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A Review on the Impact of Climate Change on Agriculture Sector: Its Implication to Crop Production and Management

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Abstract

CO_2 levels in the atmosphere grow because of global greenhouse gas emissions, causing global temperatures to rise due to the greenhouse effect. Terrestrial temperatures, on the other hand, have risen quicker than those at sea. Due to a shift in the precipitation pattern, more weather extremes are forecast in the coming weeks. Climate change is projected to result in a drop in agricultural productivity. The beneficial effects of increasing CO_2 on plants are most likely to be counterbalanced by higher temperatures and irregular precipitation. Climate change has resulted in a hotter, more humid climate, which has increased the risk of pest infestation. To avoid climate change, climate-resilient technology that is both technically sound and financially viable must be developed in an interdisciplinary manner.

Keywords: Climate change, pest infestations, temperature, greenhouse effect

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INTRODUCTION

One of the primary sources of climate change and the greenhouse effect is agriculture, which releases a lot of greenhouse gases. Climate change, on the other hand, has a major impact on agricultural production, putting food security in jeopardy. People should always be able to access enough, safe, and healthy food to suit their dietary needs and food choices, according to the World Food Programme (FAO, 1996). At present moment, the biggest danger to food security is a food shortage. Even though there is enough food to feed the existing population, more than 10% of the world's population is malnourished. Climate change is predicted to exacerbate food insecurity by rising food prices and reducing production. As a result of climate change mitigation initiatives, food may become more expensive. Drought and increased agricultural water demand are placing strain on a limited supply of water needed for food production. In areas where the climate is unfavorable for agriculture, competition for land may grow. As a result of extreme weather events linked to climate change, this might lead to a rise in agricultural prices. Heatwaves, for example, caused productivity losses in key producing areas such as Russia, Ukraine, and Kazakhstan in the summer of 2010, resulting in a significant increase in the price of essential products. As a result of rising costs, an increasing number of households have fallen into poverty, demonstrating how climate change can lead to food insecurity.

According to the Intergovernmental Panel on Climate Change (IPCC), global mean surface air temperature rose by 0.4 to 2.6 degrees Celsius in the second half of this century (depending on future greenhouse gas emissions). Agriculture, like the food processing industry, is already a major contributor to greenhouse gas emissions.

Agricultural intensification to compensate for declining productivity (partially due to climate change) and growing demand for animal products may result in even higher emissions in the future. Between 2005 and 2050, the worldwide market for animal products is expected to rise by 70%. Long-term increases in temperature and carbon dioxide may boost agricultural output, but extreme weather events, such as intense heat and drought during crop flowering, may limit these advantages. In the next century, climate change is expected to have a detrimental influence on food harvests in numerous parts of the world. Figure 1.1 shows an increasing trend toward widespread yield losses by combining average crop production estimates for all emission scenarios, locations, and with or without farmer adaptation. Climate change is anticipated to increase the frequency and severity of heatwaves (extended periods of high heat), which pose a danger to agriculture. Animals and plants may suffer from heat exhaustion and food production may suffer because of heatwaves. When the plants are in bloom, extreme temperatures can have a devastating effect on agricultural production; if this key phase is disrupted, the plants may not produce any seeds at all. As a result of heat exhaustion, animals are unable to perform at their best and are more vulnerable to disease. Because of global warming, heat waves have become more frequent and bigger.

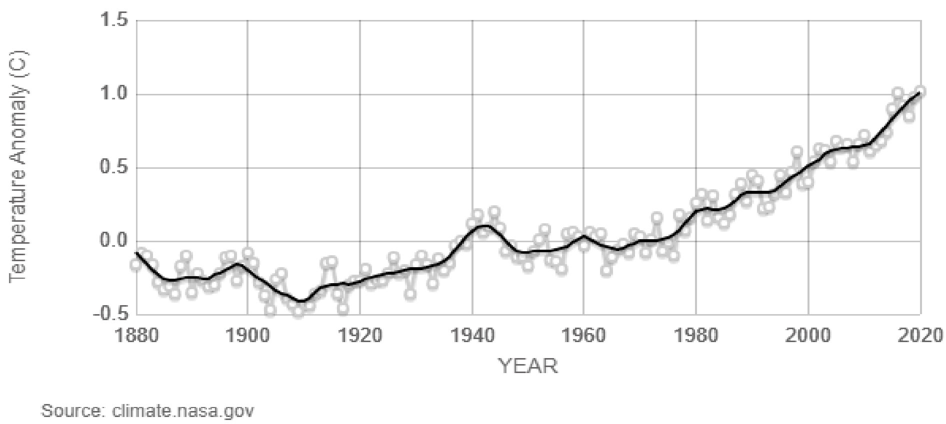

Figure 1. Trends toward widespread yield losses by combining average crop production estimates for all emissions (1880-2020)

The UK, Europe, and the rest of the globe may expect an increase in the frequency and severity of heatwaves. Underdeveloped countries are more likely to be affected by heat waves than their more developed counterparts. Droughts may become more frequent because of climate change, which may exacerbate present food security issues. Temperature, heat waves, and rainfall patterns are projected to vary because of climate change. Some areas may see a resurgence of drought, while others may see an increase in the frequency of heavy rainfall and flooding. The loss of all coastal agricultural land might be the result of rising sea levels. Insect dispersal patterns can shift with rising temperatures.

Insects, such as those that carry diseases, may be able to move north. Experiments with numerous crops have revealed that crop yields respond to environmental conditions.

We can better prepare for climate change by tracking reactions and identifying vulnerable agriculture sectors. Crop cultivars, planting dates, cultivating practices, and irrigation systems may all be adapted to climate change. In the face of climate change, scientists are researching food preservation. There are answers to the problems of climate change and extreme weather. Part of this endeavor involves reintroducing farm type, crop, or cultivar size diversity. Preparing for food shortages can also help prevent price shocks that restrict people's access to food.

The Goal of the Article

The project's primary goal is to provide a full understanding of climate effects as well as a development framework that lays out norms and standards for more effective and comprehensive crop production by identifying factors that influence crop output. In addition, the framework for implementing enhancements will be outlined.

DISCUSSION

Climate Change and Agriculture

Agriculture is the most vulnerable industry to climate change because of its size and how sensitive it is to changes in the weather. Temperature and rainfall changes have a big impact on how much food can be grown. Temperature, precipitation, and CO_2 fertilization all have different effects on different crops, places, and things that change. Warmer temperatures cut yield, but more rain is expected to make this less of a problem. Agriculture in Iran is affected by the weather, the type of crops, and CO_2 fertilization. Cameroon farmers lose money when it rains, or the temperature goes up. Because of poor policymaking and a lack of markets for agricultural exports, Cameroon's income has changed a lot. In Veracruz, Mexico, the temperature influences how much coffee can be made. It may not be profitable for growers to make coffee in the next few years, because the amount of coffee being made now is expected to drop by 34%.

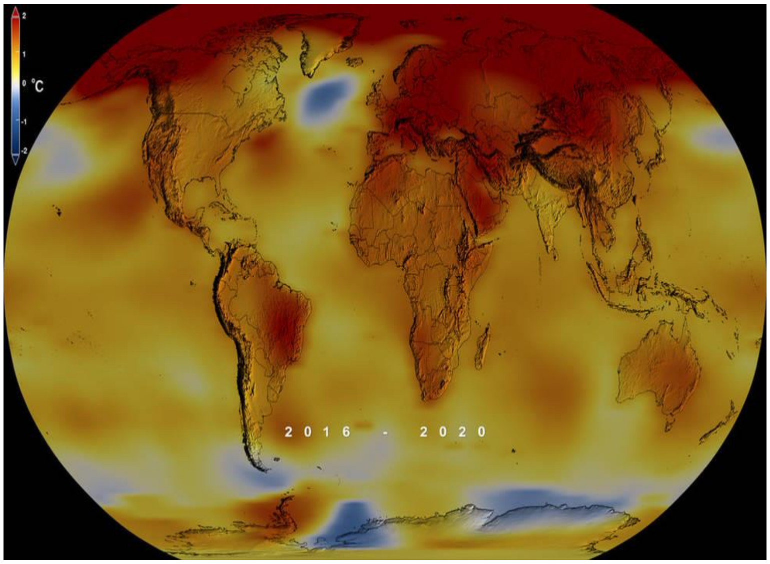

Figure 2. Global warming scenarios

Climate change affects agricultural output in different ways depending on where you live and what kind of irrigation you use. It could be bad for the environment to expand irrigated areas, but it could also make farming more productive. Temperature rises are very likely to shorten the length of crops, which will cut down on agricultural production. Wheat, rice, and maize production in both temperate and tropical countries are expected to drop by 2°C in the next few decades. This means that tropical crops are more at risk from climate change because they are closer to their high-temperature optimums, which means that they are more likely to be stressed by high temperatures. Insect pests and illnesses thrive in warm, wet places. They all affect how much food we can grow because of things like humidity, wind speed, temperature, and rainfall, and not having them could have led to an overestimation of climate change's costs. This will happen by 2100 because of the effects of climate change on wheat, corn, and rice crop yields in China. There have been more extreme weather events in the Netherlands since the 1900s, which has limited the amount of wheat that can be grown. People lost a lot of wheat because of a severe weather event. As a result of climate change, droughts are expected to get worse in most parts of the world. By 2100, drought-affected areas are expected to rise from 15.4 percent to 44 percent. The continent of Africa is thought to be the most vulnerable. Dry areas are expected to lose more than half of their food production by 2050, and more than 90% by 2100, because of the dry weather.

Many individuals in India may see temperature spikes ranging from 2.33 to 4.78 degrees Celsius this year. Climate change would reduce food production by 6–24% in many Sub-Saharan African populations over the next few decades. By 2050, Solomon Islanders are predicted to devour more fish than they produce. This is since they are expected to consume more fish than they produce. Increased CO_2 levels in the atmosphere should boost agricultural output. CO_2 levels will double during heat waves and remain higher for longer. This might harm the farming business. The severity of climate change's consequences on impoverished countries' tropical areas will be determined by where they are and how hot it is. The north and east of Sri Lanka will receive much less rain than the central highland region, which will remain constant or improve as temperatures rise. Wheat and rice yields in northwest India might increase by 28 percent and 15 percent, respectively, if CO_2 levels climbed twice as much as they do now, according to crop predictions based on resource and environmental research. Climate change will reduce agricultural production, according to many models that predict what would happen. This is seen in Table 1. Non-leguminous C3 crops cultivated in high CO_2 conditions include lower levels of N, Fe, Zn, and S, which are all found in proteins.

Weather changes have resulted in an increase in the number of bacteria and enzymes in the soil. When the temperature was 4–5°C higher than in the field, there were a lot more bacteria in the temperature gradient tunnel, but not as many in the field. This occurs when there is a high concentration of CO_2 in the atmosphere. Rice crops develop faster, both vegetatively and reproductively, and produce more seeds when temperatures reach 29 degrees Celsius. However, as the temperature climbed, the seeds did not set as effectively as before.

Causes of Climate Change

GHG concentrations have risen because of both natural and human-caused climate change. Human activity results in the emission of greenhouse gases into the atmosphere, including carbon dioxide, methane, and nitrous oxide. CO_2 levels in the air (463–780 parts per million) can increase nitrous oxide and methane emissions from upland soils and wetlands, so lowering the 16.6 percent reduction in carbon dioxide emissions projected from extending the terrestrial carbon sink.

Methane and nitrous oxide contribute 15% to agricultural emissions. Unless eating patterns and energy use in food are altered, non-agricultural greenhouse gas emissions are anticipated to continue to rise until 2055. As consumer tastes change toward higher-value commodities such as milk and meat, emissions are likely to grow significantly faster. Reduced meat consumption, mitigation of technology, or a combination of the two can be utilized to reduce greenhouse gas emissions. According to the IPCC, livestock contributes between 8% and 10% of total greenhouse gas emissions, however, a lifecycle analysis indicates that livestock might contribute up to 18% of total emissions. The cattle industry's primary sources of greenhouse gas emissions include enteric fermentation, N_2O emissions, liming, fossil fuels, organic farming, and fertilizer manufacturing. Nitrogen-based chemical fertilizers may contribute to the generation of greenhouse gases. Improved agricultural production management might result in a 38 percent reduction in nitrogen fertilizer consumption. Energy consumption is lowered by 11%, yields are enhanced by 33%, and greenhouse gas emissions are reduced by 20% because of improved crop management.

Mitigation and Adaptation to Climate Change

Concerns about climate change's impact on farming push farmers to act. As a result, adaptation requires knowledge. Mitigation initiatives will lessen water stress, but those who remain will need to adapt. Climate-resilient farming includes crop diversification, land preservation, and water collection. Because of this, farming systems are more resilient to climate change, providing food security. Human behavior is the best way to assess local, genuine, and practical elements of climate change education. Only a minority of farmers favor GHG reduction while the majority of farmers support adaptation, underscoring the significance of integrating adaptation and mitigation. Adaptive mitigation options include resource conservation, cropping system technology, and socio-economic or policy initiatives, (Cao et al. 2010). Small and marginal farmers suffer the most from ignorance. Climate change is putting African farmers at risk because of a lack of management and financial consequences. Agronomic practices including shifting planting dates have helped to prevent climate change. For the northeastern planting, October 22–28, October 24–30, and October 21–27 for the southwest planting in Punjab, India, Farmers in Sub-Saharan Africa who cultivated their crops sequentially lost the least amount of money. In Kenya, agroforestry can aid in the country's ability to adapt to climate change. Alternate rice drying, mid-season drainage, improved cow feeding, N-use efficiency, and soil carbon all have the potential to minimize greenhouse gas emissions. Changing planting dates and cultivars can help offset climate change. Farmers' responses to climate change are influenced by the distribution of technology. The focus is on market integration, public research, and capacity building.

Using ecologically friendly farming methods helps to prevent soil erosion and maintain soil cover. Decreases greenhouse gas emissions, reduce the amount of fertilizer needed and enhances the soil's ability to absorb carbon. Conservation agriculture relies heavily on crop rotation. Using no-till wheat farming in South Asia saves farmers 15–16 percent in cultivation costs. It is possible to increase yields while reducing risk by using dryland farming. No-till farming releases only a little quantity of carbon dioxide into the atmosphere. Partnerships between farmers and institutions have established an atmosphere that is conducive to CA adoption by providing the necessary resources. Climate variability and extremes, as well as social, political, and economic factors, have a significant impact on farming. The cost consequences of poor nutrient management are enormous.

By using no-till farming, cover crops, fertilizer management, and agroforestry, organic matter in the soil may be raised (SOC). Carbon sequestration reduces CO_2 emissions by 5–15%. Greenhouse gas emissions are reduced when rice is grown directly in the field. DSR provides 76.2 percent less global warming than transplanted rice while generating 60 percent fewer greenhouse gas emissions. It outperformed transplanted rice by 10.8%. Up to 73 percent of field preparation time and 56 percent of crop irrigation water can be saved with the use of aerobic rice. A long-term option is to micro-irrigate aerobic rice. Rice fields produce fewer methane emissions than previously thought. Lack of water reduces food production by 600–2900 pcal. Using drip irrigation will help to reduce groundwater overdraft and climatic stress. Groundwater is also saved as a result. Dripper irrigation is utilized in intensive farming, notwithstanding the paradox of Jevons. When it comes to saving money and preserving our natural resources, drip and sprinkler irrigation systems are ideal. Sprinkler irrigation may reduce GHG emissions by up to 80% (USD 476.03–691.64), but it needs a great deal of water pressure to work. Agrologists may cut back on the quantity of nitrogen they use without affecting their bottom lines. In the field, precision agriculture prevails. Nitrogen is being wasted by farmers in northwestern India. Climate change is expected to aggravate abiotic stress.

Rice cloning may be used to transfer the gene into high-yield rice cultivars in South Asia. After 18 days, these submersion-resistant variations exceed the original. Climate-smart agriculture conserves water reduces fertilizer usage, and stores carbon. Agricultural subsidies benefit local communities and support environmentally friendly practices. Technology is used to deliver nutrients, water, and the structure of the soil. Stone bunds, zai, half-moons, and other semiarid West African farming practices. CSR improved cotton output and resource utilization in Punjab. Crops of rice and wheat are under threat on the Indo-Gangetic plain.

According to (Boselloet et al., 2005) Climate-smart farming is being used by farmers to increase yields. The eastern Indo-Gangetic plains favor direct sowing, LLL, zero tillage, crop insurance, and irrigation scheduling. Everything from geography to culture to economics to technology affects them. These approaches complement one another as well.

Economic Impact of Climate Change and Climate-Smart Agriculture Technologies

Climate change, according to a recent study, might cost the world economy 10% of its overall value by 2050. According to a study conducted by the Swiss Re Institute, taking no action on climate change is not an option. The research assumes that present temperature rises will continue and that the Paris Agreement's and net-zero emission goals will not be realized. With a best-case GDP decrease of 5.5 percent and a worst-case GDP reduction of 26.5 percent, climate change is anticipated to have the largest impact on Asian countries. However, the studies revealed significant regional disparities. If temperatures drop below 2 degrees Celsius, advanced Asian economies are anticipated to lose 3.3 percent of GDP and 15.4 percent of GDP, respectively, while ASEAN nations are expected to lose 4.2 percent and 37.4 percent, respectively. In the worst-case scenario, China might lose more than a quarter of its GDP, compared to ten percent for the US, Canada, and the UK, and eleven percent for Europe.

According to the estimate, if temperature rises are kept below 2°C, the Middle East and Africa will face a 4.7 percent reduction, and 27.6°C in the worst-case scenario. According to (Shakooret et al., 2011) research, the economies of South and Southeast Asia are the most vulnerable to the physical difficulties provided by global warming.

Malaysia, Thailand, India, the Philippines, and Indonesia, for example, have the fewest resources for mitigating and adapting to the effects of global warming. According to the study, these countries will profit the most from global efforts to reduce global warming. According to the study, many industrialized countries in the northern hemisphere were less vulnerable to climate change than countries in the southern hemisphere because they were less exposed to bad weather patterns linked to global warming and had more resources to deal with climate change's effects. In reaction to climate change, climate-smart agriculture (CSA) is a technique for restructuring and reorienting agricultural production (Lipper et al. 2014). The most widely used definition is provided by the Food and Agricultural Organization of the United Nations (FAO), which states that CSA is agriculture that increases productivity, improves resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and improves national food security and development goals in a sustainable manner.

Food security and development are two of CSA's main goals with productivity, adaptation, and mitigation emphasized as the three interconnected pillars necessary to reach this goal (FAO 2013; 2 Lipper et al. 2014). CSA's mission is to increase agricultural output and revenue from crops, livestock, and fisheries in a way that is both sustainable and environmentally friendly. As a result, food and nutritional security will increase. A crucial concept for boosting productivity is sustainable intensification. Farmers' susceptibility to short-term risks is reduced, but their resilience is increased as CSA improves their capacity to adapt and survive in the face of shocks and longer-term pressures. The importance of safeguarding the ecological services that ecosystems provide to farmers and others is emphasized. These services are required to maintain manufacturing operations and adjust to climate change. Whenever and wherever possible, the CSA will work to reduce and/or eliminate greenhouse gas (GHG) emissions. This means that we cut emissions for every calorie or kilogram of food, fiber, or fuel generated. Deforestation caused by agriculture must be avoided. We must also ensure that soils and trees are managed in such a manner that their capacity to act as carbon sinks and absorb CO_2 from the atmosphere is maximized.

Implication and Recommendation

As the world's population grows, so does the need for agriculture to supply it with food and nourishment. The future climate and its probable repercussions are still shrouded in mystery, but various studies have concluded that agricultural output would decline as a result of climate change in the coming years. A pest infestation, soil fertility, irrigation resources, physiology, and metabolic processes in plants were all impeded by important climatic factors such as temperature, precipitation, and greenhouse gases. To counteract the negative effects of climate change on agricultural sustainability, several mitigation and adaptation measures have been developed. There are many ways to reduce greenhouse gas emissions, including using stress-tolerant varieties, using ICT-based agrometeorological services, reducing carbon emissions, using less water and increasing yields, and utilizing innovative irrigation techniques such as raised beds and direct-seeded rice.

According to (Deutsch et al. 2018), there are many ways to conserve water, including laser land leveling and rainwater harvesting, as well as micro-irrigation, crop diversification, and the use of micro-irrigation and raised-bed planting (agricultural extensions to enhance capacity-building). Reduced negative consequences of climate change are a major factor in increasing agricultural adaptability, which may be achieved in large part through these measures.

Climate change is expected to cause significant economic losses at the local and global levels, which can be mitigated by these initiatives, Bailey,et al. (2015). However, to be more effective, these interventions must be coordinated at the regional or local level. Farmers' income should rise as a result of mitigation and adaptation efforts without jeopardizing the long-term viability of agricultural output. However, because of the uncertainty surrounding the future effects of climate change, effective mitigation and adaptation strategies are now out of reach. A multidisciplinary regional strategy is used to produce climate-resilient technology. Adaptable cultivars, well-thought-out agronomic strategies, and effective pest control for crops are all necessities. Climate-smart technologies must be taught and educated to farmers to be applied in the field with ease.

REFERENCES

Adams R.M., Hurd B.H., Lenhart S. & Leary N. 1998. Effects of global climate change on agriculture: An interpretative review. *Clim. Res.* 11, 19–30.

Bailey R., Benton T.G., Challinor A., et al., 2015. Extreme weather and resilience of the global food system 2015. Final Project Report from the UK-US Taskforce on Extreme Weather and Global Food System Resilience, The Global Food Security program, UK.

Bosello F. & Zhang J. 2021. Assessing Climate Change Impacts: Agriculture; FEEM Working Paper No. 94.05; CMCC Research Paper No. 2; Elsevier: New York, NY, USA, 2005; Available online: https://ssrn.com/abstract=771245 (accessed on December 13, 2021).

Cao L., Bala G., Caldeira K., Nemani R. & Ban-Weiss, G. 2010. Importance of carbon dioxide physiological forcing to future climate change. Proc. *Natl. Acad. Sci.* USA 107, 9513–9518.

Challinor A.J., Watson J., Lobell D.B., Howden S.M., Smith D.R. & Chhetri N. 2014. A meta-analysis of crop yield under climate change and adaptation. *Nat. Clim. Chang.*, 4, 287–291.

Deutsch C.A., Tewksbury J.J., Tigchelaar M., Battisti D.S., Merrill S.C., Huey R.B. & Naylor R. 2018. Increase in crop losses to insect pests in a warming climate. *Science*, 361, 916–919.

Dey M.M., Gosh K., Valmonte-Santos R., Rosegrant M.W. & Chen O.L. 2016. Economic impact of climate change and climate change adaptation strategies for the fisheries sector in the Solomon Islands: Implication for food security. Mar. *Policy*, 67, 171–178.

Gay C., Estrada F., Conde C., Eakin H. & Villers L. 2006. Potential impacts of climate change on Agriculture: A case of study of coffee production in Veracruz, Mexico. *Clim. Chang.*, 79, 259–288.

Gray S.B. & Brady S.M. 2016. Plant developmental responses to climate change. *Dev. Biol.*, 419, 64–77.

Groenigen K.J.V., Osenberg C.W. & Hungate B.A. 2011. Increased soil emissions of potent greenhouse gases under increased atmospheric CO_2. Nature, 475, 214–216.

Kahrl F., Li Y., Su Y., Tennigkeit T., Wilkes A. & Xu J. 2010. Greenhouse gas emissions from nitrogen fertilizer use in China. *Environ. Sci. Policy*, 13, 688–694.

Kang Y., Khan S. & Ma X. 2009. Climate change impacts on crop yield, crop water productivity, and food security—A review. Prog. *Nat. Sci.*, 19, 1665–1674.

Karimi V., Karimi E. & Keshavarz M. 2018. Climate change, and agriculture: Impacts and adaptive responses in Iran. *J. Integr. Agric.*, 17, 1–15.

Kumar R. & Gautam H.R. 2014. Climate change and its impact on agricultural productivity in *India. J. Climatol. Weather Forecast*., 2, 1-3.

Lesschen J.P., Berg M.V.D., Westhoek H.J. & Oenema O. 2011. Greenhouse gas emission profiles of European livestock sectors. *Anim. Feed Sci. Technol.,* 166–167, 16-28.

Li Y., Ye W., Wang M. & Yan X. 2009. Climate change and drought: A risk assessment of crop-yield impacts. *Clim. Res.,* 39, 31–46.

Mahato A. 2014. Climate change and its impact on agriculture. *Int. J. Sci. Res. Publ.,* 4, 1–6.

Mendelsohn R. 2009. The impact of climate change on agriculture in developing countries. *J. Nat. Res. Policy Res*., 1, 5–19.

Molua E.L. & Lambi C.M. 2007. The Economic Impact of Climate Change on Agriculture in Cameroon; Policy Research Working Paper; The World Bank: Washington, DC, USA, pp.1-31.

Montzka S.A., Dlugokencky E.J. & Butler J.H. 2011. Non-CO_2 greenhouse gases and climate change. Nature, 476, 43–50.

O'Mara F.P. 2011. The significance of livestock as a contributor to global greenhouse gas emissions today and soon. *Anim. Feed Sci.* Technol., 166–167, 7–15.

Popp A., Lotze-Campen H. & Bodirsky B. 2010. Food consumption, diet shifts, and associated non-CO_2 greenhouse gases from agricultural production. *Glob. Environ. Chang.,* 20, 451–462.

Porter J.R., L Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell & Travasso M.I. 2014. Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

Powell J.P.; Reinhard, S. 2016. Measuring the effects of extreme weather events on yields. Weather Clim. Extrem. 12, 69–79.

Reyer, C.P.O., Leuzinger S., Rammig A., Wolf A., Bartholomeus R.P., Bonfante A., Lorenzi F.D., Dury M., Cloning P., Jaoude R.A., et al. 2012. A plant's perspective of extremes: Terrestrial plant responses to changing climatic variability. *Glob. Chang. Biol,* 19,75–89.

Rosenzweig C. &Liverman D. 1992. Predicted effects of climate change on agriculture: A comparison of temperate and tropical regions. In Global Climate Change: Implications, Challenges and Mitigation Measures; Majumdar, S.K., Ed.; PA The Pennsylvania Academy of Sciences: Grove City, PA, USA, pp. 342–361.

Shakoor U., Saboor A., Ali I. & Mohsin A.Q. 2011. Impact of climate change on agriculture: Empirical evidence from the arid region. *Pak. J. Agri. Sci.,* 48, 327–333.

Soltani A., Rajabi M.H., Zeinali E. & Soltani E. 2013. Energy inputs and greenhouse gases emissions in wheat production in Gorgan, Iran. Energy, 50, 54–61.

Stern D.I. & Kaufmann R.K. 2014. Anthropogenic and natural causes of climate change. *Clim. Chang.,*122, 257–269.

Stevanovic M., Popp A., Campen H.L., Dietrich J.P., Muller C., Bonsch M., Schmitz C., Bodirsky B.L., Humpenoder F. & Weindl I. 2016. The impact of high-end climate change on agricultural welfare. *Sci. Adv.,* 2, e1501452.

Tubiello F. N., Soussana J. F. & Howden S. M. 2007. Crop and pasture response to climate change. Proceedings of the National Academy of Sciences, 104(50), 19686-19690.

Waha K., Muller C., Bondeau A., Dietrich J.P., Kurukulasuriya P., Heinke J. & Lotze-Campen H. 2013. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Glob. Environ. Chang.*, 23, 130–143.

Wheeler T. & Von Braun J. 2013. Climate change impacts global food security. *Science*, 341(6145), 508-513.

Zhang P., Zhang J. & Chen M. 2017. Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. *J. Environ. Econ. Manag*, 83, 8–31.