

Crop Adaptation to Climate Change

Adaptation to Climate Change

by Caron Gala Bijl and Madeline Fisher

Editor's note: The following article was adapted from an official CSSA position statement, "Crop Adaptation to Climate Change," which is available online at www.crops.org/science-policy/position. The statement has been approved and adopted by the CSSA Science Policy Committee and was developed by a working group of the committee. The working group consisted of Charlie Messina, S.E. Taylor, Renee Lafitte, Rebecca L. McCulley, Mark E. Westgate, James E. Specht, Kenneth J. Boote, Seth C. Murray, Amir M.H. Ibrahim, Caron Gala Bijl, & Karl Glasener.

Throughout history, farmers have adopted new crop varieties and adjusted their practices in

accordance with changes in the environment. But as global temperatures continue to rise, the pace of environmental change will likely be unprecedented. More frequent and intense precipitation events, elevated temperatures, drought, and other types of damaging weather are all expected to take tolls on crop yield and quality, making the challenge of feeding an estimated 9 billion people by 2050 exceedingly difficult.

Extreme weather events are already affecting agricultural systems around the world. For example, after a 10-year drought, Australia experienced catastrophic floods last fall and winter, leading to the loss of an estimated \$6 billion in grain harvests. Unpredictable and severe weather can also leave the most volatile regions of the world even more vulnerable to instability due to greater hunger and poverty. Thus, learning to adapt our food production systems to a rapidly changing climate is critical to ensuring global food security and political stability.

In light of this, CSSA has developed and adopted a position statement: "Crop Adaptation to Climate Change." Researched and assembled by a working group of scientists from academia and industry, the statement (i) reviews the impacts of variable weather conditions arising from climate change on cropping systems, (ii) reports the progress to date in adapting crops and management practices to new conditions, and (iii) offers focus areas for increasing the speed at which global agricultural systems can adapt to climate change.

The goal is to offer guidance and priorities to federal agencies and private foundations funding research and development, policy makers, the scientific community, and economic sectors as they determine the avenues to best address the pressures facing agriculture today while also developing plans to optimize tomorrow's cropping systems.

"Thanks to the many participating scientists for developing a strong vision of the capacity, value, and role for CSSA in meeting the challenges of

climate change through crop adaptation,” says Texas A&M University soil and crop scientist David Baltensperger, who is the CSSA’s Science Policy Committee chair. “Their efforts represent a framework from which to make funding decisions on long-term investments to secure our food supply in the face of climate change.”

A summary of the position statement follows.

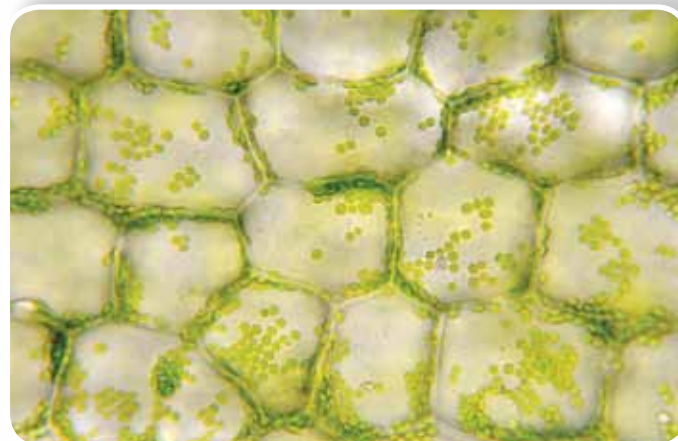
How Will Climate Change Affect Cropping Systems?

Beyond its direct effects on weather, climate change will increase both abiotic stresses, such as drought, and biotic stresses, such as pest pressure, on agricultural systems. Of greatest concern and largely unknown are the influences that interactions among different types of stresses will have on crops.



season. Current temperatures in the American Midwest are optimum for production, while southern U.S. temperatures already exceed the optimum. Temperature events higher than normal are expected to reduce cereal and grain legume yields. Elevated temperatures are known to shorten the grain-filling period, for example, and to reduce pollen viability and weight gain in grain. Moreover, elevated temperature changes can result in warmer, less severe winters, which sometimes allow diseases and pests to survive and overwinter, increasing the likelihood of reduced yield the next cropping season. For all of these reasons, adapting crops and cropping systems to new seasonal fluctuations and temperatures will require region-specific strategies.

Carbon dioxide (CO₂) is fundamental to crop carbohydrate production (important for crop productivity and yield) and overall plant metabolism. It also plays an important role in climate change. Atmospheric CO₂ concentrations have risen dramatically over the past 200 years



Drought is expected to limit the productivity of more than half of the earth’s arable land in the next 50 years, and competition for water between urban and agricultural areas will compound the problem. While the use of brackish and saline water could also help alleviate the world’s water problems, this option is only possible with the development of salt-tolerant crops or management practices that alleviate salt stress. As a result, to limit the impact of drought, there is an urgent need for crop varieties and cropping systems that conserve water and retain yield during periods of water scarcity. Developing these crops is difficult, however, because of the interplay of crop response systems to drought at the genomic, metabolic, biochemical, and physiological levels. To make drought-tolerant varieties available to farmers, interdisciplinary teams of scientists working at the cellular, plant, and field scales must work together to discover ways to manipulate these complex, multi-level processes and improve crop response.

Temperature influences the growth and development of all crops, shaping potential yield throughout the growing

and may reach 450–1000 μmol by the end of this century, according to the Intergovernmental Panel on Climate Change. Rising CO₂ levels will likely boost the overall productivity of many crops, although important tropical grasses like maize, sugarcane, and sorghum and some cellulosic biofuel crops don’t respond as well to elevated CO₂ levels. Increases in productivity could be offset, though, by pressures such as insect and fungal pests, ozone, and more variable precipitation, although the degree to which this occurs will depend on the physiology and biochemistry of each crop.

Ozone, an important greenhouse gas and agricultural pollutant, continues to increase because of fossil fuel combustion. Crops take ozone into their leaves during photosynthesis, where the gas lowers photosynthetic rates and accelerates leaf death, affecting crop maturity and productivity. Present-day global yield losses due to ozone are estimated at approximately 10% for wheat and soybean and 3–5% for rice and maize.

Biological stresses on cropping systems include weeds, insects, viruses, bacteria, and fungi. Temperature is consid-

ered the most important factor in determining how insects affect crop production and yield, and some populations of insect species, such as flea beetles, are showing signs of overwintering because of warmer winter temperatures. Viral, bacterial, and fungal pathogens also respond greatly to temperature as well as to humidity and rainfall. Thus, as the growing season lengthens and winters moderate due to climate change, pressures from plant, microbial, and insect pests are expected to rise due to an increased capacity for overwintering, greater movement of organisms, and expanded adaptation zones.

The climate has always been in a state of flux, but the current rate of change is much faster, and the range of weather variables much broader than ever seen before in modern agriculture. Today, two primary approaches for adapting crops to these conditions exist: (i) improving existing crop cultivars and developing new crops and (ii) devising new cropping systems and methods for



managing crops in the field. These approaches include the specific strategies discussed below.

Strategies for Improving Existing Cultivars and Developing New Crops

Integrate beneficial traits into existing crops through use of germplasm collections, related datasets, and breeding. Historically, crop scientists have identified and selectively adapted crops to exhibit desirable traits that allow them to achieve optimum yields while withstanding stresses, such as drought, heat, and water-logging. The success and speed of breeding efforts depend, however, on the ability of breeders to access optimal germplasm and quality information about germplasm material. Today's breeders rely on genetic and environmental information in both private and public germplasm collections, such as the USDA's public National Plant Germplasm System. To support continuous improvement of germplasm that can be used to develop cultivars adapted to climate change, there

is a need to acquire, preserve, evaluate, document, and distribute plant genetic resources for a wide range of crops and their wild relatives. In addition, biotechnology methods that allow scientists to screen crop traits are already changing how germplasm banks are used. Expanded use of these resources and methods will help researchers more quickly identify adaptive traits, represented by genes or groups of genes, which contribute to stress resistance.

Identify crop germplasm that tolerates stresses related to climate change. Yield drops when crops experience drought, excessive heat, or surplus water deviating from the optimum for growth during key stages, including pollination, flowering, and filling periods, when carbohydrates and nutrients assimilate inside grain, tubers, or fruit. Cultivars are now being developed that tolerate excessive heat during pollination for cowpea and corn and flooding early in the growing season for soybean and rice. Maize hybrids are also being developed that show better synchronization of pollination and flowering under heat and water stress. Even so, we have only accessed a small portion of the vast information available about abiotic stress tolerance because information and research is often limited to the most prominent crops; broader investigations and datasets are needed.

Concerted efforts are needed for the screening of crop germplasm for susceptibility to many biotic and abiotic stresses. U.S. farmers already experience significant yield losses from pests despite the use of improved crop varieties and agrichemicals for pest and pathogen control. As the climate changes and becomes more variable, the interactions among crops, pests, and pathogens will likely become even more complex and need to be studied. Continued work in this area will provide new germplasm material for plant breeders to incorporate into adapted varieties that are productive for farmers.

Employ new mapping and cataloging techniques. Rapid, high-throughput screening of crop genetic material and other new methods are now possible because of computer imaging, robotics, and supercomputers. These technologies allow researchers to identify adaptive traits expressed in different environments more quickly and increase the probability of finding key clusters or groups of genes that control traits for resistance to drought and other abiotic stresses. As the cost of genome sequencing drops, researchers will also be able to sequence more than one cultivar per crop. This will allow them to uncover the genomic basis of water, resource, and nutrient-use efficiencies and identify locations on the genome where breeders have most successfully selected and bred for adaptive traits in the past. Moreover, genome-wide prediction and breeding simulations are helping breeders make better selections in their programs because they can better predict the outcome of breeding decisions. Overall, high-throughput screening combined with advanced genomics and prediction methods will allow crop scientists to develop

cultivars adapted to new environments at a faster pace, broadening the options for farmers.

Develop new crops. New crops will likely play a key role in maintaining and increasing agricultural production. Domestication began only 5,000 to 12,000 years ago for our oldest crops such as maize, wheat, potatoes, and sorghum while blueberries and wild rice were domesticated more recently. Development and domestication of crops has enabled us to modify them to optimize yield and nutritional qualities. Today, some scientists are crossing perennial relatives of crops such as maize, millet, rice, sorghum, sunflower, and wheat with their annual, domesticated counterparts for use in developing perennial grain crops. Additionally, a growing interest in bioenergy has also encouraged the domestication and breeding of C₄ grasses, including switchgrass, and miscanthus. Domestication and breeding of new



crops is a long-term solution, requiring many years of effort before formal testing can be performed.

Expand field-level evaluations of crop germplasm. The modern crop breeder's toolkit, which provides access to global genetic resources and technology, combined with large-scale field-level research, will help uncover previously unknown genetic sources and regions on DNA associated with abiotic stress tolerance. Overcoming the knowledge gap related to abiotic stress tolerance will enable both applied and basic researchers to develop long-term strategies that maximize delivery of new, improved cultivars. Therefore, field-based research programs and related breeding efforts must be supported, integrated, and expanded to engage the full spectrum of crop development scientists, including breeders, physiologists, and geneticists.

Strategies for Devising New Systems and Methods for Managing Crops

New management systems are being developed to increase crop resilience toward climatic stresses and maintain

productivity and yield. Because agriculture will not experience the same vulnerability to climate change in all regions, site-specific cropping systems and management practices are needed that match yield potential with inputs, soil fertility, and the range of climate variability in each area.

Growers have needed to modify cropping systems in the past, of course, either in response to gradual climate change or as crops were moved into new geographical regions. This process of adaptation required extensive trial and error, disrupting farm economies and sometimes food supplies. However, research and development in the public and private sectors provides information allowing producers to adapt more fluidly. Research technologies and management tools that can accelerate the adaptation of cropping systems include simulation modeling and remote sensing. These technologies, combined with faster and better communica-



tion of location-specific recommendations, will likely help minimize the negative economic impacts that can otherwise accompany *ad hoc*, untested changes in cropping systems.

Use crop models in decision-making. Crop models integrate important information about processes and allow scientists to estimate the impact of changes in crop genetics and crop and soil management methods. Crop models can also be used to compare crop management strategies, helping producers weigh both economic and environmental considerations as they make decisions about crop varieties, cropping dates, and management practices.

Apply remote sensing and precision agriculture technologies. Remote sensing using both satellite and on-the-go field equipment scanners can reduce the resources needed to measure crop characteristics like cover, leaf greenness, growth rate, and biomass across a broad range of cropping systems and environments. This information then allows researchers to assess the effectiveness of modifications in cropping systems and can help producers make precision agriculture production decisions. These tools will be of great use in understanding the effects of a changing envi-

ronment at the field scale and the appropriate agronomic methods needed to respond to such changes.

Monitor crop condition. Short- and long-term monitoring of factors such as pathogens, changes in field conditions, crop productivity, and weather patterns is essential for building an information base on which future decisions and innovations can draw. Remote sensing of crop, weather, and pest conditions, for example, can be used by farmers for adaptive management or by governments as an early warning signal for climate-based food security crises. Databases also permit modeling of both biotic and abiotic climate change effects on crops in specific regions. In short, long-term monitoring is needed to develop strategies for crop/cultivar deployment and associated management practices that offer farmers the best chance for a productive harvest.



Optimize water-use efficiency. With climate change, water supplies are expected to become threatened in certain regions of the world, but water management strategies, such as drip irrigation, can conserve water and protect vulnerable crops from water shortages. To evaluate the effectiveness of these practices, agronomists often calculate the amount of crop yield per unit of water, or water productivity. Also known as achieving “more crop per drop,” water productivity can be improved through advances in cultivars, plant nutrition, irrigation practices based on real-time crop need, and better drought and heat tolerance in crops grown in rain-fed systems.

Optimize land use. Sustainable yield intensification uses existing arable land more efficiently and avoids bringing new land into production. Higher yields have also been shown to reduce greenhouse gas emissions, thus helping minimize agriculture’s contribution to climate change.

Climate change has far-reaching implications for food security, health, and safety. The impacts of climate change are in fact already becoming evident, and there is no

indication that these trends will reverse in the foreseeable future. Action must therefore be taken now to adapt crops and cropping systems in a timely manner and prevent unpredictable and undesirable outcomes. New crop varieties, cropping systems, and agricultural management strategies are needed that provide farmers with options for counterweighing climate changes.

Needs for the Future

This CSSA position statement identifies the challenges that crop science can address to adapt cropping systems to climate change in the short term. However, uncertainties and limited predictability in the long term require an infrastructure that drives innovation and implements crop adaptation strategies in a sustainable manner. In particular, research investments and efforts are needed to further:

- understand the physiological, genetic, and molecular basis of adaptation to drought, heat, and biotic stresses likely resulting from climate change;
- translate new knowledge into new agricultural systems that integrate genetic and management technologies. In other words, both breeding and agronomy will contribute to adaptation;
- transfer knowledge effectively and make technologies and innovations widely available to increase food production and stability.

CSSA recognizes that both private- and public-sector research and development are fundamental to building a sustainable approach to crop adaptation to climate change. Collaboration and communication between these sectors is also essential to create knowledge and develop and transfer new technologies. Although the contributions of government, universities, and industry may vary with crop, region, and time, the roles of each can be tailored appropriately.

While both private- and public-sector research is vital to improving crops and production systems, the government of the United States—in the form of the land grant university system—plays another critical role: It trains the next generation of crop scientists, agronomists, breeders, and growers. Without these human resources, society will have little or no capacity to adapt to climate change.

In summary, CSSA finds that an effective, planned response to climate change must include provisions for significant investments in and strengthening of crop science research that provides knowledge and information on adapting cropping systems to our changing environment.

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