Journal of Life and Social Sciences
eISSN: 3006-2675
www.bbasrjlifess.com
J. Life Soc. Sci, 2024; Volume, ***3****: 27*
Review Article *Open Access*

GLOBAL CLIMATE CHANGE AND ITS INFLUENCE ON CROP PRODUCTION

MUSHTAQ F, AKRAM MH, USMAN M, MOHSIN M, *NAWAZ MS

Department of Agronomy, University of Agriculture Faisalabad, Pakistan
**Correspondence author email address: shahidnawaz74328@gmail.com*

(Received, 6th March 2023, Revised 14th April 2024, Published 22nd April 2024)

Abstract *Global food security and agricultural productivity are threatened by climate change. The temperature increases due to the greenhouse effect as greenhouse gas emissions in the atmosphere increase. Increased CO2 concentrations, which contribute substantially to greenhouse gas emissions, have enhanced plant growth and productivity due to improved photosynthesis. Conversely, elevated temperatures undermine this benefit through the subsequent consequences of disrupting crop maturation, accelerating vegetation migration, intensifying insect infestations, impeding crop respiration rate, and augmenting evapotranspiration. The quantity and activity of soil microorganisms and enzymes are both impacted by climate change. This review examines scientific publication data about climate change, encompassing its probable origins, immediate consequences, and agricultural ramifications arising from its impacts on plant metabolism and physiology. Additionally, the economic repercussions, known and potential impacts on insect infestation, agricultural output, and plant growth, and mitigation strategies are examined in this study.*

[Citation: Mushtaq, F., Akram, M.H., Usman, M., Mohsin, M., Nawaz, M.S. (2024). Global Climate Change and its Influence on Crop Production. J. Life Soc. Sci, ***2024****: 27]*

Keywords: *climate change; greenhouse gas; abiotic stresses; agriculture*

Introduction

Climate change is one of the most urgent problems contending with the world in the present day. Divergences in the average values of meteorological variables, including temperature and precipitation, are deemed pivotal indicators of climate change by scientists. The altered composition of the atmosphere caused by increased human activity has led to catastrophic climate change. Despite this, Europe's CO_2 emissions are considerably greater than those of Asia and North America combined (514 billion metric tonnes). Since 1751, the United States has been the leading contributor of carbon dioxide to the global total, contributing one-fourth of the total emissions (399 billion metric tonnes). China ranks second with 200 billion metric tonnes in its possession. The European Union (EU-28), a coalition of 28 nations collaborating to establish targets, was formerly accountable for 22% of carbon dioxide (CO_2) emissions. Africa contributes less than 3% to global emissions on account of the negligible amount of carbon dioxide produced by the average African. On the other hand, nations that have traditionally produced few emissions are now influencing worldwide emissions (Sathaye et al., 2006). Fertilization of crops rises in tandem with atmospheric CO_2 concentrations, whereas energy demands associated with temperature fall. As a result of climate change, certain conditions have improved while others have deteriorated. Over the twentieth century, climate change primarily yielded favorable outcomes. Before 1980, a significant proportion of developed nations experienced uninterrupted growth, while the majority of underdeveloped nations encountered hardship. In the twenty-first century, both developed and developing countries are being impacted by climate change (Tol, 2013). The trajectory of climate change is anticipated to substantially deteriorate in the coming years. The Kharif and Rabi seasons are anticipated to bring the lowest and maximum temperatures in Pakistan, respectively, to Punjab. By the middle of the twenty-first century (2040-2069), the annual maximum and minimum temperatures for the Kharif and Rabi seasons are projected to increase by 1-3 and 2-3 degrees Celsius, respectively. During the Kharif (25–35 percent change) and Rabi (minimum change) seasons, precipitation in the region would fluctuate (Bokhari et al., 2017). According to PRECIS (Providing Regional Climates for Impact Studies), by the end of the twenty-first century, both the minimum and maximum temperatures in Punjab, India, are projected to increase. Radiation waves and frost may occur from March to June. It is anticipated that China will experience an additional 0.5 degrees Celsius of temperature increase, attributable to variations in precipitation, latitude temperatures, and other climate-related factors. Global warming will be mitigated if the increase in temperature stays below 1.5 degrees Celsius (Chen & Sun, 2018). In the coming decades and years, precipitation and snowfall may become more frequent and severe due to fluctuations in global temperature. Drought and flooding are extreme precipitation occurrences that are influenced by geography. Due to significant precipitation, river flows in South and East Asia are anticipated to be greater than in Southern Africa and South America. Precipitation and snowfall patterns in the Indus River Basin are prone to variation over time and space. The upper basin of the Indus will be subject to greater precipitation than its lower counterpart. Moreover, it is their conviction that the upper basin will experience a more rapid warming process compared to the lower basin. In the future, the Northeastern United States could experience warmer weather extremes, less precipitation, and reduced freezing. The impacts of these emissions shifts will be further intensified by increased pollution (Ning et al., 2015). Northeastern China will experience more severe precipitation as greenhouse gas emissions increase (Zhang et al., 2010). Disturbances in precipitation or snowfall significantly impact agriculture negatively, especially in regions with limited resources. It significantly affects agriculture and agricultural output. Over the past two decades, agricultural output in emerging nations has increased by 9 percent. Undoubtedly, droughts are to blame, as farmers attempted to cultivate additional land to make up for harvests lost to droughts. A reduction in global warming to 1.5 degrees Celsius as opposed to 2 degrees Celsius would result in a 76% decrease in global food insecurity (Betts et al., 2018). As a result of the impacts of climate change, agriculture is becoming more difficult. Betts et al. (2018) calculate that industrialized nations will only necessitate a 24% annual augmentation in agricultural production by 2050, while impoverished countries will be compelled to implement a 60% increase. A multitude of studies have provided evidence that agriculture is significantly impacted by climate change. For instance, it is anticipated that wheat and maize yields will decrease by 5.5 and 3.8 percent, correspondingly. Droughts, heat stress, cold stress, and salt accumulation are all consequences of climate change. The quantity of insects in cereals and the accessibility of water are both impacted by climate change (Malhi et al., 2021). The effects of climate change on the economy, vegetation populations, and agricultural output will be examined in this study. Additionally, potential mitigation and adaptation strategies will be examined to gain a more comprehensive understanding of the anticipated consequences of climate change.

Reasons for Climate Change

Temperature increases brought on by both natural and man-made sources have resulted in higher greenhouse gas emissions (Baul & McDonald, 2015). Aside from carbon dioxide, methane, and nitrous oxide, other compounds released by human activity also play a role in the ozone layer's thinning. The 16.6% benefit of increasing the terrestrial carbon sink may be negated by increased releases of methane and nitrous oxide from montane soil and wetlands due to elevated CO2 concentrations in the atmosphere (463–780 ppm) (Stern & Kaufmann, 2014). Two greenhouse gases released into the Earth's atmosphere as a result of agricultural operations are nitrous oxide and methane. If present dietary energy intake and consumption patterns stay largely unchanged at 1995 levels, global non-agricultural greenhouse gas emissions are expected to rise until 2055. Emissions are expected to rise due to shifting consumer tastes and the rising use of more expensive products like milk and meat. Emissions can be decreased by using technology, cutting back on meat consumption, or doing both at once (Van Groenigen et al., 2011). The Intergovernmental Panel on Climate Change (IPCC) estimates that the greenhouse gas emissions from the livestock industry account for 8–10.8% of global emissions. A lifecycle analysis (Popp et al., 2010) suggests that the global greenhouse gas emissions from the livestock sector may account for up to 18% of the emissions. Liming, enteric fermentation, and lowering greenhouse gas emissions are three ways that could help lessen the pollution that causes global warming and is brought on by cattle. Even with a 38% decrease in their use, advances in agricultural production management do not stop artificial nitrogen fertilizers from contributing to greenhouse gas emissions in the agriculture industry. Food production increased and greenhouse gas emissions decreased by 33% as a result of a 33% reduction in agricultural emissions. This results in a 33% increase in harvests and an 11% energy savings.

Shift in Environment and Agriculture

Agricultural sectors are the most susceptible to the adverse effects of climate change on account of their extensive scope and precariousness to meteorological fluctuations; such repercussions could potentially have substantial economic implications. Climate change not only affect agriculture but also change the biochemical properties of the soil (figure 1).

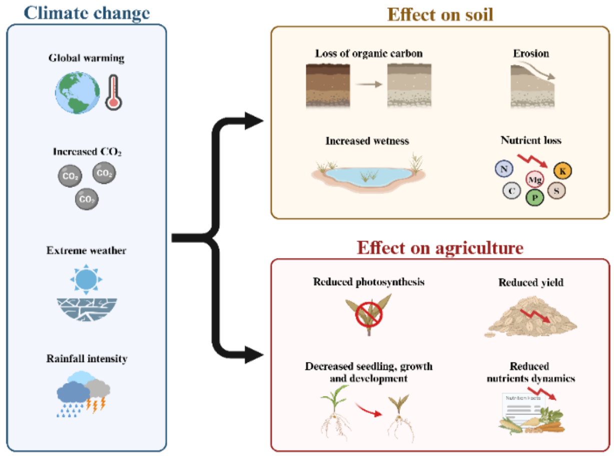

Figure 1. Effects of changing climate on agriculture and soil

Effects of fluctuating precipitation and rising temperatures on agriculture

Climate change is becoming a major reason for the occurrence of various abiotic stresses as mentioned in figure 2. Temperature and precipitation fluctuations caused by humans affect global food production. Diverse geographies and rates of variation in elements such as temperature, precipitation, and CO_2 fertilization have distinct impacts on plant development. Rainfall frequency may help to mitigate the effects of rising temperatures on precipitation. Several factors contribute to climate change in Iran, including CO_2 fertilization, crop adaptation, and climate scenarios (Mendelsohn 2009). The aridity and increased temperature in Cameroon have resulted in financial losses for the country's farmers. Because there are few markets for its commodities and the government makes poor decisions, Cameroon's income fluctuates. Recent research has established that the quantity of coffee cultivated in Veracruz, Mexico is influenced by temperature. A 34% decline in coffee production is anticipated to occur within the following four years. There will be layoffs of growers as a consequence. Climate change affects agriculture in a variety of ways, contingent on the geographical location and watering practices of crops. Agriculture may cause environmental degradation through the increased use of water by farmers to promote growth. Temperature fluctuations are anticipated to influence the growth of plants. The production of wheat, rice, and maize will decrease by 2% if global temperatures increase by 2 degrees Celsius (Karimi et al., 2018). Tropical vegetation becomes increasingly vulnerable to heat stress in response to rising temperatures. More severely, they are poised to incur losses due to the impacts of global climate change.

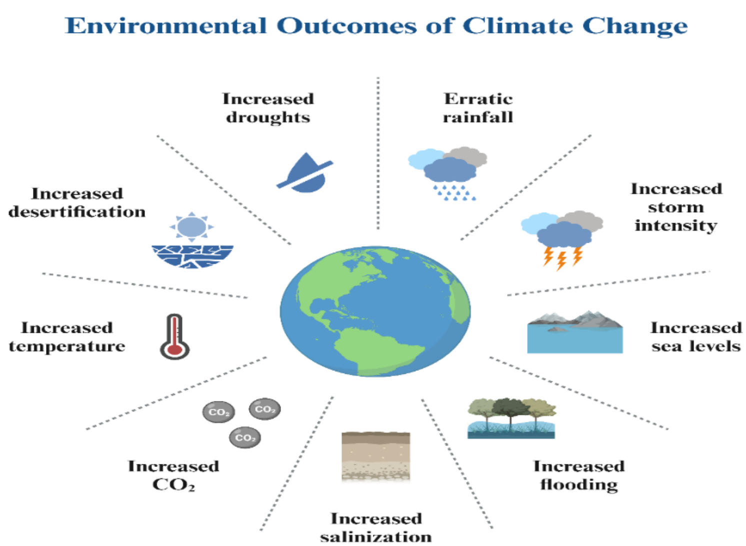

Figure 2. Changes in environment due to changing climatic patterns

The effects of climate change on soil microbiota

The abundance and functionality of soil microorganisms are climate-dependent. It was identified that microorganisms in a temperature gradient tunnel possessed an environment that was 4-5 degrees Celsius warmer than their immediate environs. Temperature and enzyme activity of bacteria and fungi that fix nitrogen and degrade phosphorus increased substantially across a broad temperature range. Notwithstanding this, results were optimized at or near the optimum temperature. The toxicity, beneficialness, or ineffectiveness of microbes and fungi that inhabit plants is determined by temperature (Zilberman et al., 2004).

Climate change-related yield losses

Food price increases may result from crop losses, which may also have unintended consequences for agriculture worldwide. The global GDP may decline by 0.3% by 2100, according to Challenger et al. (2014). Food supply in developing countries will be more severely impacted by climate change than in any other region, according to the international nonprofit 52°C. Temperatures in India may rise by 2.73°C to 4.78°C as a result of longer heat waves, and rising CO2 levels may be detrimental to the agricultural sector (Stevanović et al., 2016). By 2100, a one-degree Celsius increase in global temperatures will cost farmers in Rawalpindi, Pakistan, 4,180 rupees per acre. The magnitude of precipitation will have an impact on whether or not their net income increases by 642.21 or 377.4 rupees. A 10–20% increase in global surface temperatures could potentially result in greater crop losses for rice, maize, and wheat. One to twenty-four percent less food production is expected to occur in Sub-Saharan Africa due to climate change. Predictions indicate that by 2050, the Solomon Islands will be incapable of satisfying the global demand for seafood. A decline in the mean quantity of fish ingested may pose a threat to worldwide food security (Kumar & Gautam, 2014).

Response of plants to changing climates

Physiological processes are more prone to be induced by extreme variations in these components as opposed to typical climate changes. Temperature and quantity of precipitation or snowfall have a substantial effect on how plants utilize water. The responses of various plant species and developmental stages to climate change vary. Dey et al. (2016) outline the diverse mechanisms by which plants can react to stress, which encompass root elongation, reduction in the angle at which roots terminate their growth, and yield decline. The temperature rose by 0.42 K as the quantity of CO_2 in the atmosphere decreased, resulting in reduced water absorption by plants. The body is subject to both direct and indirect effects of CO_2 increases, which also result in a 3.33 K increase in land surface temperature (Grey & Brady, 2016). Increased harvestable yields should result from crop-specific modifications in plant development as CO_2 levels rise. If adversity is absent, C4 plants will produce more water while C3 plants will require less. It is anticipated that rising temperatures and more erratic precipitation patterns will offset the benefits of increased CO_2.

Climate change's beneficial effects on agricultural output

Globally, climate change has led to an increase in agricultural productivity. These limited changes, whatever their quality, will not have much of an impact on low-latitude areas. Elevations of carbon dioxide over the point at which the temperature doubles can lead to serious economic problems (Cao et al., 2010). The tropical ecosystems of developing countries will be severely impacted by climate change. In Sri Lanka's arid north and east, agricultural production is expected to decline sharply with rising temperatures, whereas, in the country's milder central highlands, it is expected to rise or stay steady. The cost of adaptation is determined by how quickly people are affected by climate change (Aydinalp and Cresser, 2008).

A greater vulnerability of the crop to different types of pests

It is expected that climate change will exert an influence on the survival and progression of pathogens. A change in the climate or weather patterns of a given region will almost undoubtedly increase the vulnerability of crops to pests, diseases, and weeds. Lower latitudes generate less, whereas higher and middle latitudes generate more (Compant et al., 2010). Conversely, losses due to insect pest infestations are anticipated to increase by 10 to 25 percent for every degree of temperature rise. Pest migration and population growth may increase as a result of climate change, endangering agricultural viability and production, since pest populations are primarily influenced by abiotic factors like temperature and humidity. The infestation has spiked the cost of pest management. Elevated precipitation and temperature caused a decline in wheat prices in the United States, whereas prices of pesticides for corn, potatoes, and soybeans skyrocketed. Under the high 2050 scenario, the Colorado potato beetle and European maize borer are projected to cause damage to 43% and 48% of arable land, respectively. In the scenario of rising temperatures in Central Europe, these pests could also endanger desolate regions with high temperatures. It is anticipated that thirty species of invading insects will increase in population. It is anticipated that the construction and forestry industries in Sweden will be impacted by rising temperatures (Rosenzweig et al. 2001).

In response to elevated CO_2 concentrations, C3 weeds augment their leaf area and biomass. C4 weeds pose a threat to C3 plants but do not pose a threat to C4 plants. Weeds vie for water and nutrients with crops as a result of the latter's greater nutrient requirements. Crop-weed competition is undergoing dynamic shifts due to climate change. Since it affects plant growth and modifies how herbicides function, climate change affects their efficacy. Wheat weeds, which are vital to global food security, ought to benefit from climate change (Krankina et al., 1997). Weed control necessitates the formulation of novel management strategies that incorporate the impacts of climate change. If climate change is not incorporated into the development of new management strategies, weed control will become more difficult. As insect reproduction is enhanced by warmer and more humid conditions, climate change is anticipated to worsen pest infestations across a wide range of crops. It is location-dependent and contingent on the adaptability of pests to altering weather patterns.

Climate Change Mitigation and Adaptation

Because they are concerned about the effects of climate change on their livelihoods, farmers desire the freedom to act. Nevertheless, true transformation is contingent upon a thorough comprehension. Although it is feasible to mitigate water stress, those who are still exposed to it must develop adaptive strategies to deal with increased levels of stress (Bajwa et al., 2020).

Management practices

Agroecological and conventional farmers may benefit from technologies that capture precipitation, increase biodiversity, and preserve healthy soils. These strategies, according to van Vuuren et al. (2011), improve agricultural systems and soil, thereby guaranteeing food availability irrespective of climatic conditions. In addition to preventing soil erosion and preserving soil health, these plants absorb CO2. Integrating concrete illustrations of human behavior into ecological development and climate change education is the most efficacious approach. The importance of adapting to climate change and reducing greenhouse gas emissions was emphasized by farmers. By modernizing agricultural systems, implementing technological resource conservation measures, and transforming the legal, cultural, and economic spheres, it is possible to prevent climate change. Small and disadvantaged producers face significant challenges in adapting to the impacts of climate change due to their limited understanding of the subject matter. That indicates their probability of losing is increased. They are particularly vulnerable due to their limited capacity to adapt to climate change, which may result in a decline in their income. Seed sowing, among other agricultural technologies, has significantly contributed to the deceleration of climate change. The cultivation of wheat is permissible in the central and southwest areas of Punjab between October 22 and October 28. When Sub-Saharan African farmers implement sequential cropping and sow during favorable weather conditions, they experience minimal crop loss. Kenyan small-scale producers can reduce greenhouse gas emissions and adapt to climate change with the aid of agroforestry. In addition to feeding cattle and adding carbon to the soil, devising innovative techniques for drying rice and draining water from crops can all contribute to the reduction of greenhouse gas emissions. Changes as elementary as adjusting the schedule and variety of crops cultivated can exert a substantial influence on the phenomenon of climate change. Climate change has significantly affected the adoption of agricultural technologies. Talent development, market integration, and government funding for research are the three most significant factors (Sandhu et al., 2020).

Conservation agriculture

Conservation agriculture has the potential to progressively restore the ecological harm inflicted by conventional tillage through the mechanisms of soil erosion reduction, crop diversity enhancement, and land cover preservation. Conservation in agriculture decreases the use of fertilizers, emissions of greenhouse gases, and carbon deposition in fields. Sustainable agriculture comprises the following practices: crop rotation, soil cover, and minimal soil disturbance (Lal et al., 2011). South Asian producers can achieve labor cost savings of 15-16% through the implementation of tiller-free wheat production. Zero-tillage crops increase the consistency of wheat and maize yields. There has been support for no-till agriculture as a means of carbon sequestration and mitigation of climate change. There has been a robust contention for many years that no-till cultivation could potentially mitigate or halt the phenomenon of global warming. The adoption of CA is influenced by various factors, including the economic motivations of farmers, the formation of farmer organizations, and processes that facilitate local adaptation (Sandhu et al., 2020).

Water-saving irrigation techniques

To mitigate the effects of global warming and groundwater depletion, drip irrigation is recommended. This plant exhibits drought tolerance and reduces its reliance on soil water. The increased use of trickle irrigation in intensive agriculture further complicates the Jevons dilemma. Sprinklers and trickle irrigation have the potential to mitigate greenhouse gas emissions and foster sustainable economic development. Spray irrigation has the highest incremental mitigation costs, ranging from USD 476.03 to USD 691.64 per metric tonne, and may lead to an increase in greenhouse gas emissions, according to Lou et al. (2013).

Precision agriculture

Soil-specific agricultural practices enable farmers to achieve profitability while reducing nitrogen usage. Consequently, conventional field management is anticipated to lag behind precision farming in terms of financial gains. The lack of literacy among farmers in northwest India hinders their ability to accurately apply nitrogen fertilizer. By consulting a leaf colour chart (LCC), one can ascertain the optimal timing and quantity of fertilizer to apply to a given plant. According to Aydinalp and Cresser (2008), rice yields were approximately equivalent to the 120 kg N/ha needed for fertilization when LCC was below 4. In comparison to standard nitrogen fertilizer at different concentrations, this fertilizer treatment resulted in respective reductions of 11 and 16 percent in methane and nitrous oxide emissions. By substituting nitrogen fertilizer for the conventional method, the research revealed that wheat nitrous oxide emissions were reduced by 18%. Utilizing laser field leveling (LLL), farmers are increasing their crop yields and profits. 0.5 kg/acre of paddy crop yields were increased by LLL in Raichur, Karnataka. The farm's annual net income increased by 5,000 INR as a consequence. Utilizing this method, farmers have prevented crop losses caused by inclement weather and saved money (Krankina et al., 1997).

Biotic and abiotic stress-tolerant crops

Through plant reproduction, new species of plants that can adapt to their surroundings can be produced. To ascertain the probability of a species flourishing in a particular environment, it is imperative to conduct an exhaustive investigation from various perspectives. This approach involves reducing the duration of the reproduction process and conducting multiple assessments of germplasm placement. The frequency and intensity of abiotic stress are anticipated to escalate due to the impacts of climate change. Therefore, cultivars that can withstand duress are of utmost importance. As a consequence of cloning SUB1A, numerous high-yield rice varieties are now cultivated in South Asian nations. During the initial eighteen days, cultivars that are capable of thriving in water exhibit superior performance compared to those that are not (Grey & Brady, 2016).

Climate-smart agriculture

In response to climate change, climate-smart agriculture implements measures to reduce carbon, water, fertilizer, and weather utilization. To facilitate the adaptation of farmers to climate change, information is obtained, local institutions are kept informed, climate-friendly policies are advocated, and farmers are offered incentives. The delivery of nutrients and water is conducted in an environmentally responsible fashion, thereby conserving soil structure. The agricultural output of small-scale producers in semi-arid West Africa was enhanced through the utilization of stone bunds, zai, and half-moons. Cotton production and revenue increased for Pakistani farmers through the adoption of environmentally sustainable agricultural practices (Rosenzweig et al., 2001). Preventing widespread hunger, the Indo-Gangetic plain can only produce a finite quantity of rice and wheat before a famine ensues. Several farmers have demonstrated a desire to augment the productivity of conventional agricultural practices through the integration of climate-smart agriculture technologies. Eastern farmers employ laser land leveling, or LLL, as opposed to their Western counterparts who depend on weather predictions and crop insurance (Sandhu et al., 2020). These strategies possess a high potential for benefiting individuals and are straightforward to implement. Everything is contingent on where and how individuals employ technology, in addition to their perception of it. When combined with other medications, they generate even greater advantages.

Climate Change's Economic Impact and Climate-Smart Agriculture Technologies

An increase in temperature exceeding 3 degrees Celsius is considered hazardous, while one that surpasses 7 degrees Celsius has the potential to be fatal. The societal cost of one tonne of carbon dioxide (CO2) increased by 2% annually in 2015, reaching USD 29. If individuals collaborate to combat climate change, the fisheries industry in the Solomon Islands could flourish. The impact of climate change on agricultural markets will reduce the global GDP by 0.26 percent. Forecasts for the weather in the 2080s indicate that annual declines in household well-being of 0.2% to 1.0% are probable (Powlson et al., 2014). It is anticipated that a rise of one degree Celsius in global temperatures will lead to market and non-market expenditures constituting 12% of GDP. If the current approach to combating climate change persists, it will lead to a substantial economic divide (Baul & McDonald, 2015).

Prospects and Conclusions Regarding the Future

In an endeavor to produce sufficient food in the face of climate change, farmers are hampered by a growing population. Agricultural production would be affected by climate change, even though numerous studies have shown that the future climate and its repercussions are extraordinarily unpredictable. The climatic system's physiology and metabolism, as well as the insect population and soil fertility, are all influenced by the aforementioned parameters. Numerous endeavors have been undertaken to mitigate the adverse impacts of climate change on agricultural sustainability and to adapt to its effects. Utilizing ICT-based agrometeorological services facilitates the conservation of soil nutrients and the reduction of soil stress through functions such as leaf color mapping, crop residue management, and precise fertilizer delivery. Adaptive plants and ICT-based agrometeorological services are additional methods of mitigating soil stress. Adaptive plants are agricultural extensions designed to increase capacity. The aforementioned modifications diminish the likelihood that climate change will impede the growth and development of plants. The effects of climate change on the local and global economies can be mitigated through the implementation of these measures. Effective regional or local planning is essential to achieving these goals. Over time, farmers whose practices are proactive and adaptable in response to climate change ought to experience enhanced financial stability and employment prospects. In other words, our understanding of climate change is insufficient to formulate adaptation and mitigation strategies that are effective. Developing technologies resistant to climate change is essential to a regional strategy. The inability to adapt to changing climatic conditions will hinder the productivity of crops. A comprehensive comprehension of weather-related field equipment is imperative for the farmer.

References

Aydinalp, C., & Cresser, M. S. (2008). The effects of global climate change on agriculture.

American-Eurasian *Journal of Agricultural & Environmental Sciences*, **3**(5), 672–676.

Bajwa, A. A., Farooq, M., Al-Sadi, A. M., Nawaz, A., Jabran, K., & Siddique, K. H. M. (2020). Impact of climate change on biology and management of wheat pests. *Crop Protection*, **137**, 105304.

Baul, T. K., & McDonald, M. (2015). Integration of indigenous knowledge in addressing climate change.

Betts, R. A., Alfieri, L., Bradshaw, C., Caesar, J., Feyen, L., Friedlingstein, P., Gohar, L., Koutroulis, A., Lewis, K., & Morfopoulos, C. (2018). Changes in climate extremes, fresh water availability and vulnerability to food insecurity projected at 1.5 C and 2 C global warming with a higher-resolution global climate model. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **376**(2119), 20160452.

Bokhari, S. A. A., Rasul, G., Ruane, A. C., Hoogenboom, G., & Ahmad, A. (2017). The past and future changes in climate of the rice-wheat cropping zone in Punjab, *Pakistan. Pakistan Journal of Meteorology*, **13**(26).

Cao, L., Bala, G., Caldeira, K., Nemani, R., & Ban-Weiss, G. (2010). Importance of carbon dioxide physiological forcing to future climate change. *Proceedings of the National Academy of Sciences*, **107**(21), 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. *Nature Climate Change*, **4**(4), 287–291.

Chen, H., & Sun, J. (2018). Projected changes in climate extremes in China in a 1.5 C warmer world. *International Journal of Climatology*, **38**(9), 3607–3617.

Compant, S., Van Der Heijden, M. G. A., & Sessitsch, A. (2010). Climate change effects on beneficial plant–microorganism interactions. *FEMS Microbiology Ecology*, **73**(2), 197–214.

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 fisheries sector in Solomon Islands: *Implication for food security. Marine Policy*, **67**, 171–178.

Gray, S. B., & Brady, S. M. (2016). Plant developmental responses to climate change. *Developmental Biology*, **419**(1), 64–77.

Karimi, V., Karami, E., & Keshavarz, M. (2018). Climate change and agriculture: Impacts and adaptive responses in Iran. *Journal of Integrative Agriculture*, **17**(1), 1–15.

Krankina, O. N., Dixon, R. K., Kirilenko, A. P., & Kobak, K. I. (1997). Global climate change adaptation: examples from Russian boreal forests. *Climatic Change*, **36**(1), 197–215.

Kumar, R., & Gautam, H. R. (2014). Climate change and its impact on agricultural productivity in India. Journal of Climatology & Weather Forecasting.

Lal, R., Delgado, J. A., Groffman, P. M., Millar, N., Dell, C., & Rotz, A. (2011). Management to mitigate and adapt to climate change. *Journal of Soil and Water Conservation*, **66**(4), 276–285.

Malhi, G. S., Kaur, M., Kaushik, P., Alyemeni, M. N., Alsahli, A. A., & Ahmad, P. (2021). Arbuscular mycorrhiza in combating abiotic stresses in vegetables: An eco-friendly approach. Saudi *Journal of Biological Sciences*, **28**(2), 1465–1476.

Mendelsohn, R. (2009). The impact of climate change on agriculture in developing countries. *Journal of Natural Resources Policy Research*, **1**(1), 5–19.

Ning, L., Riddle, E. E., & Bradley, R. S. (2015). Projected changes in climate extremes over the northeastern United States. Journal of Climate, 28(8), 3289–3310.

O'Mara, F. P. (2011). The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. *Animal Feed Science and Technology*, **166**, 7–15.

Popp, A., Lotze-Campen, H., & Bodirsky, B. (2010). Food consumption, diet shifts and associated non-CO2 greenhouse gases from agricultural production. *Global Environmental Change*, **20**(3), 451–462.

Powlson, D. S., Stirling, C. M., Jat, M. L., Gerard, B. G., Palm, C. A., Sanchez, P. A., & Cassman, K. G. (2014). Limited potential of no-till agriculture for climate change mitigation. *Nature Climate Change*, **4**(8), 678–683.

Rosenzweig, C., Iglesius, A., Yang, X.-B., Epstein, P. R., & Chivian, E. (2001). Climate change and extreme weather events-Implications for food production, plant diseases, and pests.

Sandhu, S. S., Kaur, P., Gill, K. K., & Vashisth, B. B. (2020). The effect of recent climate shifts on optimal sowing windows for wheat in Punjab, India. *Journal of Water and Climate Change*, **11**(4), 1177–1190.

Sathaye, J., Shukla, P. R., & Ravindranath, N. H. (2006). Climate change, sustainable development and India: Global and national concerns. *Current Science*, 314–325.

Stern, D. I., & Kaufmann, R. K. (2014). Anthropogenic and natural causes of climate change. *Climatic Change*, **122**(1), 257–269.

Stevanović, M., Popp, A., Lotze-Campen, H., Dietrich, J. P., Müller, C., Bonsch, M., Schmitz, C., Bodirsky, B. L., Humpenöder, F., & Weindl, I. (2016). The impact of high-end climate change on agricultural welfare. *Science Advances*, **2**(8), e1501452.

Tol, R. S. J. (2013). The economic impact of climate change in the 20th and 21st centuries. *Climatic*

Change, **117**(4), 795–808.

Van Groenigen, K. J., Osenberg, C. W., & Hungate, B. A. (2011). Increased soil emissions of potent greenhouse gases under increased atmospheric CO2. *Nature*, **475**(7355), 214–216.

van Vuuren, D. P., Isaac, M., Kundzewicz, Z. W., Arnell, N., Barker, T., Criqui, P., Berkhout, F., Hilderink, H., Hinkel, J., & Hof, A. (2011). The use of scenarios as the basis for combined assessment of climate change mitigation and adaptation. *Global Environmental Change*, **21**(2), 575–591.

Zhang, Y.-G., Nearing, M. A., Zhang, X.-C., Xie, Y., & Wei, H. (2010). Projected rainfall erosivity changes under climate change from multimodel and multiscenario projections in Northeast China. *Journal of Hydrology*, **384**(1–2), 97–106.

Zilberman, D., Liu, X., Roland-Holst, D., & Sunding, D. (2004). The economics of climate change in agriculture. *Mitigation and Adaptation Strategies for Global Change*, **9**(4), 365–382.

Zou, X., Cremades, R., Gao, Q., Wan, Y., & Qin, X. (2013). Cost-effectiveness analysis of water-saving irrigation technologies based on climate change response: A case study of China. *Agricultural Water Management*, *129*, 9–20.

Declarations

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Funding

Not applicable

Conflict of Interest

Regarding conflicts of interest, the authors state that their work was carried out independently without any affiliations or financial ties that could raise concerns about biases.