LETTER

Is increased corn yield really the silver lining of climate change?

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Although it is possible that warming while temperature maxima decreased (1) contributed to increasing yields, a much more careful analysis is warranted before making potentially harmful statements such as "better weather experienced by US maize accounts for 28% of yield trends since 1981," as Butler et al. (2) state in PNAS. To effectively measure contributions of climate changes to yield, two alternatives are possible (but unequal in strength of results): (*i*) a dataset containing the same varieties grown from 1981 to 2017 with minimal changes to management practices (empirical approach) or (*ii*) including periods when shifts in temperature trends were not following those in the period studied, along with many more variables to explicitly account for changes in cultural practices and genetics—not simply $\beta_1 y$ to describe all "other factors" (modeling approach), as this is ineffective to measure the impact of all agronomic traits. Since corn breeding is mainly done by private companies, the dataset for the first option is not publicly available. However, changes in climate have previously been reported as contributing to a mere 0.01 t/ha per decade (3, 4). Unfortunately for the second option, corn progress data (planting dates, flowering, etc.) are available only starting in 1979 (5), hindering one's ability to extend the analysis to earlier periods when temperature trends were different (6).

Genetic gains, likely the largest contributor to Butler et al.'s (2) other factors, have been studied through what are called "era studies." In these, corn varieties representing each decade or year are cultivated together, sometimes in multiple environments to account for gene–environment interaction, to evaluate proportional yield gains due to genetic and agronomic improvement. Multiple studies in the United States have found genetic gains to be between 0.77 and 0.92 t/ha per decade in periods between 1930 and 2011 (3, 7, 8). Should genetic gains fall within those estimates, there would be only a 0.06 t/ha per decade increase in yield due to cultural practices according to Butler et al. (2). When relying solely on modeling approaches, it is important to note interactions between genetics and cultural practices are difficult to untangle: upright leaves and increased stress resistances have allowed continuous increase in planting density of ∼1,000 plants per hectare per year (3, 7, 8).

Addition of new terms ideally reduces error variance, but correlation between these can lead simply to explained variance shifts between explanatory variables (Table 1, $\beta_{3,EGF}KDD_{y,c,EGF}$ in Reduced B vs. Full). Adding agronomic parameters to the model (planting density and fertilizer use, available on a state level starting in ∼1990), reduces the *n* to 9,195 observations within 775 counties (Table 2). According to Butler et al. (2), the variance explained by these parameters would be coming out of $\beta_1 y$ (other factors). However, the percent variance explained by weather parameters is reduced from 24.4 to 20.5%, and further to 19.4% if planting density and fertilizers, respectively, are included in the model (Table 2).

Taking this into consideration, the analysis should consider using only yield increases above that of genetic gains and improvements in agronomic practices for climate-related effects, or many more terms should be included.

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Table 1. Contribution of parameters to explained variance (R^2) in different models and analyses

	Dominance analysis[†]				Variance components[‡]	
	Full (as in ref. 2)	Full+PRC[§]	Reduced A[¶]	Reduced B[#]	Full (as in ref. 2)	Full+PRC[§]
Parameter*	Percent variance explained					
$\beta_{0,c}$	29.8	29.8	29.3	29.6	57.1	57.6
$\beta_1 y$	21.0	20.3	32.1	32.1	0.3	0.4
$\beta_{2,VEG}GDD_{y,c,VEG}$	1.8	1.7			<0.01	<0.01
$\beta_{2,EGF}GDD_{y,c,EGF}$	1.9	1.7			<0.01	<0.01
$\beta_{2,LGF}GDD_{y,c,LGF}$	7.7	7.2			<0.01	<0.01
$\beta_{3,VEG}KDD_{y,c,VEG}$	6.1	5.5			<0.01	<0.01
$\beta_{3,EGF}KDD_{y,c,EGF}$	6.7	5.8		13.5	0.03	0.03
$\beta_{3,LGF}KDD_{y,c,LGF}$	3.4	2.7			<0.01	<0.01
$\beta_{4,LGF}PRC_{y,c,LGF}$		1.1				<0.01
$\beta_{4,LGF}PRC_{y,c,LGF}$		1.8				<0.01
$\beta_{4,LGF}PRC_{y,c,LGF}$		1.2				<0.01
Residual						42.1
Model total	78.4	78.8	61.4	75.1		

EGF, early grain filling; GDD, growing degree days; KDD, killing degree days; LGF, late grain filling; PRC, seasonal precipitation; VEG, vegetative.
*Parameters defined by Butler et al. (2).
[†]Using *relaimpo* R package.
[‡]Using ASReml-R with all terms included as random effects.
[§]Full model with precipitation included.
[¶]Model without any weather parameter.
[#]Using only $\beta_{3,EGF}KDD_{y,c,EGF}$, as suggested by magnitude of Bayesian information criterion reduction in forward selection.

Table 2. Contribution of parameters to explained variance (R^2) in different models and analyses using a subset of 775 counties (10 states) accounting for 9,195 county-years, from 1990 to 2017

	Percent variance explained[†]			
Parameter*	Reduced B[‡]	Full (as in ref. 2)	Full+dens[§]	Full+dens+fert[¶]
$\beta_{0,c}$	27.7	28.6	26.9	27.0
$\beta_1 y$	32.1	18.9	11.7	10.6
$\beta_{2,VEG}GDD_{y,c,VEG}$		1.9	1.5	1.4
$\beta_{2,EGF}GDD_{y,c,EGF}$		1.3	0.9	0.8
$\beta_{2,LGF}GDD_{y,c,LGF}$		13.6	10.3	9.5
$\beta_{3,VEG}KDD_{y,c,VEG}$		1.7	1.5	1.5
$\beta_{3,EGF}KDD_{y,c,EGF}$	6.3	4.1	4.4	4.3
$\beta_{3,LGF}KDD_{y,c,LGF}$		1.9	2.0	1.9
$\beta_4$density			13.0	12.1
β_5N				1.8
β_6P				1.0
β_7K				0.6
Total	66.1	72.0	72.2	72.4
Weather	6.3	24.4	20.5	19.4

dens, density; EGF, early grain filling; fert, fertilizer; GDD, growing degree days; KDD, killing degree days; LGF, late grain filling; PRC, convective precipitation rate; VEG, vegetative.
*Parameters defined by Butler et al. (2).
[†]Dominance analysis using *relaimpo* R package.
[‡]Using only $\beta_{3,EGF}KDD_{y,c,EGF}$, as suggested by magnitude of Bayesian information criterion reduction in forward selection.
[§]Full model with plant density (number of plants per area) data included.
[¶]Full model with plant density and fertilizer use data included.

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