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Climate Change, Agriculture, and Adaptations: Policy Recommendations for Conservation Agriculture

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Introduction

The increase of greenhouse gases in the atmosphere over the last several decades has led to a warming of the planet at a rate faster than any other point in human history (Dessler, 2016). The agricultural industry has contributed to this change in climate and been affected by the results. Sixty percent of human methane emissions come from agriculture and waste, but the net effect of agriculture on the climate is sometimes difficult to quantify or assign value to (Dessler, 2016). At the most basic level of photosynthesis, plants depend on carbon dioxide to grow and flourish, and an increase in the supply of plant food has demonstrable benefits for agriculture. However, these benefits are limited, regional, and sometimes deceptive, while the consequences of a warming planet are many, overwhelming, and still being discovered with each passing year.

To address these issues, farmers must look to adaptive solutions to continue to produce nutritious and healthy crops. These adaptations may include crop diversification, genetic modification, and conservation agriculture. All three pose unique and important contributions in a warming world, but conservation agriculture holds the unique position of being both a mitigation and adaptation strategy. Therefore, future policy should highlight conservation agriculture, especially in developing regions where small-scale, rural farmers are most common. Conservation agriculture is particularly useful for subsistence farmers as it does not require much special technology, and is easily adaptable to one's conditions or necessities. This all seeks to not only secure but also increase food security, particularly among the world's most vulnerable populations. According to the World Food Programme, food security is defined by availability, access, and utilization of healthy and nutrient-rich foods (World Food Programme), all of which will be endangered by the growing effects of climate change. Implementing effective policy and promoting adaptations and mitigations is necessary for global food security.

As Earth's climate changes, the benefits of a warmer environment will soon be eclipsed by the dangers of the same. So long as these risks are acknowledged, there are adaptations, best practices, and policies that can be undertaken to minimize the damage being done by current action and protect these critical products from future change.

This paper seeks first to examine the effects of climate change on traditional agriculture, including the benefits of increased carbon dioxide and the numerous consequences. We will then pose some potential adaptive measures to preserve agriculture and food security, including crop diversification, the use of genetically modified crops, or conservation agriculture, as well as how these adaptations will affect subsistence farmers in Sub-Saharan Africa. Finally, we will make policy recommendations in order to implement these adaptive measures.

Benefits of Climate Change for Agriculture

The rising level of carbon dioxide (CO_2) in the atmosphere and the warming of the Earth offer a number of clear, measurable benefits for the plant life on this planet and the agricultural industries dependent on growing and cultivating crops. At the fundamental level of the relationship between plants and carbon dioxide, an increase in CO_2 increases crop yields in two major ways. First, it increases the rate of photosynthesis, the transformation of light energy, water, and CO_2 into the sugars plants need to survive, and the byproduct of oxygen, which humans (and other animals) need to survive. Increasing the availability of CO_2 speeds up this process, driving accelerated growth (Singh & Jasrai, 2011). Studies have applied this concept to individual crops, and found that elevating CO_2 increases yield across major crop groups, including maize, rice, soybeans, and wheat (Singh & Jasrai, 2011). The second effect of increased CO_2 is a reduction in the loss of water through transpiration. Transpiration is the process through which plants physically gather CO_2. Tiny pores in the surface of leaves open to collect CO_2 from the atmosphere, letting out water vapor in the process. When these pores do not need to open as wide to gather the same amount of CO_2 in a greenhouse-gas-enriched environment, less water vapor escapes through the narrower openings, meaning more water is retained (Hille, 2016). This makes crops more resistant to drought, more able to thrive in water-scarce environments, and less vulnerable to temperature extremes (Hille, 2016). Since each of these dangers is a likely effect of climate change, the fact that the same catalyst—increasing greenhouse gases—is driving a positive change to offset risk may seem like good news for the farmers and agribusiness.

However, at best, these benefits are limited to a few areas of the world. For the northern hemisphere (the northernmost parts of Europe, Asia, and North America), climate models predict that a rise in CO_2 will lead agricultural productivity to increase (IPCC, 2014). In the United States, the growing season of 2100 could last more than a month longer than it does today (Figure 1, left panel), the first frosts setting in over a month later (Figure 1, right panel), while the retreat of land ice will expose arable land usually lost to an early freeze (Walthal et al., 2013).

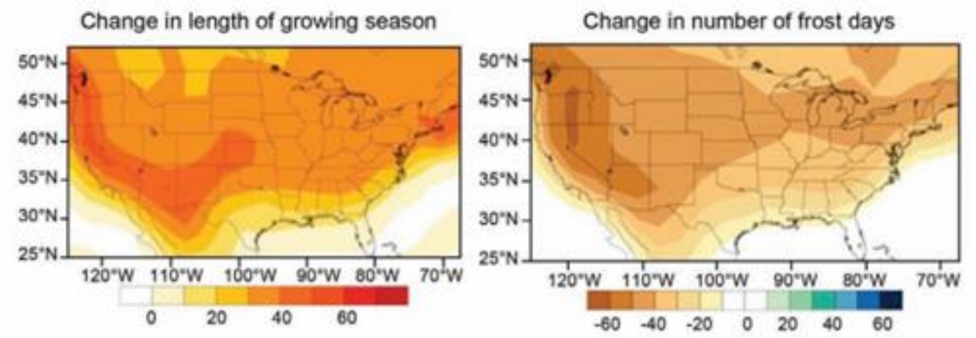

Fig. 1. High emissions projection of changes (number of days) in the U.S. growing season and number of days below freezing. (Walthal et al., 2013)

In the mid-latitudes and southern hemisphere, however (including most of the world's developing nations), the opposite trend can be seen, with crop yields projected to decrease throughout the remainder of the 21st century (IPCC, 2014). A closer examination of the other impacts of climate change reveals that even these apparent benefits come with extreme downsides.

Consequences of Climate Change

While increasing CO_2 has benefits for crop yields and water retention, it also has consequences for crop productivity, a measure of how well human populations can make use of the land and what is being grown (Walthal et al., 2013). As CO_2 levels and temperatures rise, precipitation also changes. Warmer oceans translate into increased evaporation, so rainfall, on a global level, also increases (Dessler, 2016). More rainfall might seem like yet another benefit, but once again, the regional variations in this change generate significant consequences. The change in precipitation follows one general (and damaging) pattern: everything already in place intensifies. Deserts expand and become even more arid; floodplains are flooded for more of the year. Even more damaging, seasonal precipitation changes. High latitudes will see far less snow, which serves to retain water until spring, and more rain, which generates immediate runoff, leading to a greater loss of nutrient-rich topsoil in winter and a greater danger of summer drought (Dessler, 2016). For agriculture, these changes spell trouble. Every major type of crop production will see decreased productivity due to their reliance on stable water sources (Walthal et al., 2013). Farmers will have no way to account for new uncertainty, particularly as changes to precipitation, groundwater, and freshwater systems like rivers and streams will vary widely from locality to locality (Walthal et al., 2013). Even climate scientists have limited ability to predict future precipitation patterns at local scales, which depend on transformations of clouds at a level too small for models to properly account for (Dessler, 2016). Further, new highs in temperatures will harm livestock. As periods of intense heat become more frequent, animal metabolism changes, demanding more and more plant-based feed to output the same amount of meat or dairy for human consumption (Hoegh-Guldberg, 2010). Further, at certain points of heat stress, animals die (Walthal et al., 2013). Spreading droughts, declining soil quality, and the loss of livestock represent drastic shocks to agricultural systems worldwide. But some places will be hit much harder than others.

Many developed nations are concentrated in low-risk areas for agriculture and have the resources to establish security nets and policies to safeguard against unforeseen circumstance should their food supply begin to experience interruptions. By contrast, many developing nations find themselves in both the regions most vulnerable to a changing climate, and in the position least prepared to adapt. Food security, defined by the United States Department of Agriculture (USDA) as "the ability to obtain and use sufficient amounts of safe and nutritious food," is necessary for survival (Brown et al., 2014). While the developed regions of the world will see overall increases in crop yields through the turn of the next century (Figure 2; lower panel), developing regions can expect to see losses outpace gains within the next ten years (Figure 2; upper panel). By 2090, developing nations would no longer see any gains in crop yield at all; a 100% loss by 2109 (Food and Agriculture Organization, 2016).

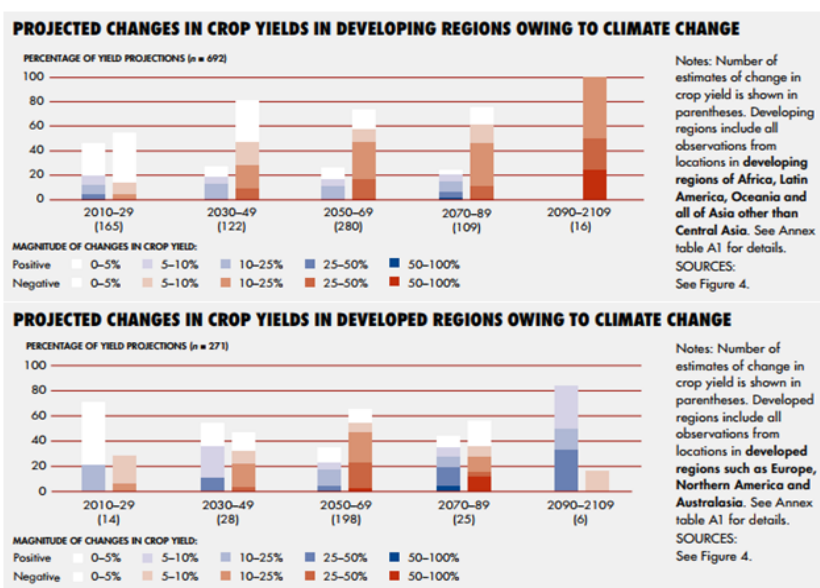

Fig. 2. Projected changes in 21st century crop yields. Developing nations (above) versus developed nations (below). (Food and Agriculture Organization, 2016)

Community agriculture and self-sustenance farming are most at risk in a warming world, with small-scale production far less able to afford the costs of adaptation (Food and Agriculture Organization, 2016). While some argue that regional dangers can be overcome by redistributing the locations responsible for most crop production, this is a solution that relies heavily on global policies which have been slow in the making. It also relies on current "benefits" remaining beneficial in a rapidly changing world. Sometimes, benefits are deceptive.

The single most significant benefit agriculture receives from climate change is the increase in crop yields. Yet crops are hardly the only plants on Earth; weeds benefit from increased CO_2 just as much as (and sometimes more than) the plants human populations rely on for food (Walthal et al., 2013). Weed proliferation is an example of the ways climate change magnifies existing dangers not dissimilar from the magnification of temperature extremes. Other such magnifications occur with vulnerabilities to disease and insects (Walthal et al., 2013). Meanwhile, even increased growth may not be the benefit it seems to be. Bigger is only better (when it comes to agriculture) if it contributes to the health and wellbeing of human civilization. The growth caused by elevated CO_2 is certainly bigger, but, scientists have just begun to discover, not better. By speeding up the rate at which plants grow, CO_2 generates a decline in the quality of plant nutrition: Crops fail to absorb nitrogen in balance with the increased carbon, and instead expand mostly through the production of carbohydrates and sugars, leading to lower iron, lower zinc, and an overall decrease in protein, which is crucial for a human (and animal) diet (Hille, 2016; Myers et al., 2015; Davis et al., 2004). This phenomenon, known as nutrient collapse, could have major consequences for public health. If crop yields are growing but are only yielding sub-par food, even the regions experiencing an agricultural boom will be unable to meet the needs of their populations, let alone the parts of the world experiencing decline.

Mitigation and Geoengineering

Without interference, the effects of climate change on agriculture will be drastic. However, there are steps that can be taken to ensure that food production is still viable. One option is mitigation, which includes taking preventative measures to try to avoid the worst of climate change. Mitigation strategies would likely include both large-scale renewable technology and some degree of climate policy in order to reduce and prevent greenhouse gas emissions in the future. Many estimates say that these policies would focus on carbon pricing in order to incentivize the use of cleaner technology. However, due to both the politicization of the issue in places like the United States and the financial incentives against renewable technology and carbon pricing, it seems unlikely that either of these things will happen globally quickly enough to make a meaningful difference (Dessler, 2016). Geoengineering is another strategy, but it too requires political and financial support. In addition, lots of the proposed geoengineering methods have potential risks that scientists cannot rule out (Dessler, 2016). In addition to mitigation and any future implementation of geoengineering technology, the world must also look towards adaptive solutions to keep our crops alive.

Adaptations

As the effects of climate change are starting to be realized, there is a growing need for adaptive methods for agriculture in order to guarantee food security. Traditional agriculture techniques are suffering from the effects of climate change, and at the same time, the population is growing. There are about 800 million people worldwide who are "food insecure," and of those, 180 million are small children (Liang and Skinner, 2005). This number is likely to increase as the world's population continues to grow and as the effects of climate change make food production more difficult. The world needs to see a major increase in food and crop output, but that increase must come from productivity, not more land dedicated to farming (Liang and Skinner, 2005). Farmers all over the world are looking to achieve that through the use of crop diversification, genetically modified crops, and conservation agriculture. These strategies are discussed next.

Crop Diversification

Crop diversification, as opposed to monocropping, is a longstanding approach to reduce the risks posed by disease, soil depletion, and extreme weather. The most common reasons for crop diversification include widening income or food sources, seasonality, labor demands, market demands, and as a response to climate change. Because of these reasons, this practice is thought to be one of the best methods for subsistence farmers (Adjimoti et al., 2017). Crop diversification can also help to limit many of the risks generally associated with agriculture. Due to climate change, the habitable zones of many insects are expected to grow, and with it the abundance of these pests. By employing crop diversification practices, farmers can create something of a natural barrier around crops that can't withstand the pests with those that can. A diverse crop system will also promote more animal diversity in the area, and those animals might be natural insect predators (Lin, 2011). Studies of crop diversification practices in Lao PDR and Cambodia have also found a significant reduction in insect pests as compared to monocropping systems (Vernooy, 2015). Another major risk factor of agriculture is plant disease. In a diverse crop system, the spread of disease will be much slower, as not all species are susceptible to the same diseases. The effect of climate change on individual plant diseases is largely unknown, as there are many other relevant factors and many types of diseases. Currently, agroecosystems with a higher plant diversity experience much less disease and blight than systems with only one or two primary species. This increases the number of healthy crops and the productivity of the space (Lin, 2011). Agricultural vulnerability is another problem that is often solved with crop diversification. Vulnerability is defined as the degree to which species and ecosystems are unable to deal with the negative effects of climate change (Vernooy, 2015).

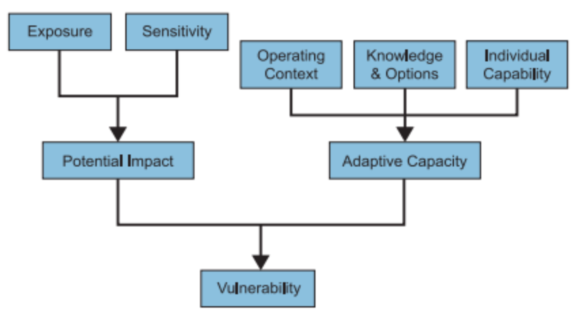

Fig. 3. Factors that contribute to a system's vulnerability to climate change (Walthal et al., 2013).

In more closely managed agricultural systems, buffer species can help protect plants from the effects that they cannot deal with. An example of this is agroforestry, where the trees provide the right amount of shade, water, and nutrients to vulnerable species (Lin, 2011).

Potential Problems with Crop Diversification

Like many other adaptive strategies, there are some downsides associated with crop diversification. There is currently very little official research backing up the benefits of crop diversification, and many pushing for agriculture adaptation focus their efforts on biotech solutions. Another major concern is the financial incentive against crop diversification. In countries like the United States, where the government subsidizes the production of five major commodity crops, farmers have little reason to want to diversify their plantings (Lin, 2011). There is also a false belief that monocrop systems produce a greater number of crops (Lin, 2011). It is also possible that in a diverse crop system, some important crops are neglected in favor of others (Vernooy, 2015). However, despite these faults, many farmers are turning to crop diversification to try to combat some effects of climate change. Additionally, crop diversification can lead to early forms of genetic modification as farmers see which traits and species are most resilient against certain challenges, which provides the theory behind another type of adaptation, GMOs (Vernooy, 2015).

Genetically Modified Organisms

Genetically modified organisms (GMOs), otherwise referred to as "modern biotechnology" or "gene technology," are emerging as a looked-to measure against the effects of climate change (WHO Report, 2014). In recent years, there has been a lot of controversy surrounding the use of GMOs in food products, leading to it being banned in several countries. However, many are now saying that GMOs will help to feed the world in the face of climate change. The World Health Organization (WHO) defines GMOs as "...organisms… in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination." Currently, the three major concerns of GMOs as it pertains to human health are allergen risks (cross-breeding with crops that are known allergens), gene transfer (accidental transfer of genes that are known to have negative impacts on human health), and outcrossing (accidental cross contamination of crops with less desirable plants). Currently, the risk for the first two is very low, and though there have been some cases of the latter, many countries are taking steps to address this problem (WHO Report, 2014). GMOs have a lot of potential in terms of solving hunger and malnutrition. In recent years, activists have pointed to the success of the Golden Rice project to make the case for genetically modified crops. Scientists bred a new crop called Golden Rice, named so for its yellow color, to be rich in Vitamin A. It was then introduced into areas of the world where Vitamin A Deficiency was especially prevalent. In some of these areas, such as Southeast Asia, about two thirds of people's daily nutritional intake comes from rice, so this new strain of Golden Rice is particularly efficient at delivering key nutrients to the people (IRRI).

Now, people are looking at GMOs not only as a potential solution to world hunger and malnutrition but as an adaptation to better deal with the effects of climate change. Sub-Saharan Africa is one of the regions most heavily impacted by climate change, and it is also home to many subsistence farmers who cannot afford to see a decrease in crop productivity. Nigeria, for example, is losing about 350,000m^2 of land annually due to the increase in size of the desert. It is more important than ever for Nigerians to use what land they still have efficiently. Not only is the country facing a land shortage, but rising temperatures would mean less water to irrigate their crops and negative impacts on the development of maize, rice, and sorghum, which are three of Nigeria's biggest crops. Nigerian farmers have a desperate need for new technology to increase the productivity of land space, and in recent years, GMOs have been the answer to that need (Iloh and Gidado, 2016). Many key crops, such as sorghum, have seen an incredible development thanks to gene technology. The three major production limitations for sorghum include pests, disease, and abiotic stress due to extreme weather or temperature events, drought, or unideal soil. These three factors alone lead to about $1 billion in production losses worldwide (Liang and Skinner, 2005). Sorghum is now being engineered to include thaumatin-like protein (TLP). The genetically modified sorghum was found to be much more drought resistant, and in some cases the TLP can help protect the plant against freezing (Liang and Skinner, 2005).

Gene technology has proven to be instrumental in maintaining Nigeria's agricultural systems. Nigeria has been using GMOs since 1995, and in this time they have seen a 21% increase in production of key crops with only a 2% increase of land devoted to farming these crops (Iloh and Gidado, 2016). Nigerian farmers have also been using crops engineered to be more tolerant to herbicides. Because of this, they can devote less time and energy to tilling and ploughing the land to get rid of the last year's crop. No-till farming also reduces erosion and increases soil productivity. Some of Nigeria's genetically modified crops are also insect-resistant, meaning the farmers can devote less money to insecticides (Iloh and Gidado, 2016). Nigeria is not the only Sub-Saharan country using GMOs to combat the effects of climate change on agriculture; in Tanzania, a major drought in recent years has significantly impacted the growth of maize, the primary food source for about a quarter of Africans. For a long time, Tanzania has been strictly against the idea of genetically engineered foods, but are now willing to put those ideas aside for the sake of feeding its people. Tanzania is now planting drought-resistant maize, which hopefully will mark an improvement in quality of life for subsistence farmers (Molteni, 2016). It is within reason that the growing use of GMOs in developing countries will help to ensure that food security is still possible in the face of climate change.

GMO Policy and Recommendations

Currently, only four African nations have embraced GMOs, with the rest being hesitant to allow them without restriction for fear that there is not enough evidence of their safety (Cerier, 2017). Therefore, it follows that for GMOs to have worldwide success as an agricultural adaptation, there must be more research to assure policymakers of their dependability, and that research should be widely shared across borders. A potential policy in a wealthier, more developed region should include efforts to research and publish official findings on GMOs, while underdeveloped regions should move to take steps to begin to implement gene technology with the support and knowledge of more developed nations. This could also serve to address the concerns and controversies that have emerged regarding GMOs, such as the fear of crossbreeding or allergen risks. With more readily available evidence-based information, the general public may feel more comfortable letting GMOs into their diets and farming practices. Developed countries should also move towards policy that would make genetically modified seeds public domain rather than intellectual property, which would make them more accessible to subsistence farmers in underdeveloped countries.

Conservation Agriculture

Conservation agriculture is one of the most trusted forms of alternative farming. Conservation agriculture, or CA, is most commonly defined by the following three standards: minimizing soil disturbance by directly seeding and using little or no tilling, maintaining a permanent soil cover, and maintaining crop diversity and crop rotations to prevent pest problems and disease (Milder et al, 2011). In 2010, several organizations joined forces to introduce conservation agriculture to ten Sub-Saharan African countries that needed to address concerns of food accessibility, poverty, or maintaining the natural ecosystem (Milder et al., 2011). This project reported many successes, including increased crop yields, soil moisture, and soil fertility; the project also helped to empower the local community, both in terms of ownership over food and increased knowledge to combat the effects of climate change (Milder et al., 2011). Some other reported benefits of conservation agriculture include increased productivity of land, nutrients, and soil biota; reduced amounts of labor and water; higher crop yields (and thus further financial gain); and community empowerment and engagement (CU Conservation Agriculture Group, 2015). The introduction of conservation agriculture has lead to significant growth in women's power within their local communities. These effects are being felt both in the fields and in the home (Milder et al., 2011). However, it is also true that conservation agriculture is not suitable for all farms or ecosystems. This practice is somewhat unattainable for many small-scale farmers, as it requires specific seeds and land quality (Midler et al., 2011).

Conservation agriculture is being acknowledged as an extremely useful tool for farmers to adopt in the face of climate change, as CA functions not only as an adaptive strategy but also as a mitigation practice. Unlike GMOs and crop diversification, which are first and foremost adaptive strategies, conservation agriculture holds the somewhat unique position of falling into both of these categories. It is clearly an adaptive strategy, as it presents alternative methods of increasing crop yield during a time of duress, but there are also aspects of these methods that mitigate the effects of agriculture on the climate system. Agriculture is one of the leading sources of human greenhouse gas emissions (Environmental Protection Agency), and alternative methods such as conservation agriculture can have a great effect on lessening these emissions. By maintaining a more permanent soil cover, more water is retained; by not tilling the land, less energy is used. Therefore, conservation agriculture is a method that more farmers should implement as both an adaptation and mitigation strategy. In order to ensure this, it is important for policymakers and politicians in the relevant regions to take a stand in favor of sustainable agriculture.

Conservation Agriculture Policy in Africa

In discussing the agricultural policy of Sub-Saharan Africa, it is important to remember that the concept of an involved agricultural policy is a fairly recent one in the majority of this region (Zimmermann et al., 2009). Therefore, many of the government-led agricultural initiatives there are still being thought out or implemented. A major victory in Africa came in the early 2000s when the African Union introduced a new measure called the Comprehensive Africa Agriculture Development Programme (CAADP). The CAADP and the AU together have come up with four key points for the implementation of new policy and the increase of sustainable agricultural efforts. These include wide participation in the development of new policy and strategies; efforts to implement these policies and strategies across all of Sub-Saharan Africa; policy recommendations based on existing evidence; strong partnerships to increase funding (Zimmermann et al., 2009). Of course, the level and depth of policy varies from region to region across Sub-Saharan Africa, but agricultural policy is expected to significantly increase with great benefit to farmers as a result of the CAADP (Zimmermann et al., 2009)

Currently, there are several reasons why conservation agriculture has failed to take a major hold among small-scale farmers, including a lack of policy and education on the subject. In some areas where conservation agriculture efforts have been slow-moving, activists have pointed to the lack of availability of certain types of seeds that are common among conservation agriculture practices. Rural farmers also lack the educational opportunities to learn if conservation agriculture is a viable option for them based on available resources and soil type, among other technical concerns (Paul-Bossuet, 2014). Thus, experts recommend that future policy address education for small-scale farmers about conservation agriculture and its benefits. Policymakers must also address methods of sustaining farmers implementing conservation agriculture, including financial support and continued access to seeds and other resources (Ngwira et al., 2014). The Food and Agriculture Organization of the United Nations, or the FAO, outlined a series of points that should be reflected in Southern African policy in order for conservation agriculture to take on and be effective. These points include educating the public about conservation agriculture through promotional materials and outreach; covering conservation agriculture in school curricula; institutionalizing understanding of the issue by placing experts in high-level positions and by conducting research; supporting local research; facilitating economic growth by encouraging sales of surplus; promoting benefits for those who adopt conservation agriculture (African Conservation Tillage Network, 2010).

Policy Recommendation

In creating policy regarding conservation agriculture, particularly in underdeveloped regions, there are many important points to be aware of. However, it is clear that the three major concerns for policy to address are supporting rural agriculture, climate change, and classifying conservation agriculture as both a mitigation and adaptation strategy. A potential policy would cite climate change as an immediate threat to the food production and livelihood of the global community, therefore necessitating mitigation and adaptation**.** As a strategy that falls into both of these categories, conservation agriculture should be introduced to and implemented in as many agricultural practices as possible. To facilitate this, the government should provide financial support to farmers during their transition period, education and awareness to farming communities, continued access to resources such as relevant seeds and farming equipment, and subsidies to those who demonstrate a decreased carbon footprint in their farming practices. These assets could potentially come from The Green Climate Fund, which provides funding to assist developing countries in fighting climate change (Green Climate Fund). The government should also take steps to publish official research on sustainable agriculture, list its benefits, and hire experts to fill government offices.

Conclusion

Sustainable agriculture is defined by the following four qualifications: fulfilling human food and nutritional needs, conserving the environmental and land quality, maintaining the financial benefit of agriculture, and bettering the quality of life of farmers (Walthal et al., 2013). Climate change makes these goals more difficult to achieve every year. As the planet warms and water systems become less predictable, the world's most vulnerable populations will see declines in the food production necessary for survival. Even in areas where agriculture is expected to boom in response to abundant CO_2 and a favorable regional climate, rapid growth will be offset by a decline in nutrition, making food security more and more difficult to maintain.

In order to continue to achieve these standards, farmers and countries must look to new agricultural methods, such as conservation agriculture, crop diversification, and gene technology. None of these methods alone will be able to save the world's crops, due to varying climate regions and the adaptability of individual species. However, if different types of agricultural adaptations are used concurrently with mitigation strategies, it is likely that sustainable agriculture will still be viable in the future. Policy which regulates and mandates these strategies is also increasingly important. Conservation agriculture, as both a mitigation and adaptation strategy, is especially crucial for subsistence farmers to adopt, and they must have continued federal and financial support in order to have success. Government-funded research on adaptation strategies is also necessary, as many nations are hesitant to regulate agricultural practices without sufficient evidence of its benefits. The policymaking world must unite over the threat of climate change and fight for food security.

Works Cited

"About the Fund." *Green Climate Fund*, www.greenclimate.fund/who-we-are/about-the-fund.

Adjimoti, Gilbert Onionkiton, et al. "Input Policies and Crop Diversification: Evidence from the Collines Region in Benin." *African Development Review*, vol. 29, no. 3, Sept. 2017, pp. 512-23. *Ebscohost*, onlinelibrary.wiley.com/store/10.1111/1467-8268.12286/asset/afdr12286.pdf?v=1&t=jb849mql&s=fdfb292ac799fb4cce73579d82c4db452402d399.

"Advantages of Conservation Agriculture." *Cornell University College of Agriculture and Life Sciences*, CU Conservation Agriculture Group, 2015, conservationagriculture.mannlib.cornell.edu/pages/aboutca/advantages.html.

Aguilar, Jonathan, et al. "Crop Species Diversity Changes in the United States: 1978–2012." *PLOS One*, 26 Aug. 2015. *PLOS One*, journals.plos.org/plosone/article?id=10.1371/journal.pone.0136580.

Brown, M.E., J.M. Antle, P. Backlund, E.R. Carr, W.E. Easterling, M.K. Walsh, C. Ammann, W. Attavanich, C.B. Barrett, M.F. Bellemare, V. Dancheck, C. Funk, K. Grace, J.S.I. Ingram, H. Jiang, H. Maletta, T. Mata, A. Murray, M. Ngugi, D. Ojima, B. O'Neill, and C. Tebaldi. *Climate Change, Global Food Security, and the U.S. Food System.* USDA, 2015, https://www.usda.gov/oce/climate_change

Cerier, Steven. "Led by Nigeria, Africa Opening Door to Genetically Modified Crop Cultivation." *Genetic Literacy Project*, 6 Mar. 2017, geneticliteracyproject.org/2017/03/06/led-nigeria-africa-gradually-opening-door-genetically-modified-crop-cultivation/.

Davis, et al. "Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999." *PubMed*, 2004, www.ncbi.nlm.nih.gov/m/pubmed/15637215/.

Dessler, A.J. *Introduction to Modern Climate Change*. 2nd ed., Cambridge, Cambridge UP, 2016.

Fifth Assessment Report - Synthesis Report. IPCC, 2014, https://www.ipcc.ch/report/ar5/syr/.

Fields, Scott. "The Fat of the Land: Do Agricultural Subsidies Foster Poor Health?" *National Center for Biotechnology Information*, Oct. 2004, www.ncbi.nlm.nih.gov/pmc/articles/PMC1247588/.

Food and Agriculture Organization. "The State of Food and Agriculture." *Climate Change, Agriculture, and Food Security*, 2016. *Food and Agriculture Organization*, www.fao.org/3/a-i6030e.pdf.

"Frequently Asked Questions on Genetically Modified Foods." *World Health Organization*, May 2014, www.who.int/foodsafety/areas_work/food-technology/faq-genetically-modified-food/en/.

"Golden Rice." *IRRI*, irri.org/golden-rice.

Hille, Karl. “Rising Carbon Dioxide Levels Will Help and Hurt Crops.” *NASA*, 3 May 2016, http://www.nasa.gov/feature/goddard/2016/nasa-study-rising-carbon-dioxide-levels-will-help-and-hurt-crops.

Hoegh-Guldberg, Ove, and John F. Bruno. "The impact of climate change on the world’s marine ecosystems." Science 328.5985 (2010): 1523-1528.

Iloh, Andrew, and Rose Gidado. “A Nigerian Perspective: GMO Crops Can Reduce Climate Change Impacts.” *Cornell Alliance for Science*, Cornell University, 23 May 2016, allianceforscience.cornell.edu/blog/nigeria-gmo-crops-can-reduce-climate-change-impacts.

Liang, G. H., and D. Z. Skinner, editors. *Genetically Modified Crops: Their Development, Uses and Risks*. New York, Haworth Press, 2005.

Lin, Brenda B. “Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change.” *BioScience*, vol. 61, no. 3, Mar. 2011, pp. 183-93. *Oxford Academic*, academic.oup.com/bioscience/article/61/3/183/238071.

Medek, Danielle, et al. “Estimated Effects of Future Atmospheric CO2 Concentrations on Protein Intake and the Risk of Protein Deficiency by Country and Region.” *Environmental Health Perspectives*, vol. 125, no. 8, Aug. 2017, pp. 1–8, doi:10.1289/EHP41.

Milder, Jeffrey C., et al. “Performance and Potential of Conservation Agriculture for Climate Change Adaptation and Mitigation in Sub-Saharan Africa.” *EcoAgriculture Partners*, Nov. 2011. *EcoAgriculture Partners*, ecoagriculture.org/wp-content/uploads/2015/08/PerformancePotentialofConservationAg.pdf.

Molteni, Megan. “Facing Climate Change, Tanzania Can’t Afford to Fear GM Crops.” *Wired*, 14 Oct. 2016, www.wired.com/2016/10/facing-climate-change-tanzania-cant-afford-fear-gm-crops/.

Myers, Samuel S., et al. “Effect of Increased Concentrations of Atmospheric Carbon Dioxide on the Global Threat of Zinc Deficiency: A Modelling Study.” *The Lancet. Global Health*, vol. 3, no. 10, Oct. 2015, pp. e639-645. *PubMed*, doi:10.1016/S2214-109X(15)00093-5.

Ngwira, A., et al. "Adoption and Extent of Conservation Agriculture Practices among Smallholder Farmers in Malawi." *Journal of Soil and Water Conservation*, vol. 69, no. 2, Mar.-Apr. 2014. *Soil and Water Conservation Society*, www.jswconline.org/content/69/2/107.full.pdf+html.

Paul-Bossuet, Alina. “Does Conservation Agriculture Work for Smallholder Farmers in Africa?” *Climate Change, Agriculture and Food Security*, 29 Aug. 2014, ccafs.cgiar.org/research-highlight/does-conservation-agriculture-work-smallholder-farmers-africa-new-report#.Wp33t5PwbdT.

Singh, Anupa, and Y. T. Jasrai. “Response of Crop Yields to Elevated Atmospheric Carbon Dioxide.” *Proc Indian Natn Sci Acad*, vol. 78, no. 1, July 2011, pp. 45–59.

The State of Food and Agriculture 2016. Food and Agriculture Organization of the United Nations, 2016, http://www.fao.org/publications/sofa/2016/en/.

"Sources of Greenhouse Gas Emissions." *United States Environmental Protection Agency*, www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

The Status of Conservation Agriculture in Southern Africa: What Can Policy Makers Do? July 2010. *African Conservation Tillage Network*, www.act-africa.org/library.php?com=5&com2=20&com3=64&com4=42.

Vernooy, Ronnie, editor. *Effective Implementation of Crop Diversification Strategies for Cambodia, Lao PDR and Vietnam*. Bioversity International, 2015. *Bioversity International*, www.bioversityinternational.org/uploads/tx_news/Effective_implementation_of_crop_diversification_strategies_for_Cambodia__Lao_PDR_and_Vietnam_1874.pdf.

Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, L.H. Ziska. 2012. *Climate Change and Agriculture in the United States: Effects and Adaptation.* USDA Technical Bulletin 1935. Washington, DC. February 2013. 186 pages.

"What Is Food Security?" *World Food Programme*, www.wfp.org/node/359289.

Zimmermann, Roukayatou, et al. "Agricultural Policies in Sub-Saharan Africa." *German Development Institute*. *German Development Institute*, 2009, www.die-gdi.de/uploads/media/Studies_48.pdf.