

# Climate Change Impacts on U.S. Crops\*

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*Choices Magazine*, 30(2): 1–4

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Reprint 2015-10

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# Climate Change Impacts on U.S. Crops

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*JEL Classifications: Q54, Q10*

*Keywords: Crop Yields, Climate Change, Adaptation*

The Intergovernmental Panel on Climate Change's (IPCC) the Fifth Assessment Report (AR5) (Romero-Lankao et al., 2014) found that climate change is responsible in part for historical yield increases in the United States thanks to increased precipitation. Since 1999, however, yield losses have been attributed to extreme weather events, such as heat waves, storms, and droughts and the IPCC concludes that in many crop growing regions of North America optimum temperatures have been reached and further warming would be detrimental to crop yields.

## What to Expect in the Future?

Annual mean warming over most of North America is expected to exceed the expected global mean warming (1.1°C and 6.4°C by the end of the century), according to the IPCC. Regionally, annual mean precipitation is expected to increase in the Northeast of the United States and decrease in the Southwest. Along with these changes in mean conditions, an increase in the frequency of extreme weather events such as droughts, floods, and heat waves are also anticipated. These extreme events are also predicted to last longer and be more intense.

As a consequence of rising temperatures, decreasing precipitation and a greater frequency of extreme events, the IPCC projects a decline in net productivity of the major crops grown in North America by the end of the 21st century, although the scale of the impact depends on the climate models and scenarios considered. Overall, the decline is expected to be modest in the first half of the century but sharper toward 2100. The United Kingdom's Met Office's (2011) review of climate change impact studies

concur and finds that although the extent of the impact varies across studies due to differences in methodology and assumptions, the general consensus is that climate change will lower yields for the most important crops: maize, soybean, and wheat.

Several studies have focused on California, one of the United States' most productive regions, and project small changes in yields for the mid-century and declines between 9 and 29% by the end of the century, assuming no constraint on water availability. Viticulture would be the most affected due to a decrease in land suitability for grapes. Some regions in the North where water availability is not an issue are expected to benefit from climate change.

## Main Drivers: Temperature and Precipitation

The IPCC discerned two main factors of yield declines: temperature and water availability. Temperature increases are expected to be responsible for declines in corn, soy, and cotton yields of between 30 and 82% by the end of the century. It would also reduce the quality of certain crops (for example, coffee and grapes). The detrimental effect of rising temperatures is only partially offset by precipitation increases. In regions where precipitation is expected to decrease, the negative impact of temperature increases on crop yields and quality is expected to be accentuated.

## The Role of Extreme Weather Events

Crop yields will also be affected by extreme events such as extreme heat, heavy downpours, storms, and droughts. The largest risk of heat stress is expected to be in central-North

America by 2070. When considering droughts and adaptive capacity, the northeastern and southeastern United States are expected to be the most vulnerable.

### **Water Resources for Irrigation**

Most studies evaluating the effect of climate change on crop productivity consider either rainfed crops or assume that water availability for irrigation is not a constraint. However, several river basins in the United States are already subject to water stress and others are expected to be in the coming decades. Changes in rainfall and its intensity (increases in runoff intensity reduces the rainfall infiltration rate to the crop root zone) will affect the availability of water resources and, along with temperature changes will also affect crop water requirements. A recent United States Department of Agriculture (USDA) report (Walthall et al., 2012) considers the changes in relative crop returns between dryland and irrigated crops to reflect the sensitivity of yields to climatic factors. They expect continuing rainfed production in the northern regions, where rainfall increases are likely to increase soil moisture reserves. However, a decline in soil moisture in the southern regions, which would entail a decrease in dryland yields, would justify irrigation subject to water availability. Water availability is expected to be a constraint in the West and Southwest, with soil moisture decreases projected in the spring and summer under the worst case scenario. Water withdrawals are expected to exceed freshwater resources by 40% in the Great Plains, making it the most exposed region to water stress. In the West, summer and fall water availability are expected to be affected by earlier snowmelt and reduced snowpack, even if precipitation is unchanged.

### **Indirect Effects of Climate Change**

In addition to influencing yields through climate change, increases in greenhouse gas (GHG) emissions will also impact crops via carbon dioxide (CO<sub>2</sub>) fertilization effects. According to the U.S. Global Change Research Program (2009), higher CO<sub>2</sub> concentration would enhance crop yields but would also favor weeds. This would entail greater use of pesticides or hamper crop yield growth gains. Additionally, climate warming could also lead to a spatial shift of invasive weeds toward the north.

Climate change will also have direct and indirect effects on crop productivity via soil erosion via changes in rainfall, snowmelt and wind. By changing crop mixes and management practices (such as irrigation) in response to climate change, farmers will change the erosion rate. Excessive erosion rates entail losses of soil productivity, fertility, organic carbon, and nutrients. Walthall et al., (2012) report estimates soil carbon losses of between 33 and 274% by the mid-century compared to the 1990s in 10 out of 11 regions of the corn-belt when accounting for changes in

biomass and planting, tillage, harvesting dates, and adaptive changes in crop mixes.

According to Walthall et al., (2012), climate change, and especially temperature change, would also have an impact on crops via 'biologically mediated services', such as animal pollination, which is responsible for 75% of the global food crop pollination. A study simulating the effect of warming on pollinator activity found that some species of bees will provide increased pollination services, while those of the honeybee, which is currently the main crop pollinator, will decrease. Overall, due to different responses to temperature changes of various bee types, the gain from some bee species would compensate the loss of services from another, except in systems where honey bees are the only pollinator.

### **Adaptation**

The climate change impact projections on crop yields mentioned above correspond to simulations with no adaptation assumed. According to the IPCC, North America has the potential to offset yield reductions under 2oC warming thanks to adaptation strategies. For instance, spatial shifts of crop varieties are expected to reduce yield losses by between 6 to 14%. However, at 4oC warming, the effectiveness of adaptation strategies will be reduced and necessitate more drastic adaptation measures, such as livelihood and production diversification.

### **Adaptation Strategies**

Farmers can adopt two main strategies to adapt to changes in climate: changes in management practices, and changes in the location of production. In term of management strategies, farmers can adopt crop varieties better suited to new climate conditions and diversify their production to reduce their vulnerability. They can also adopt sustainable agronomic practices, such as low-tillage, live mulching or cover crops, and adapt sowing and planting dates or improve crop rotations.

Subject to water resource limitations, farmers can also adapt their irrigation strategies by expanding irrigation to previously rainfed land, or replacing irrigation systems with improved irrigation technologies with better conveyance and application efficiency. However, changes in irrigation strategies would entail a change in crop selection by favoring high value crops or less water intensive crops. At a large-scale, adaptation can take the form of spatial shift of production, with cropland shifting to areas with better climatic conditions or water availability for irrigation.

In addition to yield growth, the effect of climate change can be compensated by a growth in crop production which can be obtained either by increasing cultivated land expansion and intensification the use of cropland already in use.

Intensification can be achieved by, for instance, the densification of planting, which can make better use of the land already cultivated by improving soil fertility management; or with irrigation which enables farmers to crop land multiple times a year.

The IPCC also suggests greater institutional support to producers, which is currently deficient in some regions, to enhance adaptation. Changes could be made in water resource infrastructure and institutions to improve water allocation. The development and dissemination of daily and seasonal weather forecasts would also enable farmers to be better prepared.

## The Role of Technology

Technology has played an important role in historical yield increases. The 'green revolution' brought major productivity improvements since the 1960s with the intensification of machinery and fertilizer use, and economies of scale. More recently, biotechnology techniques have been used to develop new plant varieties in order to increase yields, tackle pest and diseases issues, and improve resistance to abiotic stresses such as droughts and cold temperatures.

According to the FAO (2002), "even if no more new technologies become available, there is still scope for increasing crop yields in line with requirements". For instance, it estimates that the ratio of wheat yields could be at least doubled by increasing actual yields to maximum yields obtainable under current technologies.

## Impact of Adaptation

The potential role of adaptation in alleviating the effect of climate change on crops has generated considerable debate. On the one hand, agriculture is very diverse and practiced across a wide range of climates, indicating that farmers can adapt to local conditions. Farmers also respond to prices, as evidenced by commodity price spikes over the past 50 to 100 years that have been met with a large supply response that have in turn resulted in decades of depressed prices and excess supply. Cross-sectional econometric analyses that Mendelsohn, Nordhaus, and Shaw (1994) termed the 'Ricardian' approach have found adaptation to be a powerful force. On the other hand, some scholars think that there is limited scope for adaptation. Using panel data, studies such as Schlenker and Roberts (2009) find limited past adaptation of seed varieties or management practices. They also attribute recent yield declines with extreme events in the United States. From that perspective, there is concern that there are extreme conditions that are intolerable to crops.

Agronomic process-based models of crop growth combined with market models of supply and demand are

another approach to evaluate the scope for adaptation (Rosenzweig et al., 2013). Although agronomic models consider, in great detail, the effect of weather, soil quality, CO<sub>2</sub>, and ozone on crop growth, they have difficulty accounting for the influence of pests, disease, management strategies, and technological progress—which on principle econometric studies account for (Attavanich and McCarl, 2014). These studies tend to find that modeled adaptation substantially alleviate yield losses, leading to a production impact a fraction of the initial yield loss but at added cost (Reilly et al., 2007).

With northern regions of the United States likely to benefit from warmer temperatures, climate change may entail northward migration of cropping areas. Walthall et al., (2012) report cites findings that the spring wheat belt is expected to move north by more than 10 degrees into western Canada by 2050. Warming would also increase wheat cultivated areas and winter-sown spring wheat would become more suited to the southern United States.

Over the last 30 years, earlier corn and soybean planting dates and lengthening of the growing season have contributed to greater yields. This trend is attributed only in a small part to warming of the mid-west, the rest being enabled by new cold tolerant cultivars and the adoption of new plating equipment and conservation tillage, which reduced the preparation time required before planting.

In a meta-analysis of more than 1700 global climate change impact assessments, Challinor et al., (2014) find that simulated yields are increased by between 7 and 15% by crop-level adaptations. The study does not provide U.S. specific results, but shows that adaptation is expected to be more beneficial for wheat and rice than for maize. Out of the different adaptation strategies considered in the various studies (changes in planting dates, fertilizer application, irrigation, cultivars, and other agronomic adaptation), changes in crop varieties is found to be the most effective.

Some strategies of adaptation also have co-benefits. For instance, no-till practices help reduce soil erosion and runoff by increasing water infiltration and soil organic matter while also reducing GHG emissions. Growing legumes and managing weeds on pastures is also a good way of improving productivity while sequestering carbon in soils. Crop diversification also alleviates the impact of climate change and reduces market shocks.

## Limits to Adaptation

As the main limit to adaptation, Walthall et al., (2012) report highlights ecological constraints such as water quality and quantity and pollution, and social barriers such as the perceived need for adaptation, which is influenced by finances, political ideas, culture, and religious ideologies. Alternatively, some mechanisms could have unintended

negative effect on adaptation. For instance, subsidized crop insurance and disaster assistance may limit the adaptation response such as diversification, at added costs to these programs. Another concern related to agriculture and climate change is that biofuels and reforestation as mitigation strategy would compete with traditional agriculture for land, possibly having a greater impact on markets than the direct influence of climate (Reilly et al., 2012).

## For More Information

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." In *USDA Technical Bulletin* 1935.

Attavanich, W., and B. A. McCarl. 2014. "How Is Co2 Affecting Yields and Technological Progress? A Statistical Analysis." [In English]. *Climatic Change* 124, no. 4 : 747-62.

Challinor, A. J., J. Watson, D. B. Lobell, S. M. Howden, D. R. Smith, and N. Chhetri. 2014. "A Meta-Analysis of Crop Yield under Climate Change and Adaptation." *Nature Climate Change* 4, no. 4: 287-91.

FAO. 2002. "World Agriculture: Towards 2015/2030. Summary Report." Food and Agriculture Organization of the United Nations.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. "The Impact of Global Warming on Agriculture: A Ricardian Analysis." *American Economic Review* 84: 753-71.

Reilly, J., S. Paltsev, B. Felzer, X. Wang, D. Kicklighter, J. Melillo, R. Prinn, M. Sarofim, and C. Wang. 2007. "Global Economic Effects of Changes in Crops, Pasture, and Forests Due to Changing Climate, Carbon Dioxide, and Ozone." *Energy Policy* 35, no. 11: 5370-83.

Reilly, J.M., J. Melillo, Y. Cai, D. Kicklighter, A. Gurgel, S. Paltsev, T. Cronin, A. Sokolov, and A. Schlosser. 2012. "Using Land to Mitigate Climate Change: Hitting the Target, Recognizing the Trade-Offs." *Environmental Science and Technology* 46, no. 11: 5672-79.

Romero-Lankao, P., J. B. Smith, D. J. Davidson, N. S. Diffenbaugh, P. L. Kinney, P. Kirshen, P. Kovacs, and L. Villers-Ruiz. 2014. "North America." Chap. 26 In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change*, edited by V. R. Barros, C. B. Field, D. J.

## U.S. Exports at Risk

Productivity of the major crops in the United States is expected to be affected by climate change. Although the United States has no food security issues, it is a major exporter of food crops and a decrease in crop yields could have serious implications for global food security. Adaptation has the potential to alleviate these yield losses, but ultimately, as stated by USDA in Walthall, et al. (2012): "the vulnerability of agriculture to climatic change is strongly dependent on the responses taken by humans to moderate the effects of climate change."

Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, et al., 1439-98. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Rosenzweig, C., J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. Thorburn, J. M. Antle, et al. 2013. "The Agricultural Model Intercomparison and Improvement Project (Agmip): Protocols and Pilot Studies." *Agricultural and Forest Meteorology* 170: 166-82.

Schlenker, W. and M. J. Roberts. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences of the United States of America* 106, no. 37: 15594-98.

United Kingdom Met Office. 2011. "Climate: Observations, Projections and Impacts."

United States Global Change Research Program. 2009. "Global Climate Change Impacts in the United States."

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