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Temperature and drought effects on maize yield

To the Editor — In their statistical analysis of temperature and rainfall effects on maize yield, Lobell *et al.* concluded[1] that excessive temperature above 30 °C during the June–August period contributed more significantly to lowering yields in the US corn belt than did the total rainfall during the same period. The authors used yield simulations from a process-based model (Agricultural Production Systems Simulator, APSIM) to verify their statistical conclusions. For reasons we outline below, we believe that these conclusions can be misleading because the major and consistent cause of rain-fed maize yield reductions in the humid and sub-humid US corn belt is the prolonged absence of significant rainfall and the resulting soil-water deficit.

First, we question the conclusion of Lobell *et al.* that rainfall during growing season (June–August) is less important in maize yield reduction than higher temperatures[1]. Their analysis of the observed data used in the study does not take into account either rainfall distribution or the rainfall not available to the crop due to surface runoff, drainage or soil evaporation. Furthermore, water stored in the soil profile at the beginning of June, should supply 150 to 180 mm of water available for transpiration — over a month's supply of water without any more rainfall. This initial soil-water supply added to the approximately 300 mm average rainfall occurring during the June–August period (Fig. 1b in ref. 1), even with a decrease of 20%, should have little influence on yield, as confirmed by their model analysis.

Secondly, use of constant transpiration efficiency (TE) in APSIM when normalized with vapour-pressure deficit (VPD) leads to biases in transpiration at high VPD. This is confirmed by the unrealistically high values of transpiration demand reported in Fig. 2c of ref. 1 (15 mm per day on apparently clear and hot days), two to three times higher than the potential evaporation calculated with commonly used and field-tested combination equations for humid and sub-humid climates like that of Iowa (Table 1).

Table 1 | Potential evapotranspiration (PET) at various vapour-pressure deficit (VPD) values as calculated with APSIM and with the Penman combination equation used by the Midwestern Regional Climate Center for Central Iowa.

T_{min}	T_{max}	VPD	APSIM	Penman
15	26	1.28	5.67	4.43
16	28	1.47	6.54	4.58
17	30	1.69	7.51	4.73
19	32	1.94	8.60	4.87
20	34	2.21	9.82	5.00
22	36	2.51	11.17	5.12
23	38	2.85	12.68	5.24
24	40	3.23	14.34	5.36

Assumptions for APSIM: 40 g m^{-2} growth, VPD is 0.75 times the difference between saturated vapour pressures at the maximum and minimum temperatures; for Penman: wind speed 1.5 m sec^{-1} and 15 MJ m^{-2} net radiation (about 55% of clear day mid-summer solar radiation). The saturated VPD equation published in ref. 1 omitted the multiplier 0.6112.

Constant normalized TE as used in APSIM is based on cell-level arguments and does not take into account whole canopy dynamics. We have shown that measured canopy TE varies considerably with management and soil cover at the same site, thus having no need for VPD normalization[2]. We are not aware of any tests of the APSIM model under field conditions in the literature that show evapotranspiration (ET) values in the 12 to 15 mm per day range as reported in the simulations in Fig. 2c of ref. 1. A recent paper[3] with maize ET values measured in the field at several sites in Iowa indicated maximum values of about 5 mm per day.

In conclusion, we believe that the influence of larger VPD resulting from higher temperatures as the cause of yield decreases is overstated and that soil-water deficit is the major and consistent reducer of yields, but that it cannot be reasonably described using seasonal rainfall alone. Extremely high temperatures are induced by drought[4], which significantly affects maize yield as in 1983, 1988 and 2012; all years having many more 'extreme degree days' greater than 37 °C than other years in central Iowa since 1961. But in many regions of the world, including the Midwest US, drought can still occur regardless of temperature. ❐

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