Impacts of Climate Change on Crop Yields

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Introduction

Human activity has led to significant changes in the climate. The climate is now guaranteed to warm anywhere between two and six degrees Celsius in the upcoming century, which means that agriculture will be unavoidably impacted (Bloom, 2010, p. 134). Land utilized for agriculture production is considerable across the globe, with 1.2 to 1.5 billion hectares containing crops, and another 3.5 billion hectares being grazed (Howden et al., 2007). Climate change currently has and will continue to have various effects on crop yields worldwide.

For example, the U.S. is consistently the largest agricultural producer and exporter of agricultural commodities in the world (Schlenker & Roberts, 2009). The concern is that climate change will induce fewer crop yields, and the country will then have a greater effect on the global food supply and their prices. Due to this, it is vital that crops throughout the globe are prepared for and adapt to these upcoming climatic events. However, there have been only a few global studies to date that have sought to assess the future of global food production as it relates to climate change (Deryng, Sacks, Barford and Ramankutty, 2011).

Adaptation research that is presently conducted can inform decisions of farmers, agrobusiness, and policy makers with preference to short-term and long-term strategies. Currently, improvement with assessment of how various factors affect agricultural systems is necessary. Each region may experience different effects, but diverse impacts will occur spanning the entire industry of agriculture. It is predicted that in order to meet projected human population growth and the per capita food requirement, the current amount of food production must double, which will be increasingly challenging with climate change looming (Howden et al., 2007).

Though practical solutions have been suggested in order to address these emerging climate-related issues in agriculture, this analysis aims to identify the primary impacts that climate change will have on crops and mitigation strategies as well as policy improvement for long-term sustainability of crop yields.

Current Concerns

Agricultural activities are a major economic, social, and cultural operation that contributes to a wide variety of ecosystem services, all of which will continue to be disrupted due to climate change. Food production crops, taking many forms and existing in their distinct locations, are highly sensitive to climate variations. For example, the El Niño Southern Oscillation phenomenon, responsible for drought cycles and flooding, has created worldwide yield variation in wheat, oilseeds, and coarse grains of between 15% and 35% (Howden et al., 2007). Examples such as this continue to become more common over the past several decades as air temperatures have been warming, as well as alterations of other elements across many of the major cropping regions worldwide (Lobell & Gourdji, 2012).

Though there are numerous components that will impact crop yields due to climate change, some of these elements will have a larger influence than others. The primary factors that currently and will continue to impact crop production due to climate change include rising temperatures, an intensified hydrological cycle, higher carbon dioxide (CO_2) concentrations and an increase of pests and disease (Lobell & Gourdji, 2012). Each of these elements is far-reaching and will have drastic implications for agriculture.

Increased Temperatures

A crop's response to increased temperatures will vary according to its optimal temperature for growth and reproduction. Some crops may thrive with the changing temperature while others will not. At a certain point, the rising temperatures will impact many crops in a similar way. Higher temperatures will accelerate crop growth leading to shorter crop duration, which creates lower yields (Lobell & Gourdji, 2012).

Rising temperatures also affect the rate of photosynthesis, respiration, and grain filling as warming during the day may increase or decrease net photosynthesis while warming at night elevates the effect of respiration without any potential gains for photosynthesis (Lobell & Gourdji, 2012). Warming leads to an increase in the saturation vapor pressure of air, which results in decreased water-use effectiveness as plants lose more water per unit of carbon gain, thereby increasing heat-related impacts (Lobell & Gourdji, 2012).

Additionally, plant cells can be damaged as temperatures rise. This occurs as warming increases the probability of heat stress during crucial reproductive periods, which creates sterility, lower yields, and the possibility of crop failure (Lobell & Gourdji, 2012). However, in some regions, such as Scandinavia, increased temperatures will allow for a two-week increase in the growing season by 2030 (Lobell & Gourdji, 2012). In addition, Northern China, Russia, and Canada will experience large gains due to frost-free periods that are desirable for crop growth as a result of increased temperatures (Lobell & Gourdji, 2012).

Intensified Water Cycle

As climate change progresses, it is expected to lead to an intensified water cycle and increase in evaporation, producing severe storms, floods and drought in different areas. Extreme precipitation events, such as floods and droughts, can hinder crop growth. Drought leads to drier soils and less water for irrigation purposes (EPA, 2017). It may also result in more diseases and can lead to the contamination of soil, land, water, crops, and animal feed, which all lower crop yields (Tirado, Clarke, Jaykus, McQuatters-Gollop & Frank, 2010).

The variation in weather will prove challenging to predict, which will lead to issues of proper crop management for farmers. Enhanced rainfall also contributes to an increase of pollutant runoff, reducing crop yield (Tirado et al., 2010). For example, in 2004, Brazil experienced a loss in soybean production due to intensified rainfall resulting from climate change, which led to poor conditions for growing crops as well as reduced crop yields (Tirado et al., 2010). The intensified variation of the hydrological cycle will ultimately adversely affect crop yields.

Higher Levels of Carbon Dioxide

Anthropogenic emissions of greenhouse gases, namely CO_2, will likely influence crop yields in a number of ways. Some studies suggest that CO_2 will not drastically impact the supply of calories over the next few decades, and may in fact benefit crop yields (Ostberg, Schewe, Childers & Frieler, 2018). Global gridded crop models (GGCMs) have suggested that an increased atmospheric concentration of CO_2 may enhance the water use effectiveness in C3 plants, which includes major crops such as wheat, rice, and soy, and C4 crops, such as maize, and could also promote the rate of photosynthesis in C3 crops (Ostberg et al., 2018).

Though these benefits of CO_2 can stimulate plant growth, it also reduces the nutritional value of the crops (EPA, 2017). The increase in atmospheric CO_2 has been linked to a reduction of the concentrations of protein and necessary minerals in most plant species, such as wheat, soybeans, and rice (EPA, 2017). Ultimately, this could have a direct impact on human and livestock health as nutritional value is lost (EPA, 2017).

Additionally, increasing CO_2 will presumably have many adverse effects past mid-century, indicating that CO_2 will eventually have negative implications for crop yields that outweigh the short-term gains (Lobell & Gourdji, 2012).

Increased Pests and Disease

Climate change results in higher temperatures and CO_2 concentrations, as well as wetter conditions at times, which are conducive to the introduction and survival of various crop-specific pests and diseases (Lobell & Gourdji, 2012). Crop pests such as insects, pathogens, and weeds, along with disease, are one of the largest obstacles for food production (FAO, n.d.).

Currently, pests, pathogens, and weeds are responsible for the loss of more than 40% of the world's food supply, and is a figure expected to increase as climate change persists (FAO, n.d.). Pesticides and chemical application to crops is already a significant cost environmentally, on human health, and monetarily, with 11 billion dollars spent on weed prevention in the U.S. each year (EPA, 2017). Climate change will lead to further application of these products to mitigate the expected increase in pests and disease.

It is predicted that the ranges and distribution of pests and disease will intensify with climate change, resulting in new and unknown difficulties (EPA, 2017). An increase of pests and disease will ultimately lead to a decrease in crop yields, greater environmental degradation, and reduction in food security.

Possible Solutions

As the severity of climate change impacts on crop yields continues to be realized, solutions are being developed and presented to address these issues. It is crucial to determine and assess options for preparing agriculture for current and future effects of climate change.

Presently, solutions include implementing sustainable agriculture practices, and adapting and altering crops based on predicted outcomes of climate change to combat potential threats to crop yields due to the changing climate. These solutions offer a means of addressing potential crop yield decreases due to climate change, but others must still be realized.

Sustainable Practices

Implementing sustainable agriculture practices such as no-till, reduced application of pesticides, incorporation of native vegetation, and others offers a practical solution to maintain crop yields as climate change impacts are realized. Many current agriculture practices are degrading to the land and further contribute to climate change. Sustainable agriculture benefits the land in multiple ways as it supports an ecological relationship.

Implementing sustainable practices has the ability to conserve energy and reduce its cost by 35%, preserve water, and reduce carbon emissions through ecological practices, which in turn enhances carbon sequestration by building healthy soil (European Commission, 2018). Through utilization of sustainable practices, crop yields have the potential to remain stable throughout the disastrous effects of climate change.

In East Africa, a study was performed that examined a maize farm that switched from conventional methods to the incorporation of sustainable practices, such as agroforestry systems (Halberg, Peramaiyan & Treyer, 2015). One benefit of the agroforestry system is that tree leaves are incorporated into soils to supply nutrients to annual crops (Halberg et al., 2015). The incorporation of agroforestry led to an increase of maize yields from when only conventional methods were applied (Halberg et al., 2015). The trees offered a means of improved and increased fertilizer for the maize as well as the ability to reduce weeds and enhance soil properties such as water uptake and phosphorous supply, creating healthier soil and improving carbon sequestration (Halberg et al., 2015).

As climate change advances water conservation, pest control and other factors will become more challenging. Sustainable practices can mitigate climate change and increase crop yields through resource conservation, suppression of pests, and increased carbon sequestration.

Adaptation Strategies

Another possible solution is to adapt to predicted impacts of climate change by altering the time and location of current crop operations. This is accomplished by modifications in crop varieties and planting times in an effort to avoid drought and heat distress throughout the hot and dry summers which are an expected result of climate change (Howden et al., 2007).

In many regions, agriculture is particularly vulnerable to climate variation, and crops' capacity to manage risk is dependent on several relevant factors.

Therefore, a crucial adaptation strategy is to improve climate risk management. It has been found that shifting locations and times that crops are grown to align with the effects of climate change will curtail the experienced impact (Howden et al., 2007).

In practice, adoption of this strategy on its own, or in combination with others, can effectively negate harmful climate change impacts while embracing the positive ones. This solution requires farmers and others in decision-making roles to become more aware of climate impacts on their crop systems, as well as which management strategies should be utilized to best adapt to climate change.

Northeast Australia has taken strides to use adaptation methods to cope with climate change impacts on crop yields (Howden et al., 2007). This was accomplished through a crop management system that has successfully adjusted to reduced frost-risk over the last several decades (Howden et al., 2007). Farmers are adopting methods that work with the changing climate in order to take advantage of its benefits, rather than fighting them, to maintain a standard of practice. It was found that this strategy nearly doubled gross margins in comparison to practices which do not incrementally acknowledge risks of climate change (Howden et al., 2007).

Adaptation strategies to climate change that integrate the predicted effects to improve crop production may be most effective in the future.

Proposed Solutions and Policies

Most likely, a combination of multiple strategies will be necessary to address the emerging effects of climate change on crop yields. Optimal solutions to address the decline in crop production due to climate change must promote sustainable production of food to maintain and increase crop yields while also implementing adaptation methods to withstand climate change.

Developing and adopting a more resilient agricultural system through the implementation of sustainable practices and adaptation to future climate events offers the most viable option to address this problem. The food system is presently unstable and unsustainable, leaving it increasingly vulnerable to the impacts of climate change. Regenerative practices such as agroforestry and others, along with adaptation strategies, can reduce the risk of crop yield decrease in years to come as it creates a more sustainable system of food production.

Potential Policy Actions

Policy surrounding the food system is complex at all levels, from local, to state, to federal, to global. However, along with the influence of special interest groups, policies within this realm are often not cohesive and lead to various conflicting policies that end up hindering the food production process (Neff, 2015, p. 204). Additionally, as the impacts of climate change are only recently being realized, and its proposed impacts on agriculture are just being discovered, much current policy is keeping climate change isolated from other issues (Neff, 2015, p. 186).

Policies that support sustainable agricultural practices and adaptation management will need to be championed. Limited attention from policy-makers is directed to climate change impacts on crop yields, though mitigation strategies could benefit all systems economically, environmentally, socially and others (Beg, Corfee-Morlot, Davidson & Afrane-Oke, 2002). For example, policies geared towards the emerging bioethanol industry in the U.S. and Europe have shifted agricultural production from food to fuel, rather than mitigation for crop yields impacted by climate change (Bloom, 2010, p. 249).

Implementation of policy that enhances social welfare throughout impending climate change risk must embrace a combination of both mitigation through the application of sustainable practices and adaptation to climatic events. In developing countries, climate change is not prominently featured in environmental or economic policy agendas, though they are the most vulnerable (Beg et al., 2002). In some countries, adopting certain mitigation strategies could lead to significant trade-offs, which makes it important that policies are suited for each specific region (Beg et al., 2002). However, every aspect will be impacted by climate change, and it is vital that policies take this into consideration and are linked with broader sets of policies.

Furthermore, disastrous climate events result in quickly shifting food and agricultural policy in an attempt to assemble crisis response as opposed to addressing practical reform in preparation for such events (Neff, 2015, p. 186). Policies must be dynamic in order to handle the ambiguous timing and extent of possible changes to the climate and the corresponding knowledge base. Additionally, a subset of policies may need to be established to regulate other means of adaptation.

The government should provide not only support through policies, but also funding and educational outreach programs to promote the success of the adoption of sustainable agriculture practices and adaptation methods to climate change. The Hadley Centre Global Environment Model version 2 (HadGEM2) revealed that by 2050, croplands that produce the top four global commodities of corn, potatoes, rice, and wheat will change (National Geographic, 2019). Shifting to regenerative farming practices while embracing adaptation strategies is more important than ever before, and will require funding and education as to what these practices entail for farmers.

The government and other organizations are currently beginning to offer more grants for those replacing conventional techniques with sustainable practices. For example, the USDA sponsors a Sustainable Agriculture program that provides resources and grants to farmers switching to regenerative practices, and the United Nations Environment recently established funding to support farmers on a global scale in their efforts to mitigate climate change (USDA, n.d.; UN Environment, 2018). Though more programs are developing, it is important that these funds are more widespread throughout the world in order for universal success in this transition.

Large, industrial farms will likely

remain in order to continue to support the growing population and continuation of the import and export market. However, government incentives for sustainable methods will aid in a more accepted shift in farming methodology to becoming more adapting to climate change, which supports greater long-term viability.

Prediction of Future Crop Capability

Recently, a new global crop model, Predicting Ecosystem Goods And Services Using Scenarios (PEGASUS 1.0) that combines climate, planting date variation, cultivar choices, irrigation, and fertilizer application on crop yield for maize, soybean, and spring wheat has been made to determine climate change impacts on crop yields (Deryng et al., 2011). The PEGASUS unites a light use efficiency (LUE) model that assesses daily photosynthesis and annual net primary production (NPP) with a surface energy and soil water budget model (Deryng et al., 2011). It also uses a dynamic allocation scheme in order to adhere daily biomass production to the individual organs of the crop, which are eventually taken from the amount of contained carbon in the storage organs at the date of harvest (Deryng et al., 2011).

In this scenario, the global increases of the mean temperature are four to five degrees Celsius, increase of precipitation is by 8% to 15%, and CO_2 concentration increase is by 600 to 640 ppm (Deryng et al., 2011). Final results suggested that adopting more sustainable management practices could prevent predicted global yield losses by 18% for maize, 12% for spring wheat, and 7% for soybean, which highlights the importance of embracing these methods to prevent decreases in crop yields due to climate change (Deryng et al., 2011).

Conclusion

Climate change will have numerous and far reaching impacts on agriculture. If not addressed, they will be devastating to the food system that is now in place. A few of the major impacts that result from climate change and will influence agriculture include rising temperatures, increased CO_2 concentrations, variation in the water cycle, and increased pest and disease presence. Each of these elements will present issues with regards to maintaining crop yields.

Possible solutions that have been introduced include implementation of sustainable agriculture practices, and increasing adaptation of crops to climate change. A combination of these strategies is likely the most practical option to prevent as much crop loss as possible. In addition to these solutions, policies that encourage sustainable agricultural practices and adaptation management are essential. Along with this, government funding and educational outreach programs for farmers to incorporate sustainable practices and adaptation methods are necessary.

The food system has entered a critical time when the solutions that are implemented today will determine how crop yields will flourish in the future. The discussed studies indicate that instating best management practices, which include sustainable food production methods and adaptation to climate change, provide greater crop yields and contribute to a more stable food system. Climate change will continue to progress, and it is vital that crop yields are further considered and addressed in order to create lasting solutions and a sustainable food system for the years to come.

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