Exploring the limits to maize water productivity in the Western Corn-Belt

Patricio Grassini [1],*, Haishun Yang [2], Kenneth G. Cassman [1]. *E-mail: patricio.grassini@huskers.unl.edu; Phone: +1-402-472-3339
[1] Department of Agronomy and Horticulture, University of Nebraska-Lincoln, P.O. Box 830915, Lincoln, NE 68583-0915, USA
[2] Monsanto Corporation, 800 N Lindbergh Blvd, St. Louis, MO 63167, USA.
University of Nebraska Lincoln | NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH

1. JUSTIFICATION & OBJECTIVES

- Competition for water resources is increasing because of limited supplies in most countries with extensive irrigated agriculture
- In Western U.S. Corn-Belt, maize is produced under irrigated (3.2 million ha) and rainfed (4.1 million ha) conditions
- We used simulation modeling to better understand factors that determine maize water productivity in these systems
- The goal was to develop an analytical framework to benchmark maize water productivity as a means to improve research, management, and policies on irrigation

2. METHODOLOGY

2.1 Hybrid-Maize model: validation for rainfed and irrigated crops

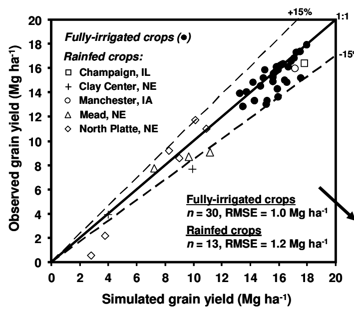


***Figure 1*. Observed vs. simulated yields for a test set of fully-irrigated and rainfed maize crops**

Hybrid-Maize (Yang *et al*., 2004) is a process-oriented model that simulates maize development and growth on a daily time step under growth conditions without limitations from nutrient deficiencies or toxicities, insect pests, diseases, or weeds

100% and **70%** of predicted grain yield were within ±15% of measured values for fully-irrigated and rainfed crops, respectively

2.2 Simulation analysis in the Western Corn-Belt : 18 locations x 20 yrs

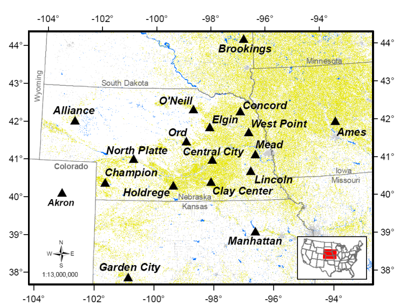
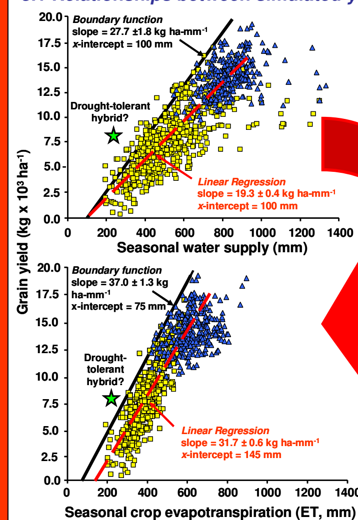


***Figure 2*. The Western Corn-Belt. Triangles are weather stations used in this study**

Grain yield and crop water balance components were simulated for fully-irrigated and rainfed crops, using 20-y weather records from 18 locations in combination with actual soil, planting date, plant population, and hybrid-maturity data for each site

3. RESULTS

3.1 Relationships between simulated yield and water supply or crop ET



The boundary defines the limit for yield over the range of water supply (initial soil water + rainfall + irrigation); the linear regression can be used by farmers to benchmark their actual water productivity

Variability decreases when the independent variable shifted from water supply to crop ET because the latter does not include water lost by percolation or left as residual soil moisture at maturity

The yield / ET boundary represents the physiological limit (≈ maximum transpiration-efficiency)

Both boundary functions provide a benchmark to test the so-called drought-tolerant hybrids

***Figure 3*. Relationships between simulated grain yield and seasonal water supply and crop ET (upper and lower panels, respectively) for rainfed (□) and fully-irrigated (▲) crops. Boundary functions and linear regressions are shown**

3.2. Explanation of variation in productivity of fully-irrigated maize

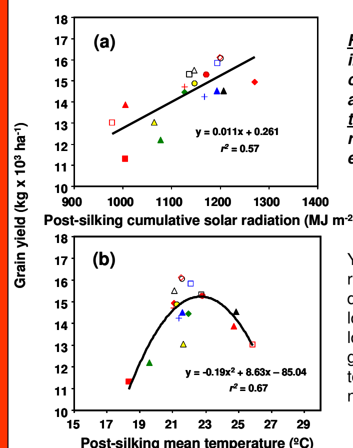


***Figure 4*. Simulated grain yield of irrigated maize as a function of (a) cumulative solar radiation and (b) average mean temperature during the post-silking phase. Each point represents the 20-year mean yield at each location**

Yield of irrigated maize depends on radiation and temperature regime during post-silking phase at each location. Highest yields occur at locations where the duration of the grain-filling phase is maximized keeping temperatures in the optimal range for net assimilation.

3.3. Comparison of actual data from field studies with maize grown under near optimal conditions in the Western Corn-Belt

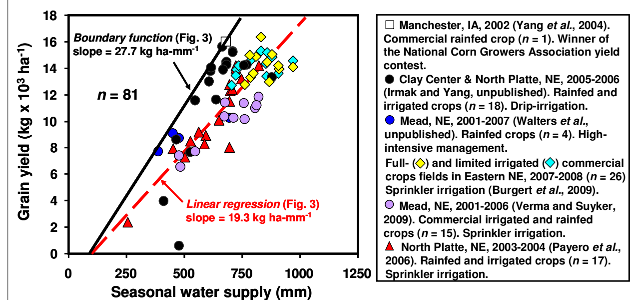


***Figure 5*. Relationship between actual grain yield and seasonal water supply**

3.4. Comparison against observed data for maize and other species

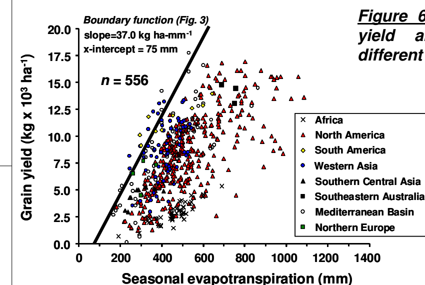


***Figure 6*. Reported actual maize yield and crop ET data across different environments**

Note that the boundary function holds for data collected by others across a wide range of environments

Transpiration-efficiency of maize is above that reported for other crop species

⇩

***Table 1*. Maximum transpiration-efficiency reported for several crop species**

Crop	Transpiration-efficiency (kg grain ha-mm-1)	Sources
Cereals		
Maize	31.7 - 37	This study
Sorghum	16-32	Garrity *et al.* (1982); Stewart (1985)
Wheat	20 - 22	Angus and Herwaarden (2001); Passioura (2007).
Oilseeds & Legumes		
Summer oilseeds (soybean, sunflower)	8 - 9	Specht *et al.* (1986); Dardanelli *et al.* (1991); Grassini *et al.* (2009)
Winter oilseeds (canola, mustard, linola)	12-13	Hocking *et al.* (1997)
Winter grain legumes (chickpea, faba bean, lentil)	12-20	Loss *et al.* (1997); Zhang *et al.* (2002)

4. CONCLUSIONS

- **Water supply imposes an upper limit to maize productivity in the Western Corn-Belt**
- **Yield of irrigated maize depends on the location-specific radiation and temperature regime during the post-silking phase**
- **The boundary functions defined in our study for the relationships between grain yield and water supply or crop ET are consistent with observations from other studies across a wide range of environments**
- **Simulated and reported data indicate that maize seasonal transpiration-efficiency is above that reported for other crops**
- **The regression between simulated yield and seasonal water supply (*x*-intercept: 100 mm; slope: 19.3 kg ha-mm-1) provides an useful benchmark to evaluate on-farm maize water productivity and to assess management and policy options**

REFERENCES:
- Grassini, P., Yang, H., Cassman, K.G., 2009. Limits to maize productivity in the Western Corn-Belt: a simulation analysis for fully-irrigated and rainfed conditions. *Agric. For. Meteor.* 149:1254-1265.
- Yang, H.S., Dobermann, A., Lindquist, J.L., Walters, D.T., Arkebauer, T.J., Cassman, K.G., 2004. Hybrid-Maize - a maize simulation model that combines two crop modeling approaches. *Field Crops Res.* 87:131-154.

ACKNOWLEDGMENTS: Support for this study comes from the Water, Energy and Agriculture Initiative, made possible with funding from the Nebraska Corn Board, the Nebraska Soybean Board, the Agricultural Research Division (ARD) at the University of Nebraska–Lincoln (UNL) and Nebraska Public Power District through the Nebraska Center for Energy Sciences Research at UNL. The senior author acknowledges financial support from the Fulbright Program for his graduate assistantship and the ARD of the Institute of Agriculture and Natural Resources at UNL.