

Soybean and wheat response to climate change

By Stephanie Yao and Dennis O'Brien, Agricultural Research Service, USDA

"The whole process is complex and delicately controlled," says Richard, with the ARS Grain Marketing and Production Research Center in Manhattan, Kansas.

Around leg joints, for example, chitin's branched-chain structure must be enzymatically snipped in a way that allows for flexibility and movement. But around the head and thorax, where protection of vital organs is key, a heavier, stiffer chitin deposition is needed, requiring a different form of trimming as well as the activation of specific CDA-encoding genes.

Chitin also plays a role inside the beetle by lining its midgut as a buffer against ingested pathogens and abrasives and to create a vessel for digestion.

A biotech procedure called "RNA interference" has proven critical to demarcating the genes' roles. Using the method, "We can knock out the function of any one of these particular deacetylase genes and observe whether the insect can survive and exactly how its development is disrupted in the absence of each gene," says Richard, whose colleagues are Karl J. Kramer, ARS retired; and KSU researchers Yasuyuki Arakane, Khurshida Begum, Radhika Dixit, Yoonseong Park, and Subbaratnam Muthukrishnan.

Shutting off genes

In lab studies, the larvae of one CDA-deficient strain developed normally until becoming adult beetles, at which point improper chitin formation kept the middle leg joints from bending, making it impossible for the insects to walk, mate, or feed. In another strain, shutting off a different CDA gene prevented the insect from shedding its old skin, or exoskeleton.

Although not every CDA gene deficiency killed the beetles outright, the inability to digest a virus particle or bend a hind leg, for example, could doom such insects under natural conditions.

"The ultimate goal," says Richard, "is to identify which genes are essential to the insect. Beyond that, you can start thinking about ways of knocking them out for pest control."

One possibility is to formulate chitin-disabling biopesticides. Another is to engineer crop plants with anti-chitin proteins that will deter beetle feeding, or perhaps entomb them in their own skins.

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Global greenhouse gas emissions are projected to rise dramatically in the next 40 years, with increased outputs of carbon dioxide (CO₂) being the main culprit. In light of our changing environment, Agricultural Research Service scientists in Urbana, Illinois, and Raleigh, North Carolina, are examining how the increase in greenhouse gases, particularly CO₂ and ozone, will affect two of the world's most widely planted crops – soybeans and wheat.

Open-top chambers offer insight

At the Plant Science Research Unit in Raleigh, ARS plant physiologists Fitzgerald Booker, Kent Burkey, and Ed Fiscus are assessing how climate change will affect soybean and wheat growth rates, crop yield, and soil chemistry by exposing the crops to the elevated levels of CO₂ and ozone projected for the year 2050.

Soybeans, wheat, and other crops grow more when CO₂ levels are elevated, because there is more carbon captured during photosynthesis for the plants to use.

But those same plants are damaged and stunted by elevated levels of ground-level ozone, a gas created when sunlight 'cooks' automotive and industrial pollutants that

originate from combustion of carbon-based fuels.

Levels of both gases are rising. The Intergovernmental Panel on Climate Change, an international panel of highly regarded scientists, estimates that CO₂ levels could be about 1.5 times greater than the current 380 parts per million by 2050. The panel also estimates that daytime ozone in the summertime, now at about 50–55 parts per billion, may rise 20 per cent over the same period.

Besides assessing the effects of future air concentrations on both crops, the researchers are conducting a five-year project to determine whether a widely accepted no-till cropping system will improve soil quality and sequester carbon when levels of the gases rise.

"We know no-till increases carbon sequestration in the soil. The question is, What is going to happen with elevated levels of CO₂, and how are changes in other atmospheric gases, namely ozone, going to affect that?" Fitzgerald says.

The Raleigh researchers have 16 open-top chambers, divided into four treatments: four with elevated ozone, four with elevated CO₂, four with both gases elevated,



To assess oxidative stress in soybean grown at SoyFACE under elevated ozone concentrations, ARS molecular biologist Lisa Ainsworth (back) and graduate student Kelly Gillespie use a liquid-handling robot to perform a high-throughput assay. (PHOTO: Peggy Greb)



Plant physiologist Fitzgerald Booker prepares to place an optical scanner into a tube that will be positioned in the soil to photograph soybean roots. The photos will be analysed to determine changes in root length and distribution caused by exposure to elevated carbon dioxide and ozone, which are pumped into the open-top field chambers. (PHOTO: Peggy Greb)



ARS scientists Carl Bernacchi (left), Don Ort (center), and Lisa Ainsworth in a plot of soybeans treated with elevated carbon dioxide (CO₂) at the SoyFACE Global Change Research Facility at the University of Illinois Research Farm in Urbana. In the foreground is an automatic retractable awning used to capture rainfall in order to investigate the interaction of drought and elevated CO₂ on soybean. Behind the scientists is an array of infrared heaters used to raise the temperature of a portion of the plot to investigate interactions with anticipated global warming. (PHOTO: Institute for Genomic Biology/University of Illinois)

and four controls. They are pumping the chamber air with up to 40 per cent more ozone and CO₂ than what is found in today's ambient air. They are also charcoal-filtering the air so they can reduce ozone in the control chambers and tease out the impact that different ozone and CO₂ levels, by themselves, have on the plants.

In addition, the researchers are putting the postharvest residues, such as plant stems, empty pods, and dead leaves, back into the chambers, essentially making them small, self-contained plots that mimic conditions found in no-till systems.

To measure changes in the soil's carbon and nitrogen content makeup, the researchers take samples twice a year. The CO₂ pumped into the chambers has a specific isotope marker so they can track it from the air through the plants and into the soil.

They are analysing the soil cores by depth to determine where composition changes may occur and also the amount of bacteria and fungi found in each layer to see whether microorganism populations or communities change.

After completing three years of the project, preliminary results show a trend for higher levels of soil carbon in chambers with elevated CO₂ but not in chambers with elevated ozone. Elevating CO₂ also reduced protein levels in wheat flour by seven per cent to 11 per cent, but it had no effect on soybean seed protein.

SoyFACE: New technology, new understanding

Researchers in Urbana and coopera-

tors with the University of Illinois at Urbana-Champaign have been working on a project called "SoyFACE" – short for Soybean Free Air Concentration Enrichment – that also measures how the projected increases in CO₂ and ozone will affect soybean production.

FACE technology, which was first used for crop research by ARS soil scientist Bruce Kimball, ARS plant physiologist Jack Mauney (now retired), and scientists from the US Department of Energy's Brookhaven National Laboratory, allows testing of plants in open-air field conditions.

ARS scientists Don Ort, Lisa Ainsworth, and Carl Bernacchi, in the Photosynthesis Research Unit, and Randall Nelson, in the Soybean/Maize Germplasm, Pathology, and Genetics Research Unit, use the technology to produce atmospheric conditions predicted for the year 2050.

Horizontal pipes arranged in an octagon about 22 metres in diameter surround each test plot. A computer measures wind direction and speed, then releases concentrated amounts of CO₂ and ozone. The wind carries the gases across the soybean crop.

"At the start of the project, we sought to understand how CO₂ and ozone affect soybean independently," says Don. "We found soybean yield increases by about 12 per cent at the elevated CO₂ concentrations predicted for 2050, half of what previous studies estimated. We also found that increased ozone is quite harmful to yield, reducing it by about 20 per cent. In fact, our study showed current levels of ozone

are already suppressing soybean yield by up to 15 per cent."

The results of the individual studies led the scientists to examine the combined effects of CO₂ and ozone on soybean. They found that elevated CO₂ partially offsets the ozone damage. These findings with SoyFACE confirm general results obtained with open-top chamber studies of ozone and CO₂ effects on crop yield conducted at Raleigh and other locations.

But the ability of SoyFACE technology to test these principles in the open air, without the environmental modifications caused by the chambers themselves, means greater confidence in our understanding of how plants respond in the real world, including the actual estimates of impact on crop yields.

Furthermore, there is much to be learned about how other interacting factors that affect ozone uptake may come into play by mid-century.

The scientists recently began studying how combined factors will affect soybean production. They are looking at drought and increased temperature, drought and increased CO₂, and elevated temperature and CO₂. They'll also be analysing how microbial communities and soil carbon storage are affected by these changes.

These projects provide valuable information that will help breeders develop soybean cultivars better adapted to an ever-changing climate.

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