Agriculture in a Changing Climate

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More than 90 percent of the world's food supply consists of agricultural crops or meat from farm animals raised on vegetarian feeds, according to The Research Council of Norway. By midcentury, the group says, farmers must produce 70 per cent more food on about the same area of farmland to keep pace with global population growth. The changing climate greatly increases difficulties in meeting this challenge. The US Department of Agriculture predicts that beyond the midcentury, climate change will detrimentally affect most crops and livestock.

Increasing amounts of carbon dioxide and other greenhouse gases increase the capacity of the atmosphere to retain heat. The higher temperature of the atmosphere heats the planet surface. Since 1900, the world's average surface temperature has risen by about 0.74°C. According to the USDA, the average temperature is predicted to warm another 1.9 to 5°C during the next century.

Effects of Climate Change on Crops

Higher maximum and minimum temperatures affect crop yields. Above a threshold, a higher air temperature adversely affects the growth of plants, as well as pollination and plant reproductive processes. Negative effects on plant growth and grain production can accelerate as the temperature rises above the optimum. A higher minimum temperature affects a plant's respiration rate at night, and can reduce crop yield and biomass accumulation. Higher temperatures also reduce productivity due to higher soil evaporation rates. The United Nation's Intergovernmental Panel on Climate Change predicts that yields of corn, wheat, and rice will probably start to drop by 2030. These three crops account for more than 60% of global food production from plants.

Unpredictable rainfall patterns are another facet of climate change. The Intergovernmental Panel on Climate Change predicts that precipitation will increase in high latitudes, and decrease in most subtropical low latitude regions. Extremes of rainfall changes – droughts and floods – clearly affect crop yield by damaging plants. Yet changes in rainfall patterns produce other deleterious effects. Excess precipitation erodes the soil and leaches nutrients from soil, whereas a decline in precipitation decreases soil moisture.

Climate change also produces indirect effects on crops. According to the US Environmental Protection Agency, farmers probably will face new challenges as weeds, pathogens, and insect pests expand their ranges to the warming north. High levels of atmospheric carbon dioxide promote the rapid growth of invasive weeds.

Effects of Climate Change on Livestock

Increasing temperatures threaten animal health. An increase in core body temperature in excess of 2°C to 3°C can disrupt fertility, increase vulnerability to disease, and limit an animal's ability to produce meat, milk, or eggs. An increase of 5°C to 7°C can kill an animal. Higher average temperatures, hotter daily maximums, and more frequent heat waves, produce heat stress. The effects of heat stress include changes in respiration, heart rate, and hormones. Animals dealing with heat stress usually drink more water and reduce the amount of dry food that they eat. This in turn, affects the animal's health and decreases weight gain.

Although heat stress may be the most significant threat to animals, climate change creates other problems. Drought decreases the quantity and quality of available feed. Increases in carbon dioxide can decrease the quality of forage, requiring cattle to eat more to obtain the same amount of nutrients. Warmer and more humid conditions promote the prevalence of parasites and pathogens.

Adapting Agricultural Practices to Climate Change

The USDA suggests methods that farmers can use to adapt to climate change in the near-term. For example, heat stress on animals can be mitigated by energy-efficient cooling for animal housing. Changing feed rations for dairy and beef cattle can reduce effects of heat stress. Animals experiencing heat stress tend to diminish feed intake at a time when they need more energy for physiological maintenance. The agency recommends feed with increased nutritional quality and lower fiber content. "In the future," says the USDA on its Climate Hubs Website, "producers may consider selecting breeds and breed types that are genetically adapted to changed climate conditions."

To ensure productivity of their fields, the USDA offers a variety of adaptation strategies that growers can use. These include changes in cultivar selection, the timing of field operations, irrigation methods, fertilization practices, and tillage practices.

New types of genetically engineered (GE) crops provide one tactic for meeting the challenge of increasingly radical climate changes. "I don't believe that gene technology or GMOs alone will save the world, but they will be part of the solution in certain areas," Atle Bones told Biotek og mat. Bones, a professor of biology at the Norwegian University of Science and Technology in Trondheim, explained that "[s]ome changes, such as climatic ones, are going to happen rapidly, so we don't have time to wait the many years it would take with conventional selection to introduce the desired traits into our crop varieties."

Engineering Crops for a Changing Environment

Researchers have genetically engineered plants that can survive in the face of decreased rainfall, one of the abiotic stresses that accompany climate change. Plants react to drought by initiating a complex cascade of responses to protect cells against the effects of desiccation and prevent water loss. The variety of methods used by plants to manage drought stress is reflected by the range of tactics that researchers use to engineer drought-tolerant plants.

The first GE drought-tolerant crop approved for sale in multiple countries is Monsanto Company's DroughtGard® Corn (MON 87460). The GE plant has a cold-shock protein B (CSPB) gene derived from *Bacillus subtilis*. CSPB protein, an RNA chaperone, appears to support a plant's cellular functions by binding cellular RNA and unfolding untranslatable secondary structures that disrupt RNA stability and translation. As a result, CSPB protein minimizes the effects of drought on many cellular functions, including photosynthesis.

During 2015, Argentina's Ministry of Agriculture, Livestock and Fisheries approved soybeans engineered to tolerate drought. The GE soybeans are a product of Verdeca, a joint venture between Bioceres (Rosario, Argentina) and Arcadia Biosciences (Davis, CA). Cells of the engineered soybeans overexpress sunflower Hahb-4, a homeodomain–leucine zipper transcription factor, which delays or blocks ethylene-induced senescence, while allowing ethylene to regulate leaf stomatal opening. The delay in senescence may enable plant cells to produce osmoprotectants that improve drought tolerance.

Researchers at DuPont Pioneer (Johnston, IA) also are genetically modifying ethylene production. They developed GE corn that downregulates ethylene synthesis, resulting in an increase of grain yield after exposure to drought stress.

In a plant exposed to water stress, glycine betaine acts as an osmoprotectant by stabilizing the integrity and function of cellular membranes. Indonesia's National Genetically Modified Product Biosafety Commission approved GE sugarcane that carries a *Rhizobium meliloti betA* gene, which encodes choline dehydrogenase. The enzyme converts choline into betaine aldehyde, which in turn is converted to glycine betaine by betaine aldehyde dehydrogenase.

Plants respond to drought stress by synthesizing abscisic acid, which triggers guard cells surrounding plant leaf stomata to close and limit water loss. Researchers at Performance Plants (Ontario, Canada) use RNA interference to downregulate farnesyltransferase in canola, corn, and rice. This results in abscisic acid hypersensitivity of guard cell anion-channel activation and closing of stomata. In the GE plants, RNA interference is controlled by a drought-inducible promoter. Consequently, normal stomatal function is restored after a drought has ended.

The genetic modification of plants to increase heat tolerance often focuses on methods to protect plant cells from injury. One strategy is to engineer plants that overexpress heat shock genes. Heat shock proteins stabilize or refold proteins that have become denatured during heat stress; they prevent protein aggregation. Another tactic is to alleviate the rapid accumulation of reactive oxygen species (ROS) in plant cells that occurs during high temperature stress. Transgenic plants with transgenes that express ROS detoxifying enzymes have a tolerance of high temperatures. Other targets for developing heat-tolerant transgenic plants include enzymes that regulate membrane fluidity and enzymes involved in osmolyte synthesis.

Plants are not exposed to either heat stress or drought stress in isolation. Studies reveal that plants respond to a combination of heat and drought stresses that cannot be directly extrapolated from the response of plants to each stress alone. Additional abiotic stresses, such as high salinity, and biotic stresses, such as new insect pests, complicate engineering of plants suited to the changing environment. As genetic engineers forge ahead to counter the effects of climate change on crops, they need to consider not only alterations in plant growth, but also possible changes in the characteristics of the plants. Nigel G. Halford (Rothamsted Research, Harpenden, Hertfordshire UK) and his colleagues at the Shanghai Academy of Agricultural Sciences warn that more research is required for "the identification of specific environmental stresses that affect grain composition in ways that have implications for food quality and safety."

Selected Sources

"Climate Impacts on Agriculture and Food Supply," *US EPA* Website (2012). Available at: http://www3.epa.gov.

"Focus on Livestock," *USDA Climate Hubs* Website (2015). Available at: http://climatehubs.oce.usda.gov.

Fugelsnes, Elin and Else Lie, "Food Crops Must Withstand Harsher Weather," *The Research Council of Norway* Website (October 7, 2011). Available at: http://www.forskningsradet.no.

Grover, Anil, Dheeraj Mittal, Manisha Negi, and Dhruv Lavania, "Generating High Temperature Tolerant Transgenic Plants: Achievements and Challenges," *Plant Science* 205–206: 38–47 (2013).

Halford, Nigel G., Tanya Y. Curtis, Zhiwei Chen, and Jianhua Huang, "Effects of Abiotic Stress and Crop Management on Cereal Grain Composition: Implications for Food Quality and Safety," *Journal of Experimental Botany*. 66(5):1145–1156 (2015).

Key, Nigel, Stacy Sneeringer, and David Marquardt, "Climate Change, Heat Stress, and U.S. Dairy Production," *USDA* Website (September 2014). Available at: http://www.ers.usda.gov.

Lavania, Dhruv, Anuradha Dhingra, Manzer H. Siddiqui, Mohamed H. Al-Whaibi, and Anil Grover, "Current Status of the Production of High Temperature Tolerant Transgenic Crops for Cultivation in Warmer Climates," *Plant Physiology and Biochemistry* 86: 100–108 (January 2015).

Meiszner, Peter, "Drought, Heat Take Toll on Global Crops," *The University of British Columbia* Website (January 6, 2016). Available at: http://news.ubc.ca.

"Pocket K No. 32: Biotechnology for the Development of Drought Tolerant Crops," *International Service for the Acquisition of Agri-biotech Applications* Website (March 2008). Available at: http://www.isaaa.org.

"Pocket K No. 43: Biotechnology and Climate Change," *ISAAA* Website (April 2013). Available at: http://www.isaaa.org.

Walthall, C.L., J. Hatfield, P. Backlund, R. Hauser, L. Lengnick, E. Marshall, and M. Walsh. "Climate Change and U.S. Agriculture: An Assessment of Effects and Adaptation Responses," *USDA* Website (September 2013). Available at: http://www.usda.gov.

Waltz, Emily, "Beating the Heat," *Nature Biotechnology* 32(7): 610–613 (July 2014).

Weiser, Matt, "Can Genetic Engineering Help Quench Crops' Thirst?" *ENSIA* Website (January 4, 2016). Available at: http://ensia.com.

Woolston, Chris, "These 5 Foods Will Be Harder to Grow in a Warmer World," *National Geographic* Website (April 7, 2014). Available at: http://news.nationalgeographic.com.

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