Stratospheric Aerosol Climate Intervention Could Reduce the Nutritional Value of Maize and Rice

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Abstract

Placing reflective sulfate aerosols in the stratosphere to reduce surface temperatures and minimize the impacts of climate change would create an unprecedented climate where the relationship between surface temperatures and carbon dioxide concentrations are decoupled. The implications of this intervention for global crop protein concentrations have not yet been explored. While elevated CO_2 concentrations are expected to reduce crop protein [1], higher temperatures may increase crop protein concentrations [2-3]. Here we report changes to global wheat, rice, soybean, and maize protein concentrations under climate change and sulfate aerosol climate intervention simulated by three global gridded crop models. We find that maintaining elevated CO_2 while reducing surface temperature increases with sulfate aerosol intervention would create small decreases to the protein concentrations of maize and rice, while wheat and soybean are minimally impacted. These decreases to protein under climate intervention relative to climate change partially offset any benefits to maize and rice yield.

Introduction

Enhanced crop growth due to elevated CO_2 fertilization is accompanied by reduced concentrations of other elements, such as nitrogen [4], which is an indicator for crop protein content. There is evidence that elevated CO_2 concentrations have the potential to reduce the protein content of major food crops [1]. There is also growing evidence that rising temperatures could have a positive impact on crop protein by enhancing nitrogen uptake and translocation through increased transpiration, as well as by accelerating nitrogen mineralization and plant metabolic rates [2-3]. Since SAI decreases surface temperatures while maintaining elevated CO_2, it has the potential to reduce crop protein content below what may be seen with climate change alone.

Methods

This analysis uses atmospheric forcing output from the Community Earth System Model, Whole Atmosphere Community Climate Model (CESM2-WACCM6) to force three global gridded crop models: CLM-crop [5], LPJ-GUESS [6], and pDSSAT [7]. Climate change scenario SSP2-4.5 was followed with SAI used to maintain 1.5 °C above preindustrial levels (ARISE-SAI-1.5) [8]. Crop model simulations were run offline at half degree resolution with crop area and fertilizer application constant at 2015 values, so impacts on crop protein are due to climate impacts alone. Crop protein content is estimated from simulated C:N ratios of crop grain. Crop protein yields are calculated by multiplying simulated crop yields by simulated protein content.

Results

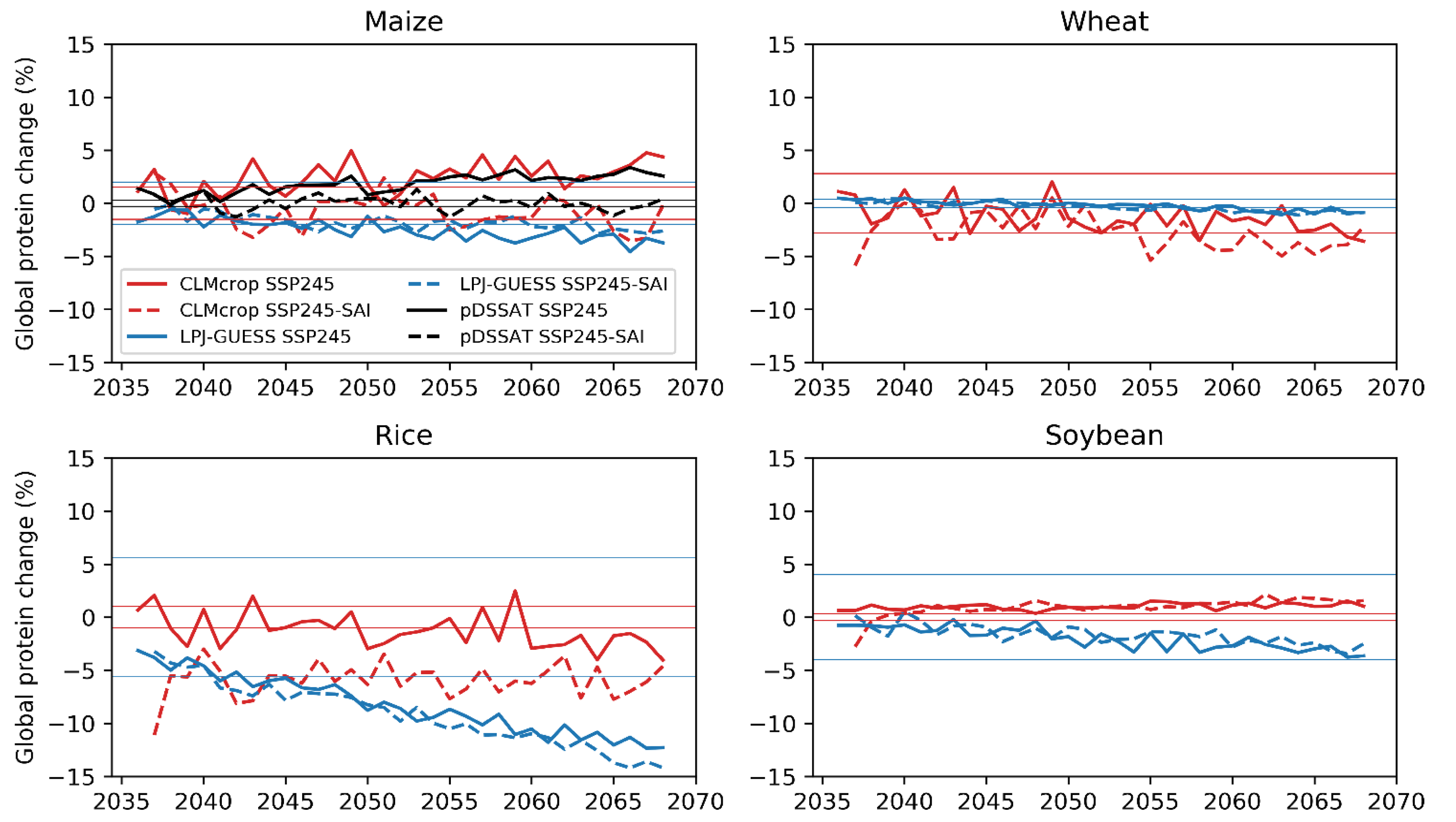

Figure 1. The annual time series of changes to global average crop protein content (Grain N:C) for maize, rice, soybean, and wheat as simulated by CLMcrop, LPJ-GUESS, and pDSSAT under SSP2-4.5 and SAI relative to the reference period (2016-2025). Horizontal lines indicate ± one standard deviation of crop protein under the reference period for each model and crop.

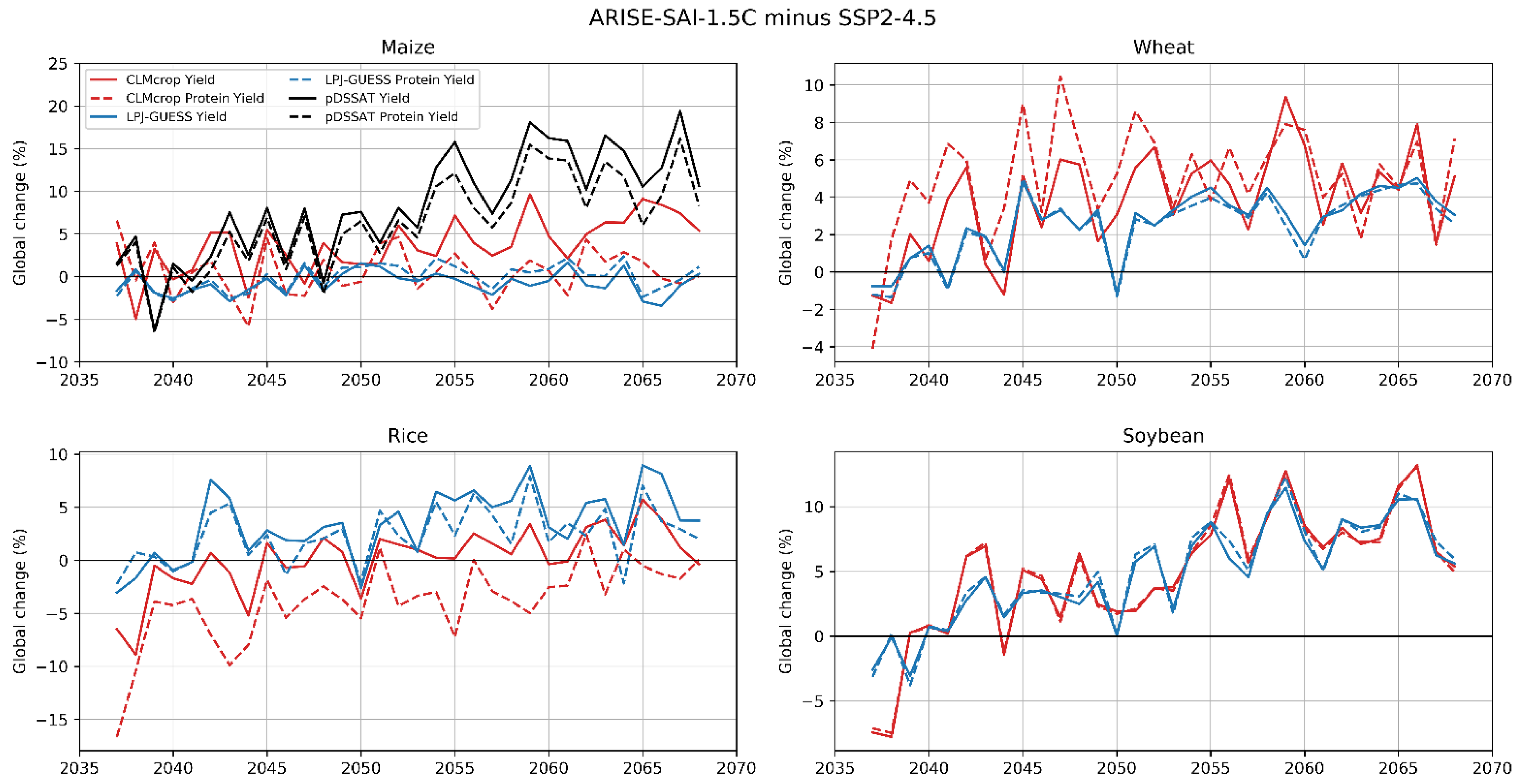

Figure 2. Time series of changes to global average yield and protein yield under SAI minus SSP2-4.5 for CLMcrop, LPJ-GUESS, and pDSSAT. Protein yield = (yield) * (protein content)

SAI decreases the protein content of global maize, wheat, and rice in CLMcrop relative to both climate change and the reference period (Figure 1). There is also a decrease to maize protein in pDSSAT by about 5% towards the end of the century under SAI relative to climate change (Figure 1). LPJ-GUESS shows very small differences to the protein content of all four crops under SAI and climate change (Figure 1). Accounting for changes to protein causes protein yields to be reduced under SAI in CLMcrop and pDSSAT (Figure 2). Rice protein yields are also decreased in CLMcrop (Figure 2). This makes the total impact of SAI on maize and rice negligible in CLMcrop, rather than being a benefit to yields when not accounting for protein (Figure 2).

Maize Protein	pDSSAT	LPJ-GUESS	CLMcrop
Malawi	-1.5	1.7	-15.5
Mexico	-2.5	1.3	-2.7
Zambia	-3.9	1.8	-23.8
Guatemala	-1.2	1.6	-2.4
Paraguay	-4.7	4.6	-27.9
South Africa	-7.6	0.9	-6.7
Lesotho	-4.9	2.9	-1
El Salvador	-2.7	2.9	0.7
Honduras	-1.5	1.8	0.1
Togo	-10.6	7.1	-21.8

Maize Yield	pDSSAT	LPJ-GUESS	CLMcrop
Malawi	36.8	-0.4	0.14
Mexico	18.3	-3.3	17
Zambia	19	-1.6	9
Guatemala	20.5	-4.8	18.7
Paraguay	57	-4.9	13.1
South Africa	12.3	-3.6	1
Lesotho	26.8	-0.1	1.1
El Salvador	32.9	-7.4	47.9
Honduras	18.6	-7.7	19.5
Togo	51.9	-6.5	24.8

Table 1. Percent change to maize protein (left) and yield (right) under ARISE-SAI-1.5C minus SSP2-4.5 (2060-2069 average) for the top 10 nations that rely on maize for daily protein consumption [9].

Nations that rely heavily on grain crops to meet their daily protein requirements will be most impacted by changes to protein under SAI. African nations such as Zambia, South Africa, and Togo show large decreases to maize protein under SAI that may not be compensated by increases to yield, although there is large model uncertainty (Table 1).

Discussion

There is large model-related uncertainty with respect to both crop yield and protein impacts from SAI and climate change. Additional work is needed to run more crop models forced by additional climate models to help reduce uncertainty. While these three crop models have been validated against observations of crop yields, more work is needed to validate them in simulating future crop protein. There is a lack of laboratory and field experiments that test how crop protein responds to elevated temperature, and more data on crop responses to current climate are needed for better model validation.

Acknowledgments

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