

PCIC SCIENCE BRIEF: PROJECTED CHANGES TO GRASSLANDS AND THREE US CROPS

Two recently published articles explore how projected changes to climate and carbon dioxide in the atmosphere may affect grasslands in temperate regions and three crops in the United States.

Addressing the first question in *Nature Climate Change*, Obermeier et al. (2017) find that the carbon dioxide fertilization effect¹ in C3 grasslands² is reduced when conditions are wetter, dryer or hotter than the conditions to which the grasses are adapted.

Publishing in *Nature Communications*, Schauberg et al. (2017) examine the second question. They find that yields for wheat, soy and corn decline at projected temperatures greater than 30°C, with reductions in yield of 22% for wheat, 40% for soy and 49% for corn. While carbon fertilization does reduce the loss in yields, the effect is much smaller than that of irrigation, suggesting that water stress at higher temperatures may be largely responsible for losses.

The increasing amount of carbon dioxide in Earth's atmosphere influences plants on our planet's surface both directly and indirectly. The direct effect arises through carbon fertilization, as plants can more easily draw down carbon from the atmosphere. The indirect effects arise primarily through the influence of carbon dioxide on the Earth's climate, which can cause changes in temperature, precipitation and the frequency and magnitude of extreme weather events. We can already see the impacts of these effects in the greening of the land's surface³, shifts in the latitude and elevation of vegetation⁴ and crop yields⁵. This raises important questions about how these forces will continue to impact ecosystems and agricultural yields in the future.

Environmental variable	Wetter conditions		Drier conditions	
Air temperature	—	↑	↑	↑
Solar radiation	↑	↑	↑	↑
Wind speed	↑	↑	↑	↑
Vapour pressure deficit	—	↑	↑	↑
Rainfall	—	—	↑	↑
Groundwater table	—	↑	↑	—

CO₂ fertilization — Not significant ↑ Weak ↑ Strong
 Low ← Variable value → High

Figure 1: Effect of different environmental conditions on carbon dioxide fertilization in C3 grasses, from Obermeier et al. (2017).

This figure shows how the strength of the carbon dioxide fertilization effect varied with the environmental conditions that the grass plots were exposed to in the three months before harvest. Black arrows indicate a strong fertilization effect, grey arrows a weak effect and dashes no effect. The background gradient indicates the value of a variable, such as temperature, with dark tones indicating a high value and light tones indicating a low value. Columns are ordered from wetter conditions, on the left, to drier conditions, on the right.

In their recent paper in *Nature Climate Change*, Obermeier et al. (2016) examine how carbon dioxide fertilization and a changing climate will effect temperate C3 grasslands. The researchers maintained six plots of temperate grassland in Germany for 16 years, exposing three to enhanced concentrations of carbon dioxide and allowing the other three to be exposed to the surrounding ambient carbon dioxide in the air. The plots were otherwise subject to the

1. Through photosynthesis, plants use carbon obtained from carbon dioxide in the air to build the organic molecules that they are made of. As the concentration of carbon dioxide in their environment increases, more carbon is available for the plants. This can cause an increase in the ease and rate of plant photosynthesis and thus an increase in plant biomass. This is called the carbon fertilization effect.
2. Plants use two forms of photosynthesis, dubbed C3 and C4. In C3 photosynthesis, which is generally favoured among plants living in cooler climates, one of the reactions between carbon dioxide and the plant's enzymes forms an acid with molecules built around three carbon atoms. In C4 photosynthesis, favoured by plants in hotter climates, one of the reactions forms an acid with four carbon atoms.
3. For more on the greening of the land's surface, see Zhu et al., 2016.
4. For a discussion of the changes in the latitude and elevation of plant types and vulnerability to future changes, see Gonzalez et al., 2010.
5. For further information on changes to crop yields as an impact of climate change, see IPCC 2014.

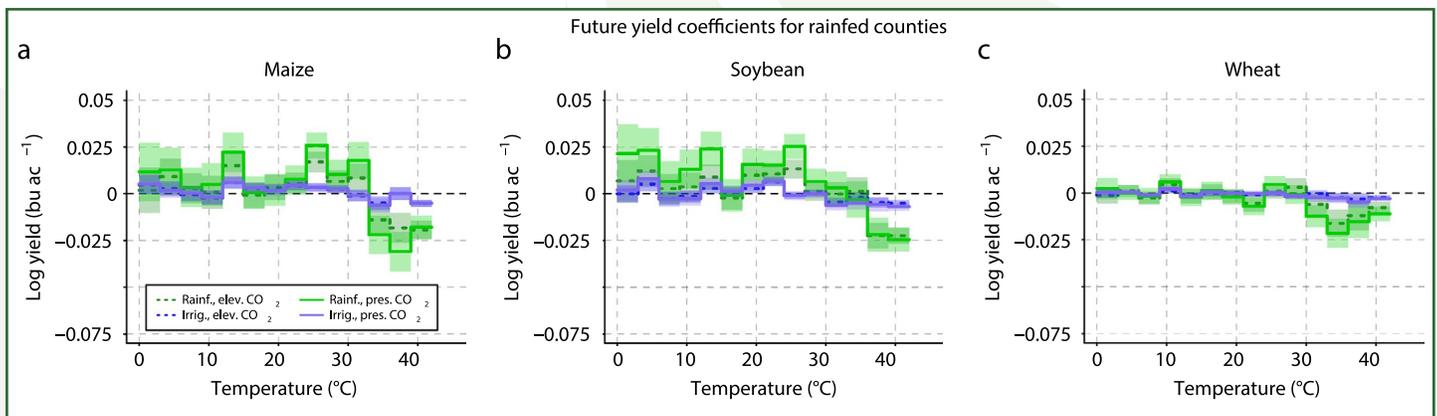


Figure 2: Simulated future yield responses of maize, soybean and wheat in rainfed regions from Schauberger et al. (2017). This figure shows the simulated future yield responses versus temperature for maize, soybean and wheat for rainfed regions in the United States from an ensemble of crop models. The yield response is per day that the crops are exposed to temperatures in the given range. These models were driven using the output of global climate models which were run using a business-as-usual emissions scenario. Dashed lines indicated elevated carbon dioxide concentrations, while solid lines indicate present-day levels. Blue lines indicate irrigation, while green lines indicate crops irrigated by rain alone.

weather conditions in the area. The researchers collected weather data from a station on the site and measured both the amount of carbon dioxide and the biomass of the grass growing in each ring. They used the harvested biomass to determine the strength of the carbon fertilization effect. They then determined how the strength of the carbon dioxide fertilization effect varied with changing temperature, solar radiation, wind speed, vapour pressure deficit⁶, rainfall and groundwater. The overall result is that the carbon fertilization effect was reduced when local weather conditions strayed beyond the normal conditions for the area to which the grass was adapted. Carbon fertilization was reduced when it was much drier or wetter than normal, when the groundwater table was much lower or higher, when the humidity strayed far from normal values, and when temperatures were much cooler or warmer than normal. Conversely, carbon fertilization was strongest when the conditions were close to normal for the three months before harvest. Some of these findings are summarized in Figure 1. Of particular interest, the carbon fertilization effect was reduced under both dryer conditions and hotter conditions. One might expect carbon fertilization to be especially valuable under dry conditions because the plants don't need to open the stomata in their leaves as much to gather sufficient carbon dioxide, meaning that less water escapes from their leaves. How-

ever, the authors do not observe a strong fertilization effect under dry conditions. This may be due to a decrease in the internal water pressure of the plant and a subsequent reduction in the transport of needed nutrients, such as nitrogen, from the soil to areas within the plants. One might also expect the fertilization effect to be more valuable at higher temperatures when the ratio of photosynthesis to photorespiration⁷ is higher, but again, this is not what the authors observe, potentially because the stomata don't need to open as wide to let carbon dioxide into the leaf, which reduces the amount of outgoing oxygen, allowing it to build up and increase the amount of photorespiration that occurs, which inhibits photosynthesis.

The authors conclude that carbon fertilization in C3 grasses will likely be weakened as climate change pushes weather outside of the realm of their normal historical conditions. This could reduce the ability of these grasses to act as a carbon sink.

Schauberger and coauthors (2017) recently explored a similar line of inquiry in *Nature Communications*, where they examine how climate change may affect US corn, a C4 plant, and soy and wheat, both C3 plants. To do this, the authors first gathered USDA crop data from 1980 to 2010 (to 2008 for wheat) and determined the relationship between yield and temperature over this period. The authors also used output from an ensemble of models that explic-

6. Vapour pressure deficit is a measure of the amount of water vapour in the air compared to the amount of water vapour that the air could hold if it were saturated, expressed in units of pressure. A low vapour pressure deficit means that the air is close to saturated, making it humid and difficult for a plant to transpire. A high vapour pressure deficit means that the air is far from saturated, indicating that it is dry and a plant can more easily transpire and dry out.

7. Photorespiration is a process that occurs in the plant's leaves when oxygen builds up that inhibits photosynthesis. Such a situation can occur when the plant's stomata are closed. During photorespiration, an enzyme in the plant that is normally used to convert carbon dioxide into an organic molecule needed by the plant instead converts carbon and oxygen into carbon dioxide.

itly represent some of the physiological processes of crops. They compared the output of these crop models with the USDA crop data in order to make sure that the models properly simulated the yield of the crops under high temperatures. Once this was confirmed, the researchers used output from global climate models, run under a business-as-usual emissions scenario, to drive the crop models and make projections of potential future yields over the 2071 to 2099 period.

Using the climate model output and the relationship between yields and temperature in observational data, the authors found that yields of all three crops could be reduced due to increased exposure to temperatures between 30°C and 36°C by the end of the century. The losses varied by plant type, with yield losses of 22% for wheat, 40% for soy and 49% for corn. Because the crop models can reliably simulate the effects of these temperatures on crop yields, the authors then examined the projections from the crop models to unfurl the individual roles of factors such as water stress, atmospheric carbon dioxide concentration and temperature. Crucially, while the yield reductions were not counterbalanced by increased carbon dioxide, they can be offset by irrigation (Figure 2). Schauburger et al.'s results suggest that the yield losses are being caused by water stress as temperatures increase. A couple of effects may be responsible.

As temperatures rise, more water evaporates from the soil, reducing the amount available to the plants. At the same time, when plants have sufficient water available, they tend to open the pores in their leaves as temperatures increase, in order to cool themselves by transpiring, which increases the plant's water use. These cause increased water loss. The plants and soil are drying out as the plants' water needs are increased. If the plants experience water stress as their water supply is depleted, their stomata start to close, reducing the amount of carbon dioxide they can take in and reducing the amount of photosynthesis taking place in their leaves. While elevated carbon dioxide concentrations can increase water use efficiency as discussed earlier, this does not offset the effects of episodic, temperature-induced water stress, which the authors suggest may be due in part to the increase in biomass and leaf area in high carbon-dioxide environments and the resulting increase in water needed for transpiration. At higher temperatures, starting at about 35°C and up, the plants are expected to wilt from direct damage to their enzymes and tissues, but these are not explicitly represented in the models that the authors used and so this was not one of the primary causes of yield loss in their study. The authors

also find that changes to respiration and maturity times were not likely to be responsible. Schauburger et al.'s results do not include the use of adaptation options such as management, fertilizer application rates and changing the type of crop being grown in a given area.

While irrigation could offset some of the yield reductions, irrigation itself is dependent on water availability. Water availability is, in turn, dependent on other factors, such as weather, competition for water for other uses and the volume and accessibility of groundwater reserves. In areas where irrigation potential is limited, farmers may have to allow their crops to be rain-fed, suffering the lower yield. Crop belts may also simply follow the cooler weather northward provided soil conditions allow this form of adaptation.

In British Columbia, grasslands make up only about one percent of the province's area. They are located mostly in the southern interior region and are largely an extension of the Great Basin Steppe Grasslands of the United States. Agricultural land extends over about five percent of the province, stretching in patches from the southern border to the area surrounding Fort Nelson in the north. BC grasslands are already under pressure from forest encroachment, urban and agricultural development, and the introduction of invasive species. They are also a mix of C3 and C4 grasses. The province is projected to warm several degrees over this century, depending on the emissions trajectory considered, and Obermeier et al.'s results suggest that the carbon dioxide fertilization effect on C3 grasses in the province may be reduced as temperatures increase, potentially reducing the productivity of these areas and their ability to act as a carbon sink.

A little over half of British Columbia's food is imported, much of that from the United States. So, changes in agricultural productivity south of the border may affect food prices and availability in the province. A northward shift of the crop belts would affect Canadian farmers, changing the crops that are viable for them to grow in each region. This could also affect food prices as well as the economies of agricultural areas.

- Gonzalez, P., et al., 2010: Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography*, **19**, 755–768, doi:10.1111/j.1466-8238.2010.00558.x.
- IPCC, 2014: Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

Obermeier, W.A. et al., 2017: Reduced CO₂ fertilization effect in temperate C₃ grasslands under more extreme weather conditions. *Nature Climate Change*, **7**, 137–141, doi:10.1038/nclimate3191.

Schauberger, B. et al., 2017: Consistent negative response of US crops to high temperatures in observations and crop models. *Nature Communications*, **8**, 13931, doi:10.1038/ncomms13931.

Zhu, Z., et. al., 2016: Greening of the Earth and its drivers. *Nature Climate Change*, **6**, 791–795, doi:10.1038/nclimate3004.