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REPLY TO KOVALESKI AND BASEGGIO:

Increased corn yields from historical climate trends are a double-edged sword

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Kovaleski and Baseggio (1) emphasize the importance of genetics and agronomic practices for determining trends in crop yield. Our recent analysis of US maize yields (2) explicitly evaluates how changes in certain agronomic practices and cultivar characteristics contribute to yield increases. We recognize the myriad factors that contribute to yield gains and welcome Kovaleski and Baseggio's (1) additional analyses.

We used US Department of Agriculture crop progress data (3) to calculate the yield gains attributable to earlier planting and longer-maturing cultivars. These changes in crop-development timing reflect the breeding and cultural practices that Kovaleski and Baseggio (1) reference but are also associated with changes in climate and seasonality. Earlier planting is enabled, in part, by warmer spring temperatures, and shifts in development timing modulate the weather experienced by crops. Together, these shifts account for nearly half of the 28% boost in yield trend that we attribute to better weather. The other half of the boost in yields is related to surprisingly benevolent cooling of the hottest summer temperatures. Prior regional-scale work on climate and crops (e.g., ref. 4) did not disentangle the yield increases from earlier planting and longer-maturing cultivars (5) but instead grouped these contributions into a generic time or technology trend.

Kovaleski and Baseggio (1) extend our publicly available code (6) to analyze the variance explained by adding state-level planting density and fertilizer data. Given that these additional data are only available for one-third of the county-years that we analyzed, it is unsurprising that their results somewhat differ. Although not directly comparable to our trend analysis, the modest 5% decrease in variance explained by weather variables in Kovaleski and Baseggio's model appears well within our reported uncertainty. The authors also note the potential utility of field-level "era studies" to calculate the influence of genetic changes on crop yields. Such studies are useful estimates of genetic change, particularly when they measure changes in physiological characteristics (e.g., ref. 7). However, it can be challenging to interpret the yield gains associated with genetics in these studies, since historical cultivars grown in modern conditions often have lower yields due to the continued evolution of pests and diseases and shifts in biophysical conditions (8).

Finally, we emphasize that our results would represent a silver lining to climate change only if there were some assurance that Midwestern climate would continue to improve. On the contrary, as we noted in our paper, "Recognition that historical improvements in yield partly depend on improvements in climate suggests that sustaining positive yield trends depends more on climate than previously appreciated." Furthermore, given continued increases in greenhouse gas concentrations, there appears to be substantial risk that future climate change will disrupt the precipitation and temperature patterns that current farming practices rely on in ways that are distinct from historical trends (9). Further study of the climatic, cultural, and genetic determinants of yields are important both for understanding the origin of past yield trends and to better prepare our agricultural systems for future climates.

1 Kovaleski AP, Baseggio M (2019) Is increased corn yield really the silver lining of climate change? *Proc Natl Acad Sci USA* 116: 10206–10208.

2 Butler EE, Mueller ND, Huybers P (2018) Peculiarly pleasant weather for US maize. *Proc Natl Acad Sci USA* 115:11935–11940.

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Data deposition: The code related to climate trends, adaptation, and US maize yields is available on GitHub (https://github.com/eebutler/us_maize_trends).

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