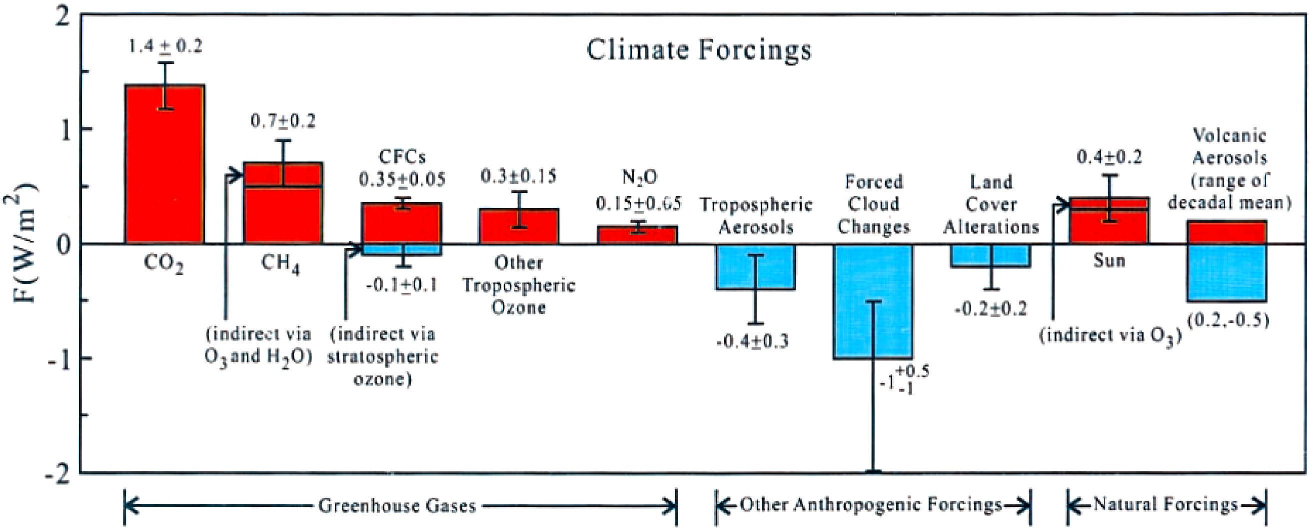

Figure 1. Showing Estimated climate forcings between 1850 and 2000 (IPCC, 1996; Andreae, 1995; Hansen et al. 2000).

Air pollutants such as nitrogen oxides, carbon monoxide, and methane, react with hydroxyl radicals in the presence of sunlight to form tropospheric O_3, which causes oxidative damage to photosynthetic machinery in all major crop plants (Wilkinson et al. 2012). Aerosols from air pollution can also cause harm. These pollution-related impacts are incredibly dangerous in agricultural areas, but the danger of tropospheric Ozone can also be a problem across continents. In fact, tropospheric O_3 concentrations above pre-industrial levels are currently found in most agricultural regions of the globe (Van Dingenen et al, 2009).

There are effects due to interaction between O_3 and elevated CO_2. For example, reduced stomatal conductance under elevated CO_2 will reduce O_3 uptake by crop plants, thereby limiting damage to the plant and maintaining biomass production (McKee et al., 1997). However, empirical evidence is mixed regarding the ability of elevated CO_2 to reduce the impact of O_3 on final yields (McKee et al., 2000). However, a higher stomatal conductance implies more uptake of O_3, increasing the sensitivity of more recent varieties to O_3 damage (Biswas et al, 2008).

Increases in precipitation (i.e. level, timing and variability) may benefit semi-arid and other areas which have shortage of water, by increasing soil moisture. But this factor could aggravate problems in regions with excess water. Similarly a reduction in rainfall could have the opposite effect. Water stress during the reproductive period of cereal crops may be particularly harmful (Stone, 2001; Hatfield et al. 2011) while the farmers may be confused enough to determine the planting season for agriculture if there are changes in the timing of the rainy season, particularly in tropical areas. Finally, more intense rainfall events may lead to flooding and water logging of soils, which are also good reasons behind crop destruction.

An atmosphere with higher CO_2 concentration would result in higher net photosynthetic rates (Cure et al., 1986; Allen et al. 1987). Higher concentrations may also reduce transpiration (i.e. water loss) as plants reduce their stomatal apertures, the small openings in the leaves through which CO_2 and water vapour are exchanged with the atmosphere. The reduction in transpiration could be 30 % in some crop plants (Kimball, 1983). However, stomatal response to CO_2 interacts with many environmental (temperature, light intensity) and plant factors (e.g. age, hormones) and, therefore, predicting the effect of elevated CO_2 on the responsiveness of stomata is still very difficult (Rosenzweig et al., 1995).

Variations in temperature within a short span of time may seem critical if it by chance interferes with the different stages of development of crops. It was observed by Wheeler et al (2000) that a few more days of extreme temperature (greater than 32 °C) at the flowering stage of many crops can drastically reduce yield. Changes in growing conditions coupled with stress factors thus affect the growth, development and eventual yield.

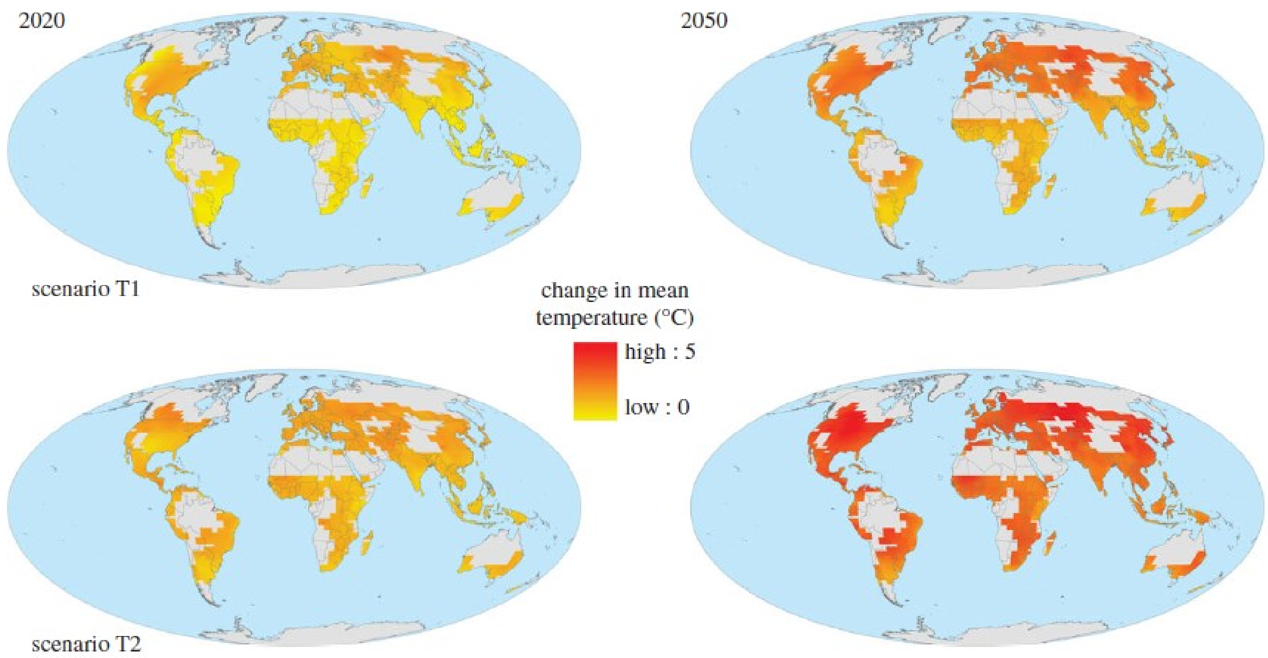

Figure 2. (Gornall et al., 2010) showing: Two projections of change in annual mean temperature (°C) over global croplands for 30-year means centred around 2020 and 2050, relative to 1970–2000. The two projections are the members of the ensemble with the greatest and least change in annual mean temperature averaged over all global croplands.

Physiological processes related to growth such as photosynthesis and respiration respond to changing temperature always. But rates of crop development are often affected when the changes in temperature or the fluctuation in temperature reaches a certain level. In the short-term, high temperatures can affect enzyme mediated reactions and gene expression, whereas in the longer term, these will have their impact on carbon assimilation and eventually on growth rates and final yield. The impact of high temperatures on final yield can depend on the stages of crop development. Wollenweber et al. (2003) stated that the plants experience warming periods as independent events and that critical temperatures of 35 °C for a short-period around anthesis had severe yield reducing effects. However, high temperatures during the vegetative stage did not seem to have significant effects on growth and development. Again Maize exhibits reduced pollen viability for temperatures above 36 °C, while for Rice grains, sterility is brought on by temperatures in the mid-30s and similar temperatures can lead to the reversal of the *vernalizing* (Subjection of seeds or seedlings to low temperature in order to hasten plant development and flowering) effects of cold temperatures in wheat. Increases in temperature above 29 °C for corn, 30° C for soya bean and 32 °C for cotton negatively impact on yields in the USA.

Figure 1 (Gornall et al., 2010) below shows that in all cases and all regions, one in a 20-year extreme temperature events is projected to be hotter. The impacts of extreme temperature events can be difficult to separate from those of drought. However this variable pattern of temperature change can yield devastating results.

3. 2. Rises in Mean Sea Level

Rise in mean sea-level is an inevitable consequence of a global warming thus contributing towards a combination of thermal expansion of the existing mass of ocean water and of extra water owing to the melting of land ice. It is presumed to cause inundation of coastal land. Regarding crop productivity, the low-lying coastal agriculture becomes vulnerable to the increase in rise of sea level. Many major river deltas contain important agricultural land due to the fertility of fluvial soils, and many small island states are also low-lying. Therefore increase in mean sea level threatens to inundate agricultural lands and salinize groundwater.

4. INDIRECT IMPACTS OF CLIMATE CHANGE

4. 1. Drought

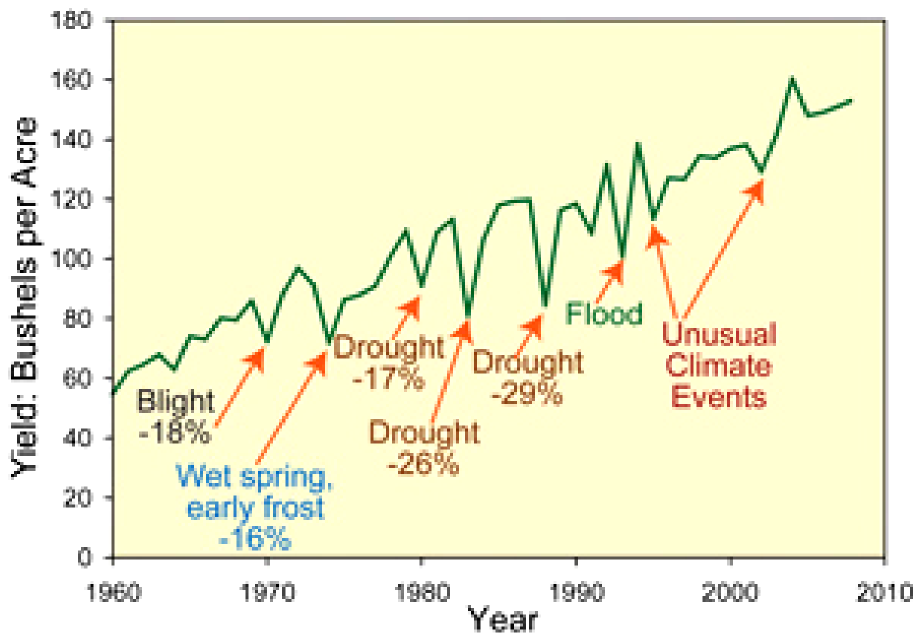

Figure 3. (USGCRP, 2009): Despite technological improvements that increase corn yields, extreme weather events have caused significant yield reductions in some years. [Source: USGCRP, 2009].

There can be a number of definitions of drought. Droughts have severe impact on agriculture. Meteorological drought (broadly defined by low precipitation), agricultural drought (deficiency in soil moisture, increased plant water stress), hydrological drought (reduced streamflow) and socio-economic drought (balance of supply and demand of water to society) are the four different kinds of drought (Holton et al. 2003).

Droughts have been occurring more frequently because of global warming and they are expected to become more frequent and intense in Africa, southern Europe, and the Middle East, most of the America, Australia, and Southeast Asia (Wiley Interdisciplinary Reviews: Climate Change, 2010). Their impacts are characterized with decreased crop production and are aggravated because of increased water demand, population growth, urban expansion, and environmental protection efforts in many areas (Drought modeling – A review, 2011). Droughts result in crop failures and the loss of pasture grazing land for livestock.

4. 2. Excessive precipitation

Heavy rainfall and tropical cyclones also account for events leading to flooding which can wipe out entire crops over wide agricultural areas, and excess water can also lead to other impacts including soil water logging, anaerobic environment and reduced plant growth.

5. THE GLOBAL SCENARIO

The Earth's average temperature has been rising since the late 1970s, with nine of the 10 warmest years on record occurring since 1995 (NOAA reports, 2005). In 2002, India and the United States suffered sharp harvest reductions because of record temperatures and drought. In 2003 Europe suffered very low rainfall throughout spring and summer, and a record level of heat damaged most crops from the United Kingdom and France in the Western Europe through Ukraine in the East (Lobell et al. 2012).

Atmospheric CO_2 concentrations have been rising rapidly since the start of the industrial era, with an average rate of growth of approximately 2 mL L21 per year in the 2000s [32]. The 2010 global average concentration of 390 mL L21 was 39 % higher than at the start of the Industrial Revolution (i.e. 278 mL L21 in 1750) (Global Carbon Project, 2011). This increased level of atmospheric CO_2 account for the overall rise in temperature throughout the world.

But somewhere this increase in temperature can be beneficial when certain places especially several temperate regions have been free from spring and autumn frost which has significantly expanded the growing season of the vegetation in those regions. For example, there will be a 2-week increase in the growing season for Scandinavia by 2030 compared to the late 20th century (Trnka et al., 2011). Northern China, Russia, and Canada are also expected to see large gains in the frost-free period suitable for crop growth (Ramankutty, 2002).

6. THE LOCAL SCENARIO

Indian agriculture is highly dependent on the spatial and temporal distribution of monsoon rainfall (Wollenweber et al, 2003). Asada & Matsumoto (2009) analysed the relationship between district level crop yield data (rainy season ‘kharif’ rice) and precipitation for 1960–2000. It was shown that different regions were sensitive to precipitation extremes in different ways. Crop yield in the upper Ganges basin is linked to total precipitation during the relatively short growing season and is thus sensitive to drought. Conversely, the lower Ganges basin was sensitive to fluvial flooding and the Brahmaputra basin depicted an increasing effect of variable precipitation on crop yield. Particularly the effect of drought was shown. These relationships were not consistent through time when trends in the precipitation levels were considered.

7. IMPACT OF GLOBAL CHANGE FACTORS

Several global change factors have imposed varying impacts in the global cropping pattern. There has been a great concern about the potential long term effects of climate change on agriculture. Many other indirect effects of global warming have been changes in runoff and changes in rates of groundwater recharge that has also affected different existing parameters of our environment. The differences of the varying temperatures between day and night and the exposures to different sources of pollution have encouraged new and improved techniques of farm management such as sowing seeds depending on the varying climatic conditions of a place thus optimising yield and dividing the cropping season into segments. Farmers have also taken an upper hand to change and revise their farming practises with response to climate change, by sowing different crops or varieties, changing the timing of field operations, or expanding irrigation, and the socioeconomic capacity; to adapt to these changes of climatic conditions.

Advances in irrigation systems have also been have been advanced because irrigation prevents the effect of global warming on crops as crops that are rain fed or particularly grown in wet areas have been found to behave similarly like irrigated crops.

8. CONCLUSION

They are a lot of uncertainties still left to be uncovered, particularly, because there is lack of information on many specific local regions, and these include the uncertainties on magnitude of climate change, the effects of technological changes on productivity, global food demands, and the numerous possibilities of adaptation. Most agronomists believe that agricultural production will be worse affected by the pace, extent and severity of climate change, not really by the slow and gradual changes that has been documented. If change is gradual, there may be enough time for adjustment of the biota and adaptation or rather acclimatising to the changing trends of climatic conditions. Rapid climate change could initially harm agriculture in many countries, especially those that are already suffering from poor soil and climatic conditions, because there is less time for optimum natural selection and adaption.

Growth rates in crop productivity to 2050 will be mainly driven by technological and agronomic improvements. Even it is highly unlikely that climate change would result in a net decline in global yields. Instead, there is a relevant question at the global scale is how much the climate change and global warming would try to put up its effect in declining the productivity with respect to its demand. Overall, the net effect of climate change and CO_2 on global average supply of calories is likely to be fairly close to zero over the next few decades, but it could be as large as 20 % to 30 % of overall yield trends. Of course, this global picture hides many changes at smaller scales that could be of great relevance to food security, even if global production is maintained (Easterling, W. E. et al. 2007).

To reduce uncertainties in global impacts, proper estimation of rates of global warming and the responses of crop yields to warming and CO_2 (and their combination) should be particularly investigated. It will never be possible to unambiguously measure the effect of changes in climate, CO_2, and O_3, given the scale of global food production and the fact that agriculture is always changing in multiple ways. However, the best available science related to climate change and crop physiology indicates that climate change represents a credible threat to sustaining global productivity growth. Many techniques have been devised to improve tolerance to existing changes, ensure adaptation techniques to upcoming rates of change like designing several simulation models necessary to keep up with demand to combat evils of climate change. Increasing the scale of investments in crop improvement and by emphasising on global change factors fruitful ways should be paved towards the growth of a sustainable agricultural yield over the next few decades.

References

[1] IPCC/WMO/UNEP, 1992. The Supplementary Report of the IPCC Scientific Assessment. *In* Climate Change. Houghton, J.T., Callander, B.A., and Varney, S.K. (eds.), Cambridge University Press, Cambridge, UK. p. 200.

[2] Intergovernmental Panel on Climate Change (IPPC), 1996. The Science of Climate Change. *In* Climate Change 1995. Cambridge University Press, Cambridge, UK.

[3] Allen, Jr., L.H., 1990. Plant Responses to Rising Carbon Dioxide and Potential Interactions with Air Pollutants. *J. Environ. Qual.* 19: 15-34.

[4] Kimball, B.A., 1983. Carbon Dioxide and Agricultural Yield. An Assemblage and Analysis of 430 Prior Observations, *Agron. J.* 75: 1211-1235.

[5] Kimball, B. A., 1983. Carbon Dioxide and Agricultural Yield. An Assemblage and Analysis of 770 Prior Observations, WCL Rep. 14, U. S. Water Conservation Laboratory, Phoenix, AZ, p. 71.

[6] Rogers, H. H. and Dahlman, R. C., 1993. Crop Response to CO_2 Enrichment. *Vegetatio* 104-105: 117-131.

[7] Battisti, D. S. and Naylor, R. L. 2009 Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323: 240-244.

[8] Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios. Accessed from (http://www.grida.no/climate/ipcc/emission/076.htm) retrieved 26 June 2007.

[9] Fraser, E., 2008. Crop yield and climate change. Accessed from (http://www.vulnerable foodsystems.com). Retrieved on 14 September 2009.

[10] UN Report on Climate Change. Accessed from (http://www.ipcc.ch/SPM2feb07.pdf). Retrieved 25 June 2007 Archived (http://web.archive.org/20070621143239/http://www.ipcc.ch/SPM2feb07.pdf) June 21, 2007 at the Wayback Machine.

[11] "Climate 'could devastate crops'" (http://news.bbc.co.uk/2/hi/science/nature/7220807.stm) BBC News. 31 January 2008. http://news.bbc.co.uk/2/hi/science/nature/7220807.stm.

[12] Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL (2008). "Prioritizing climate change adaptation needs for food security in 2030". *Science* 319

(5863): 607–10. doi:10.1126/science.1152339 (http://dx.doi.org/10.1126%2 Fscience.1152339) PMID 18239122 (//www.ncbi.nlm.nih.gov/pubmed/18239122).

[13] Olesen, J. E. and Bindi, M., 2002. Consequences of climate change for European agricultural productivity, land use and policy. *Eur. J. Agron.,* 16: 239-262.

[14] Reilly, J. et al., 2003. US agriculture and climate change: new results. *Clim. Change.* 57: 43-69.

[15] Tubiello, F. N., Rosenzweig, C., Goldberg, R. A., Jagtap, S. & Jones, J. W. 2002 Effects of climate change on US crop production: simulation results using two different GCM scenarios. Part I: wheat, potato, maize, and citrus. *Clim. Res*. 20: 259-270.

[16] IPCC, 2007. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK.

[17] Cure, J.D., Acock, B., 1986. Crop responses to carbon dioxide doubling: a literature survey. *Agric. For Meteorol*. 38: 127-145.

[18] Allen, L.H. Jr, Boote, K.J., Jones, J.W., Jones, P.H., Valle, R.R., Acock, B., Rogers, H.H. and Dahlman, R.C., 1987. Response of vegetation to rising carbon dioxide: photosynthesis, biomass and seed yield of soybean. *Global Biogeochem Cycles* 1: 1-14.

[19] Kimball, B. A., 1983. Carbon Dioxide and Agricultural Yield. An Assemblage and Analysis of 770 Prior Observations, WCL Rep. 14, U. S. Water Conservation Laboratory, Phoenix, AZ, p. 71.

[20] Rosenzweig, C. and Hillel, D., 1995. Potential impacts of climate change on agriculture and world food supply. Consequences Summer: 24: 32.

[21] Wheeler, T. R., Craufurd, P. Q., Ellis, R. H., Porter, J. R. and Prasad, P. V. V., 2000 Temperature variability and the yield of annual crops. *Agric. Ecosyst. Environ*. 82: 159-167.

[22] Wollenweber, B., Porter, J. R. and Schellberg, J. 2003 Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. J. Agron. Crop Sci. 189, 142-150.

[23] Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K.. and Wiltshire, A., 2010. Implications of climate change for agricultural productivity in the early twenty-first century, *Phil. Trans. R. Soc. B* 365.

[24] Holton, J. R., Curry, J. A. and Pyle, J. A., 2003. Encyclopedia of atmospheric sciences. New York, NY: Academic Press.

[25] Wiley Interdisciplinary Reviews: Climate Change, 2010. Drought under global warming: a review. Accessed from (http://onlinelibrary.wiley.com/doi/ 10.1002/ wcc.81/abstract), October 19, 2010.

[26] Drought modeling – A review. Accessed from (http://www.sciencedirect.com/ science/article/pii/S0022169411002393). *J. Hydrol.*, 6 June 2011.

[27] USGCRP, 2009. *Global Climate Change Impacts in the United States* . Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.). United States Global Change Research Program. Cambridge University Press, New York, NY, USA.

[28] IPCC, 2007. Summary for Policymakers: C. Current knowledge about future impacts. *In* Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Parry, M.L., et al. (ed.)). Cambridge University Press. Cambridge, UK.

[29] NOAA reports 2005 global temperature similar to 1998 record warm year. Accessed from (http://www.publicaffairs.noaa.gov/releases2006/jan06/noaa06-013.html) (Press release). NOAA. 30th January, 2006.

[30] Sacks, W.J., Deryng, D., Foley, J.A. and Ramankutty, N., 2010. Crop planting dates: an analysis of global patterns. *Glob. Ecol. Biogeogr.* 19: 607-620.

[31] Monfreda C, Ramankutty N, Foley JA (2008) Farming the planet. 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochem Cycles 22: GB1022

[32] Peters, G.P., Marland, G., Le Quéré, C., Boden, T., Canadell, J.G., Raupach, M.R., 2011. Rapid growth in CO2 emissions after the 2008-2009 global financial crisis. *Nat. Clim. Change.* 2: 2-4.

[33] Global Carbon Project, 2011. Carbon budget and trends 2010. Accessed from (http:// www.globalcarbonproject.org/carbonbudget). Retrieved on 1st August, 2012.

[34] Stone, P., 2001. The effects of heat stress on cereal yield and quality. In Crop Responses and Adaptations to Temperature Stress. Basra, A.S. (ed). Food Products Press, Binghamton, NY, pp 243-291.

[35] Crafts-Brandner, S.J. and Salvucci, M.E., 2002. Sensitivity of photosynthesis in a C4 plant, maize, to heat stress. *Plant Physiol.,* 129: 1773-1780.

[36] Willett, K.M., Gillett, N.P., Jones, P.D. and Thorne, P.W., 2007. Attribution of observed surface humidity changes to human influence. *Nature*, 449: 710-712.

[37] Ray, J.D., Gesch, R.W., Sinclair, T.R. and Hartwell, A.L., 2002. The effect of vapour pressure deficit on maize transpiration response to a drying soil. *Plant Soil,* 239: 113-121.

[38] Trnka, M., Olesen, J.E., Kersebaum, K.C., Skjelvåg, A.O., Eitzinger, J., Seguin, B., Peltonen-Sainio, P., Rötter, R., Iglesias, A. and Orlandini, S., 2011. Agroclimatic conditions in Europe under climate change. *Glob. Change Biol.,* 17: 2298-2318.

[39] Ramankutty, N., Foley, J.A., Norman, J., McSweeney, K., 2002. The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. *Glob. Ecol. Biogeogr.* 11: 377-392.

[40] Ziska, L.H., Blumenthal, D.M., Runion, G.B., Hunt, E.R. and Diaz-Soltero, H., 2011. Invasive species and climate change: an agronomic perspective. *Clim. Change,* 105: 13-42.

[41] Hatfield, J.L., Boote, K.J., Kimball, B.A., Ziska, L.H., Izaurralde, R.C., Ort, D., Thomson, A.M., Wolfe, D., 2011. Climate impacts on agriculture: implications for crop production. *Agron. J.,* 103: 351-370.

[42] Intergovernmental Panel on Climate Change, 1996. *Climate Change 1995*, eds. Houghton J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A. and Maskell, K (Cambridge Univ. Press, Cambridge, U.K.).

[43] Andreae, M., 1995. In *World Survey of Climatology*, ed. Henderson-Sellers, A. (Elsevier, Amsterdam), Vol. 16, pp. 347-398.

[44] Hansen, J., Sato, M, Ruedy, R., Lacis, A. and Oinas, V., 2000. Global warming in the twenty-first century: An alternative scenario *Proc. Natl. Acad. Sci.,* USA, 97(18): 9875-9880.

[45] Wilkinson, S., Mills, G., Illidge, R., Davies, W.J., 2012. How is ozone pollution reducing our food supply? *J. Exp. Bot.,* 63: 527-536.

[46] Van Dingenen, R., Dentener, F.J., Raes, F., Krol, M.C., Emberson, L. and Cofala, J., 2009. The global impact of ozone on agricultural crop yields under current and future air quality legislation. *Atmos. Environ.,* 43: 604-618.

[47] McKee, I.F., Bullimore, J.F., Long, S.P., 1997. Will elevated CO2 concentrations protect the yield of wheat from O-3 damage? *Plant Cell Environ*., 20: 77-84.

[48] McKee, I.F., Mulholland, B.J., Craigon, J., Black, C.R. and Long, S.P., 2000. Elevated concentrations of atmospheric CO2 protect against and compensate for O_3 damage to photosynthetic tissues of field-grown wheat. *New Phytol.,* 146: 427-435.

[49] Reynolds, M.P., Balota, M., Delgado, M., Amani, I. and Fischer, R.A., 1994. Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. *Aust. J. Plant Physiol.,* 21: 717-730.

[50] Biswas, D.K., Xu, H., Li, Y.G., Sun, J.Z., Wang, X.Z., Han, X.G. and Jiang, G.M., 2008. Genotypic differences in leaf biochemical, physiological and growth responses to ozone in 20 winter wheat cultivars released over the past. *Glob. Change Biol.,* 14: 46-59.

[51] Asada, H. and Matsumoto, J., 2009. Effects of rainfall variation on rice production in the Ganges–Brahmaputra Basin. *Clim. Res.* 38: 249-260.

[52] Welch, J.R., Vincent, J.R., Auffhammer, M., Moya, P.F., Dobermann, A. and Dawe, D., 2010. Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proc. Natl. Acad. Sci.,* USA, 107: 14562-14567.

[53] Easterling, W. E. et al. 2007. Food, fibre and forest products. *In* Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M. L., Canziani, O. F., Palutikof, J. P., Linden P. J. v. d. and Hanson, C. E., (eds). Cambridge University Press, Cambridge, UK. pp. 273-313.

[54] Lobell B. D. and Gourdji M. S. 2012. The influence of climate change on global crop productivity. *Plant Physiology*, 160 (2012) 1686-1697.

[55] Solomon S., Plattner K-G., Knutti R., Friedlingstein P. (2009) Irreversible climate change due to carbon dioxide emissions, *PNAS,* 106(6); 1704-1709.

[56] L. U. Grema, A. B. Abubakar, O. O. Obiukwu, *International Letters of Natural Sciences* 3 (2013) 21-27.

[57] Hyginus A. Nwona, *International Letters of Natural Sciences* 4 (2013) 1-9.

[58] Schneider, SH (2007). "19.3.1 Introduction to Table 19.1" (http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch19s19-3-1.html) . In ML Parry, *et al*, (eds.). *Chapter 19: Assessing Key Vulnerabilities and the Risk from Climate Change*. Climate change 2007: impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press (CUP): Cambridge, UK: Print version: CUP. This version: IPCC website.

[59] ISBN 0-521-88010-6. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch19s19-3-1.html. Retrieved 2011-05-04.

(Received 20 February 2014; accepted 26 February 2014)