CONTRIBUTOR BIO

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CLIMATE CHANGE: EFFECTS ON THE USE OF BIOTECHNOLOGY IN AGRICULTURE

Ashley Stephens

History of Climate Change and Biotechnology Effects on Agriculture

The scientific community generally defines climate change as "a large-scale, long-term shift in Earth's weather patterns and average temperatures."[1] The idea that human activity affects climate change took hold in 1896 thanks to Swedish chemist Svante Arrhenius.[2] He argued that industrial-age coal burning will magnify the natural greenhouse effect, raising Earth's surface temperature by as much as 5 degrees Celsius over the next three thousand years.[3] In 1958, scientists substantiated part of Arrhenius's claims when they proved the steady rise of carbon dioxide in Earth's atmosphere. In fact, the rise of carbon dioxide levels occurred much more quickly than Arrhenius originally predicted, which

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[1] "What is Climate Change?," Met Office of the United Kingdom Web. Last modified March 26, 2015. http://www.metoffice.gov.uk/climate-guide/climate-change.

[2] "A Brief History of Climate Change," *BBC News*, September 20, 2013, http://www.bbc.com/news/science-environment-15874560.

[3] Spencer Weart, "The Discovery of Global Warming," Center for History of Physics of the American Institute of Physics Web. Last modified February 2015. http://www.aip.org/history/climate/co2.htm.

caused scientists to question humans' role in the rapid increase.[4] Despite growing evidence of human-induced climate change, the topic was barely a blip on international and national radars. Even with the establishment of the Montreal Protocol in 1987, which limited the use of chemicals that damage the o-zone layer, the ultimate concern was human health rather than the chemicals' effects on Earth's atmosphere. Finally, climate change became a focus of the international community in 1988 with the formation of the Intergovernmental Panel of Climate Change (IPCC). Still, climate change did not gain the attention of the general public until the early 21st century when the IPCC and former United States Vice President Al Gore made a conscious effort to educate the public on climate change with the production of "An Inconvenient Truth".[5] Today, one of the main concerns in regards to climate change is its effects on the world's agriculture.

In 2014, Harvard University's environmental health expert, Seth Meyers, found that the rising levels of carbon dioxide in Earth's atmosphere reduce the nutritious value of some of the world's staple crops.[6] Meyers conducted field trials on 41 different strains of wheat, rice, maize, and soybeans on three different continents. One group of crops was grown at current average carbon dioxide levels (380-390 parts per million) and a second group of crops was grown at carbon dioxide levels expected by 2050 (548-585 parts per million). "Wheat grown in high carbon dioxide levels had 9% less zinc and 5% less iron, as well as 6% less protein, while rice had 3% less zinc, 5% less iron and 8% less protein. Maize saw comparable falls while soybeans lost similar levels of zinc and iron but, being a legume not a grass, did not see lower protein."[7] The decrease in such nutrients is a major concern as the decrease can cause a multitude of issues for the immune system, fertility, child growth and development, and blood cells.[8]

Meyer's research is not the only research showing the effects of climate change on agriculture. The two most recent IPCC assessment reports suggest climate

[4] Damian Carrington, "Climate Change Making Food Crops Less Nutritious, Research Finds," *The Guardian*, May 7, 2014, http://www.theguardian.com/environment/2014/may/07/climate-change-food-crops-nutrition.

[5] *Op.Cit.*, fn. 2

[6] *Op.Cit.*, fn. 4

[7] *Op.Cit.*, fn. 4

[8] *Op.Cit.*, fn. 4

change has both beneficial and damaging effects on agriculture. However, the damages heavily outweigh the benefits. Currently, 2.4 billion people get at least 60% of their zinc and iron from wheat, rice, maize or soybeans, which means the world will likely see a rise in iron and zinc deficiencies if something is not done to stop these crops from losing nutritional value. The prospect is daunting considering there are already 2 billion people who suffer from such deficiencies.[9] Simply eating more staple crops is a lofty goal because rising populations alone will require food production to double by 2050 without any consideration for the changing nutritional values of staple foods.[10] As the rising agricultural needs of the globe become continually harder to meet, the agricultural industry struggles to come up with agreeable methods with which to close that gap. Many such methods involve biotechnology, which according to the *United States Department of Agriculture*, involves "a range of tools including traditional breeding techniques, that alter living organisms, or parts of organisms, to make or modify products; improve plants or animals; or develop microorganisms for specific agricultural uses. Modern biotechnology today includes the tools of genetic engineering."[11] While biotechnology can make growth and production cheaper and more manageable, there are many ethical concerns surrounding the issue, particularly with respect to the altering of genes in plants and animals. As climate change continues to add to food insecurity, and as ethical concerns surrounding biotechnology increase, the following research question needs answering: How will climate change affect the use of biotechnology in world agriculture?

Conventional Wisdom

Conventional wisdom holds that many people distrust the use of biotechnology in agriculture, with a particular distrust towards genetically modified food. A *Gallup* poll conducted in July of 2013 reported that 48% of Americans believe that foods produced using biotechnology pose a serious health hazard to consumers.[12] The *Gallup* poll also found that only 12% of Americans

[9] *Op.Cit.*, fn. 4

[10] *Op.Cit.*, fn. 4

[11] "Biotechnology Frequently Asked Questions," *United States Department of Agriculture* Web. Last modified March 27, 2015. http://www.usda.gov/wps/portal/usda/usdahome?navid=AGRICULTURE&contentid=BiotechnologyFAQs.xml.

[12] "Food and Nutrition," *Gallup*, July 30, 2013. www.*Gallup*.com/poll/.

follow biotechnology in agriculture very closely, and 28% of Americans follow the issue only somewhat closely. Thus, the majority of Americans know little to nothing about biotechnology techniques in agriculture.[13] Another survey conducted by the *Pew Research Center* found that 57% of U.S. adults think genetically modified foods are generally unsafe to eat.[14] Furthermore, while climate change is a major issue for most people, food insecurity is not. A study conducted by the *Pew Research Center* shows that 54% of the world population views global climate change as a major threat to their countries. However, not even one of the 39 countries surveyed viewed food insecurity as one of the top three major threats.[15]

Based on these non-partisan public opinion polls, conventional wisdom on biotechnology in agriculture is misguided. Conventional wisdom ignores the fact that biotechnological uses, particularly genetically modified organisms, are indeed safe for consumption. A study carried out by geneticist Alison Van Eenennaam of the University of California-Davis's Department of Animal Science is the most comprehensive study of GMO food ever conducted. Van Eenennaam's research, which encompasses observations of more than 100 billion animals over the past 29 years, indicates that livestock fed GMO food is no less safe to consume by humans than livestock fed non-GMO food.[16]

This research question also challenges the conventional wisdom because the layman's view does seriously consider the fact that climate change may force the agricultural industry to turn to biotechnological solutions. The recently released IPCC report indicates that the effects of climate change on crop and food production are evidently negative in multiple regions of the world.[17] Crop yields have shown to be very sensitive to increased extreme daytime temperatures

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13 *Ibid.*

14 "5 Key Findings on what Americans and Scientists Think About Science," *Pew Research Center*, January 29, 2015, http://www.pewresearch.org/fact-tank/2015/01/29/5-key-findings-science/.

15 "Climate Change and Financial Instability Seen as Top Global Threats," *Pew Research Center*, June 24, 2013, http://www.pewglobal.org/2013/06/24/climate-change-and-financial-instability-seen-as-top-global-threats/.

16 Jon Entine, "The Debate about GMO Safety is Over, Thanks to a New Trillion-Meal Study," *Forbes*, September 17, 2014, http://www.*Forbes*.com/sites/jonentine/2014/09/17/the-debate-about-gmo-safety-is-over-thanks-to-a-new-trillion-meal-study/.

17 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 488.

and increased levels in carbon dioxide. As a result, growers have to get creative with solutions to avoid crop loss. For example, crop growers may need to genetically alter crops in order to make them more water efficient in times of drought, since traditional methods of crop growing such as irrigation may fail to bring enough water to non-altered plants. Throughout the following case studies, the data and analysis presented will show that climate change is indeed changing the way the agriculture industry works and that biotechnology is becoming an increasingly invaluable tool to said industry during this time of change.

Extreme Weather Events

Extreme weather events such as floods and droughts have increased over the past 40 years largely due to the increased concentration of carbon dioxide in the atmosphere.[18] Carbon dioxide molecules trap heat; thus, the rising culmination of such molecules in Earth's atmosphere increases the amount of heat that is unable to leave the planet. The result is warmer overall temperatures on Earth's surface, which in turn increases the likelihood of droughts and floods, as the globe has seen in recent years.[19] While the connection between warmer temperatures and droughts may be somewhat obvious, the connection between warmer temperatures and floods is not so immediately apparent. Warmer air holds more moisture, which means there is a greater likelihood of tropical storms and hurricanes.[20] The precipitation accompanying such storms is often the cause of floods. Both droughts and floods have significant, negative impacts on agriculture—particularly when it comes to crops. Each type of crop has its own specific thresholds for temperature and precipitation, which makes them especially sensitive to sudden or prolonged extreme weather events.[21]

Agricultural droughts are prolonged periods of "precipitation shortages, soil water deficits, and reduced ground water or reservoir levels needed for

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[18] Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. *Climate Change Impacts in the United States: The Third National Climate Assessment.* (Washington D.C.: U.S. Global Change Research Program, 2014), 152.

[19] Amanda Staudt, "Connecting the Dots: Hurricanes," National Wildlife Federation Web. Last modified January 2015. http://www.nwf.org/Wildlife/Threats-to-Wildlife/Global-Warming/Global-Warming-is-Causing-Extreme-Weather/Hurricanes.aspx.

[20] *Ibid.*

[21] Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 492.

irrigation."[22] Often times, droughts are accompanied by heat waves, in which temperatures rise above average for an extended period of time. The United Nations' World Meteorological Organization (WMO) released a report in 2013 indicating that the United States, Mexico, the Mediterranean basin, northern China, southern Africa and Australia, and parts of South America have been and will continue to be particularly prone to harsh drought conditions as a direct result of warming temperatures.[23]

Crops are particularly sensitive to the increased frequency of droughts, because droughts indicate an extreme change in temperature, carbon dioxide levels and precipitation frequency. Every crop species needs to grow in specific temperatures in order to maximize both yield and nutritional value. When non-optimal temperatures persist for a prolonged period of time as they do in droughts, the crops suffer either total failure or a significant loss in yield and nutritional value. For example, 2012 corn yields in the United States were reduced 12% per month because of a drought that caused high nighttime temperatures.[24] Furthermore, high temperatures during the pollination stage of fruit, grains and fibers may lead to significant losses in both yield and nutritional value.[25] While warmer temperatures can make crops grow faster, those temperatures also reduce the amount of time seeds have to grow and mature below optimal timeframes. In turn, the seeds cannot soak up enough nutrients from the soil to come to fruition.

One of the few benefits of elevated carbon dioxide levels is the increased water-efficiency in crops, although the reason for this causal relationship is unclear.[26] While this is a much-needed relief, the increased water-efficiency is not enough to fully protect these crops from droughts. A study conducted in Africa, consisting of 20,000 trials over the span of nearly a decade, indicated

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22 "Drought Public Fact Sheet," National Weather Service Web. Last modified May 2008. http://www.nws.noaa.gov/os/brochures/climate/DroughtPublic2.pdf.

23 United Nations World Meteorological Organization, "The Global Climate 2001-2010: A Decade of Climate Extremes," (Geneva: July 3, 2013), 9-10.

24 Marc Schober, "WASDE: Largest Corn Yield Reduction in a Decade" Ag Web. Last modified March 30, 2015. http://www.agweb.com/WASDE-Largest-Corn-Yield-Reduction-in-a-Decade/.

25 Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. *Climate Change Impacts in the United States: The Third National Climate Assessment.* (Washington D.C.: U.S. Global Change Research Program, 2014), 155-156.

26 *Ibid.*

that for each day temperatures rose above 30°C, there was a 1.7% decrease in crop yield.[27] California's driest year on record is 2014, during which the state saw a 1% drop in orange production, an 8% drop in grape production, and a 4% drop in peach production.[28] The crop reduction is significant because California is one of the largest producers of such crops in the United States.

The main adaptations for droughts include the development of drought-resistant crops, and the increased efficiency and use of irrigation systems. The development of drought-resistant crops will improve crop yields by an estimated average of 10-20%.[29] Drought-resistant crops are genetically modified plants that have had drought-resistant genes from other plants inserted into their genomes. Unfortunately, this type of molecular breeding is limited to the farmers who can afford it, which often times excludes small farmers and farmers in developing countries.[30] This limiting factor is combatted by the Generation Challenge Program (GCP), which aims to standardize phenotyping protocols, provide access to and promote the use of genetic diversity, and to "use genetic diversity and advanced science to develop products for plant breeding program[s] to improve the livelihoods of resource-poor farmers in marginal, drought-prone environments".[31]

Floods are another result of extreme weather that significantly affects agriculture. Floods usually occur following tropical storms, hurricanes and cyclones, which scientists believe are occurring more frequently because the warmer air holds more moisture.[32] The Caribbean region in particular has fallen victim to hurricanes, floods and droughts. From 2002 to 2008 Jamaica's agriculture sector sustained heavy crop loss due to flooding by Hurricanes Charley and Ivan, and a seven-month drought that followed the flood.[33] Tropical Storms Wilma

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27 Antonia Okono, Philippe Monneveux, and Jean-Marcel Ribaut. "Facing the Challenges of Global Agriculture Today: What can we do about Drought?" *Frontiers in Physiology*, Vol. 4 no. 289 (October 2013): 1-3.

28 "California Drought 2014: Crop Sectors," *United States Department of Agriculture* Web. Last modified September 12, 2014. http://ers.usda.gov/topics/in-the-news/california-drought-2014-farm-and-food-impacts/california-drought-2014-crop-sectors.aspx.

29 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 515.

30 *Op.Cit.*, fn. 27

31 *Op.Cit.*, fn. 27

32 *Op.Cit.*, fn. 29

33 United Nations Food and Agriculture Organization, "Climate Change and Agriculture in Jamaica: Agriculture Sector Support Analysis," (2013), 5-7.

and Noel and Hurricanes Dennis, Dean and Emily succeeded the drought and caused major flooding and continuous rainfall.[34] These extreme weather events devastated the Caribbean's agricultural industry. Unfortunately, preliminary data indicates that the entire Caribbean region expects to see a rise in both floods and droughts over the next century.[35] Europe will also experience an increase in flood issues as flood instances may double by 2050.[36] Similarly, the United States and Southeastern Asia will experience more flooding because of an increase in hurricane occurrence and severity.[37] Adapting to floods is considerably more difficult to manage than droughts because the excess water essentially drowns the plants. Some of the only ways to protect crops from floods is the traditional use of barriers such as levees or the movement of crop fields to higher grounds.[38] In the future, biotechnology may provide another solution in the form of flood resistant crops. Such crops may be possible as scientists with University of Nottingham and the University of California Riverside recently discovered the molecular mechanism plants use to detect low oxygen levels.[39]

Weeds, Insects, and Diseases

Three pests have always plagued agricultural crops: weeds, insects, and diseases. According to the *National Climate Assessment* conducted by the U.S. Global Change Research Program, weeds account for 34% of crop loss, insects account for 18% of crop loss, and diseases account for 16% of crop loss.[40] The national average reflects worldwide averages as well. According to the 2014 IPCC report, insects and diseases account for 18% and 16% of worldwide annual crop loss.[41]

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34 *Ibid.*

35 *Op.Cit.*, fn. 33

36 Steve Connor, "Frequency of Severe Flooding Across Europe to Double by 2050," *The Independent*, March 2, 2014, http://www.independent.co.uk/.

37 *The World Bank*, "Turn Down the Heat," (Washington DC: June 2013), 182.

38 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 506-507.

39 "Breakthrough in the Production of Flood Tolerant Crops," *University of Nottingham*, (Press Release: October 23, 2011). http://www.sciencedaily.com/releases/2011/10/111023135638.htm.

40 Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. *Climate Change Impacts in the United States: The Third National Climate Assessment.* (Washington D.C.: U.S. Global Change Research Program, 2014), 158.

41 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts,

In the United States alone, the public and private sectors spend a combined $11 billion annually just to combat weeds.[42] Unfortunately, for crops, scientists project that the pest problem will only rise over the next century.[43]

Increases in carbon dioxide levels not only increase the water-efficiency in crops, but it also increases the water-efficiency in the invasive weeds that the farmers wish to avoid. There is also evidence to suggest that these weeds thrive more than crops in these hotter, more carbon dioxide rich conditions.[44] North America in general is set to experience the northward migration of invasive weeds.[45] In the United States, invasive weed species such as *Privet* and *Kudzu*—weeds traditionally found in southern states—may expand their territory into northern United States as changes in temperature occur.[46] The weed migration is not just limited to North America; an increase in overall average global temperature will result in the rapid expansion of weed seed dispersion across the entire world.[47] Thus, crop growers everywhere can expect to deal with weeds they may have never encountered before, which means crop growers will have to invest in researching and implementing ways to combat the new weeds. In the meantime, their crop yields will be at the mercy of untamed weeds.

Adaptations utilized to combat weeds are becoming increasingly ineffective. A disappointing finding is the apparent reduced effectiveness of one of the most popularly used herbicides in the world: Glyphosate (also known as RoundUp). Within the next century, glyphosate's effectiveness will considerably reduce due to the projected increases in carbon dioxide levels.[48] If newer technologies are not developed, farmers will have to resort to more frequent sprayings, which impose costs on the economy, the environment, and human health.

With increasing temperatures, there will also be a spike in the population of harmful insects. Insects "synchronize their development and reproduction with warm periods and are dormant during cold periods. Higher winter temperatures

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Adaptation and Vulnerability," (March 31, 2014), 500.

42 *Op. Cit.*, fn. 40

43 *Op. Cit.*, fn. 40

44 *Op. Cit.*, fn. 41

45 *Op. Cit.*, fn. 41

46 *Op. Cit.*, fn. 40

47 *Op. Cit.*, fn. 41

48 *Op. Cit.*, fn. 40

increase insect reproductive rates and allow for multiple generations."[49] Unlike crops, insects have the ability to adapt to a changing climate very quickly because of their high reproductive ability, short generation time, and high mobility. High mobility allows the insects to move around, as certain locations become unfavorable to them while other locations become more favorable.[50] The potential for insect mobility now leaves crops open to entirely new insect problems, which could prove devastating to entire growing seasons. What makes the situation even worse is that producers may be unable to predict and thus unable to prevent which insects will attack their crops. Warmer trends may expose coffee crops in Ethiopia, Kenya, Uganda, Rwanda, and Burundi to an increase in the population of the coffee berry borer—one of the most devastating insects to coffee plants.[51] On average, crops in Spain face at least one new insect every ten months as the pests migrate northward from Africa.[52] The population of the coffee nematode, a parasitic worm, will likely increase in Brazil while the walnut pest population in California also increases because of rising temperatures.[53]

Like weeds, harmful insects are often the target chemical sprayings known as pesticides. These pesticides aim to kill insects by disrupting growth and development.[54] Crops are also genetically modified to release a toxin that kills harmful insects. However, insects are highly adaptable creatures and within a few generations, they become resistant to the genetically modified crops.[55] In this regard, biotechnology may not be as useful in combatting the effects of climate change as the ability of insects to quickly gain resistance to genetically modified crops outweigh the heavy financial costs of creating those crops.

Scientists have yet to conduct in-depth studies of the effects of climate change on diseases, but the *National Climate Assessment* suggests that high

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[49] *Op.Cit.*, fn. 40

[50] Moshe Coll and Tarryn Schuldiner-Harpaz, "Effects of Global Warming on Predatory Bugs Supported by Data Across Geographic and Seasonal Climatic Gradients" PLOS One, Vol. 8 no. 6 (June 2013): 1-9.

[51] *Op.Cit.*, fn. 41

[52] *Op.Cit.*, fn. 40

[53] *Op.Cit.*, fn. 40

[54] "Insects, Nematodes, and Biotechnology." *National Institute of Food and Agriculture,* (March 18, 2009).

[55] *Ibid.*

temperatures and drought increase aflatoxin production—a toxin produced by fungi that grow near and on crops. Insects can increase the production of aflatoxins—which are harmful to humans and livestock—in host crops.[56] Europe's crops face a variety of diseases including the phytophthora cinnamomi disease, which causes roots to rot, and the phoma stem canker in oilseed rape, which kills seedlings before they have a chance to grow.[57] Europe will also see an increase in winter infection root and stem diseases, Fusarium blight, and a black rot fungus. Denmark, Finland, Iceland, Norway and Sweden will be seeing an increase in both pathogens and insects, as they will be less protected by the cold, long winters.[58] While the Nordic countries will become more suitable for cereal crops, they will also become more suitable for diseases such as Eyespot and Anamorf. These two diseases alone could result in 50% crop yield reductions if the diseases cannot be controlled.[59] Bananas grown in Angola and Guinea face an increased risk of Black Leaf Streak Disease as minimum temperatures continue to increase across Africa.[60] The conventional adaptation for dealing with crop diseases is fungicides, which like herbicides and pesticides, involve spraying chemicals onto the plants. However, diseases are showing increasing resistance to fungicides which means other adaptations must be explored.[61]

Reduced Yields and Nutritional Value

Food security is an increasing concern in the face of the growing evidence towards climate change's negative effects on agriculture. With demand for food already set to increase by 14% per decade until 2050, reduced yields is considered a major threat to food security. Furthermore, from now until 2050, experts expect the average worldwide crop yield to drop by as much as 2% per

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56 *Op.Cit.*, 40

57 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 497.

58 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 501.

59 Asko O. Hannukkala et. al., "Pests and Diseases in a Changing Climate: A Major Challenge for Finish Crop Production" *Agriculture and Food Science*, Vol. 20 (2011): 3-14.

60 *Op.Cit.*, fn. 58

61 Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. *Climate Change Impacts in the United States: The Third National Climate Assessment.* (Washington D.C.: U.S. Global Change Research Program, 2014), 161.

decade.[62] Beyond 2050, the average crop yield decrease will likely rise beyond 2%. Already, the thinning Ozone layer is blamed for roughly 10% of wheat and soybean yield loss and 3-5% of the yield loss for maize and rice.[63] There is a consensus among scientific research than an average temperature increase of 3°C or more will reduce all crop yields if adaptations are not undergone.[64]

The relationship between climate change and yields is often both region and crop specific and thus, it is pertinent to examine several different regions and crops.[65] Perennial crops are crops that are planted once and harvested repeatedly over many years. Perennial crops grown in Africa face grave danger where rising average temperatures will leave little land suitable for planting.[66] The conventional adaptation to this problem would be to plant crops at a higher altitude. However, the high-altitude option will be severely limited due to the scarcity of suitable higher altitude locations. In the absence of a better solution, Africa faces the very real risk of catastrophic economic troubles due to severely reduced yields of high-value perennial crops such as tea, coffee and cocoa.[67] South America faces a similar fate as Africa in regards to its perennial crops. Costa Rica, Nicaragua, Columbia, and El Salvador face a 40% reduction in coffee crop productivity if they do not relocate coffee crops to higher altitudes by 2050.[68]

Grain crops also face a significant reduction in yields due to average rising temperatures. If the temperature rises only 3°C, both Africa and South Asia face an overall 8% yield reduction by 2050 in wheat, maize, sorghum and millets.[69] In the event of a 5°C rise in temperature, Africa stands to lose 19% of its maize yields and 68% in bean yields.[70] Central America, Brazil, and the Andean Region face a significant decrease in crop yields that will lower food security of

62 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 505.

63 *Ibid.*

64 *Ibid.*

65 Intergovernmental Panel on Climate Change, "*Climate Change 2014: Impacts, Adaptation and Vulnerability*," (March 31, 2014), 506.

66 *Ibid.*

67 *Ibid.*

68 *Ibid.*

69 *Ibid.*

70 *Ibid.*

the area's poorest populations.[71] Such crops are vital to food security across the globe because they serve as one of the core components of the typical human diet. Furthermore, grain crops such as corn also serve as the main component of livestock diets, which further threatens the food security of humans.

A popular adaptation is to extend growing seasons for oilseed, wheat, soybeans, and maize into cooler months to compensate for the increase in warmer months at the tail end of growing seasons. Studies have shown that changing planting dates may help increase yields by as much as 17%.[72] While this may be enough in areas such as South America, earlier planting dates do not work for areas like the Mediterranean, where early planting is dependent on adequate rainfall in the autumn season. However, it is likely that rain in the area will decrease during the autumn which means planting dates could be pushed back rather than pushed forward.[73] A second adaptation is moving crop-planting areas further north and south of the equator—in areas where global warming has raised temperatures to suitable crop-growing conditions. A third option involves selective breeding and genetic engineering, in which growers design and breed plants to withstand higher temperatures. However, this takes anywhere from 8 to 20 years to develop.[74] It also involves maintaining extensive gene banks from which producers would be able to select favorable genes. The more genetically diverse such banks are, the more options scientists will have from which to pull favorable genes for biotechnological adaptations.

Aside from the steady rise in average global temperatures, water scarcity also affects crop yields. An estimated 80% of the world's crop area is rain-fed. Moreover, this rain-fed area accounts for 62% of the world's staple crops.[75] With rainfall becoming more sporadic and unpredictable, these numbers are likely to dwindle.[76] Although irrigation will be affected by changing rainfall and runoff patterns, it will remain a key aspect of maintaining crop yields in the face of climate change. As a testament to irrigations effectiveness, irrigated

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71 *Ibid.*

72 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 507.

73 *Ibid.*

74 *Ibid.*

75 United Nations Food and Agriculture Organization, "Climate Change, Water and Food Security," (September 2008), 47.

76 *Ibid.*

crops account for 40% of the world's food supply despite the fact that irrigation is responsible for watering only 20% of the global crop area.[77] Clearly, irrigation is efficient despite its economic costs. Furthermore, irrigation is vital to densely populated countries such as China, Pakistan and India, where water may be a scarce resource. [78] Future adaptations will likely involve a focus on the expansion and improvement in the efficiency of current irrigation systems.

Food security is not just about the amount of crops we can produce; it is also about the nutritional value of those crops. There is evidence that increased temperatures cause cultivated plants to mature more quickly than the soil can handle. The faster growth is due to the increased levels of carbon dioxide in the atmosphere, which increases the rate of photosynthesis.[79] Thus, even though plants grow faster (and thus, can be picked earlier), the plants lose some of their nutritional value because the soil cannot provide those nutrients quickly enough.[80] Even if crop yields remain constant over the next century, it would take more food to provide people with adequate nutritional value. Cereal crops (wheat, rice, and corn) grown under elevated carbon dioxide levels have decreased protein content.[81] Mineral concentration in edible plant tissues is also reduced when grown under increased levels of carbon dioxide.[82] Early evidence suggests that biotechnology can be used to increase micronutrients such as vitamins and beta-carotene into crops.[83] Scientists identify genes that perform the needed function and inject them into the genomes of the desired

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77 United Nations Food and Agriculture Organization, "Climate Change, Water and Food Security," (September 2008), 48.

78 United Nations Food and Agriculture Organization, "Climate Change, Water and Food Security," (September 2008), 50.

79 United Nations Food and Agriculture Organization, "Climate Change, Water and Food Security," (September 2008), 74.

80 Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. *Climate Change Impacts in the United States: The Third National Climate Assessment.* (Washington D.C.: U.S. Global Change Research Program, 2014), 155.

81 Roberto Confalonieri et. al., Climate Change and Agriculture in Latin America, 2020-2050: Projected Impacts and Response to Adaption. (Washington D.C.: World Bank, 2012), 18.

82 Intergovernmental Panel on Climate Change, "Climate Change 2014: Impacts, Adaptation and Vulnerability," (March 31, 2014), 501.

83 Geoffrey Barrows et. al., "Biotechnology and Food Security" *Journal of International Affairs*, Vol. 67 no. 2 (Spring/Summer 2014): 91-105.

crops.[84] The world heritage site, Kew Gardens, is home to a seed bank that holds wild, undomesticated relatives of the world's twenty-nine most crucial crops.[85] One of the reasons these crops are saved is to provide a buffet of genes to choose from in the event that crops need to be enhanced with certain types of genes.

Implications

Climate change has and will continue to affect world agriculture. The severity of extreme weather events will rise over the next century. Drought-resistant crops are already available to farmers and researchers continually work toward making even more crops drought-resistant. Flood-resistant crops are not yet in use, but there is progress toward their development with the discovery of the molecular mechanism plants use to detect low oxygen. Changing weather patterns have caused an increase in invasive weeds, insects, and diseases. The increasing pest problem will be difficult to control considering increasing resistance to chemical solutions. Enhanced irrigation systems will be vital in combatting water scarcity, but many scientists fear this will not be enough to maintain sufficient crop yields.

Climate change has already begun to push agriculture away from the equator. The migration is deeply concerning because countries near the equator are the ones with the most food insecurity.[86] Climate change has also pushed crops to higher altitudes. Unfortunately, there are only so many high-altitude places in the world and there is only so far north or south to push crop fields. The evidence presented in the case studies suggests that migration of crop fields is not a sustainable answer for the long-term despite its efficiency in the short-term.

Although it may be too early to tell precisely how climate change will affect world agriculture, it appears that sustainable world agriculture lies increasingly within biotechnology. The main setback to biotechnology is the time, effort, and money it takes to research and develop needed solutions. However, a rise in the use of biotechnology in agriculture may be inevitable. The world

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will need both drought and flood-resistant crops. The world will need crops

84 *Ibid.*

85 Nicola Davis, "Safeguarding the Future of Food Security," *The Guardian*, May 10, 2014. http://www.theguardian.com/environment/2014/may/14/kew-food-security.

86 *Op.Cit.*, fn. 82

to be more weed, pest and disease resistant. The world will need crops that can withstand higher average temperatures with less water. Finally, the world will need crops with dense nutritional value. In the short-term, conventional adaptations of crop field migration, increased herbicide and insecticide sprayings, and enhanced irrigation systems may meet these needs. However, these solutions become increasingly unrealistic in the long run due to a variety of reasons including limited growing areas and high environmental costs. The implications of the lack of other long-term options means that biotechnology may be a keystone solution to the negative effects of climate change on world agriculture. There is still much controversy over the use of biotechnology in the food we eat, but the fact of the matter is we may not have a choice if we want to maintain complete and nutritional diets.