A simulation approach for evaluating maize yield potential in different environments

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What is yield potential?

Yield of a cultivar in the environment to which it is adapted when grown with minimal possible biotic or abiotic stresses.
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\[ Y_p = \int_{\text{emergence}}^{\text{maturity}} (Genetics \times Solar \times Temp) \, dt \]
To achieve yield potential of an environment:

- Maximize utilization of growing season (= optimal cultivar)
- Minimize possible biotic and abiotic stresses (nutrients, water, pests)
- Optimize plant population
Why yield potential important?

- Cultivar selection & crop management
- Risk assessment
- Carbon sequestration
- Global food security & preservation of natural ecosystems and biodiversity.
Objectives:

Quantify

- Yield potential of maize grain across NE
- Yield potential of maize stover across NE
- Their temporal variability?
Nebraska (NE):

• A wide range of environmental conditions

• The climatic variation from the western to eastern borders of Nebraska is greater than from the eastern Nebraska border to the Atlantic ocean
Growing Degree-Days Across NE

LEGEND

Accumulated growing degree-days, base 50°F, were derived from the period of 1981 to 1990, without an upper threshold.

From this calculation, these growing degree-days represent the total heat units available for plant growth throughout the year and were based upon:

\[
\frac{T_{\text{max}} + T_{\text{min}}}{2} = 50°F
\]

The growing degree-day surface was generated from a terrain regression applied to the USGS 3 arc-second digital elevation models (DEM's; 1:24,000) with a final resolution of 300 m.

- Less than 2000
- 2001 to 2400
- 2401 to 2800
- 2801 to 3200
- 3201 to 3600
- 3601 to 4000
- 4001 to 4400
- 4401 to 4800
- 4801 to 5200
- 5201 to 5600
- 5601 to 6000
- 6001 to 6400
- 6401 to 6800
- 6801 to 7200
- 7201 to 7600
- 7601 to 8000
- 8001 to 8400
- 8401 to 8800
- 8801 to 9200
- 9201 to 9600
- 9601 to 10000

A cooperative project of the National Drought Mitigation Center, School of Natural Resources, University of Nebraska, and the USGS Northern Plains Regional Office.
Annual Precipitation Across NE

Legend
Mean annual precipitation was derived from a population of 195 weather stations with 1961 to 1990 normals (Owenby and Eddy, 1992). The precipitation surface was constructed from a terrain regression applied to the DEMs (1:250,000) with a final resolution of 200 m.

- Red: Less than 350 mm
- Brown: 351 to 400 mm
- Orange: 401 to 450 mm
- Yellow: 451 to 500 mm
- Green: 501 to 550 mm
- Blue: 551 to 600 mm
- White: 601 to 650 mm
- Light green: 651 to 700 mm
- Dark green: 701 to 750 mm
- Medium green: 751 to 800 mm
- Cyan: 801 to 850 mm
- Blue: Greater than 850 mm

A.S. Agricultural Research and Extension Sites

Corn Hybrid Tests (1993)
Annual Potential Evapotranspiration Across NE

LEGEND

Mean annual potential evapotranspiration was derived from the Newhall Simulation Model (Van Bavel et al., 1982) using 1961 to 1990 normals for precipitation and temperature from a population of 120 weather stations (Owenby and Ecclis, 1992). The potential evapotranspiration (PET) was calculated using the Thornthwaite (1948) approximation and applied to the 3 arc-second digital elevation model (DEM; 1:250,000), using a terrain regression approach.

- Less than 575 mm
- 576 to 600 mm
- 601 to 625 mm
- 626 to 650 mm
- 651 to 675 mm
- 676 to 700 mm
- 701 to 725 mm
- Greater than 725 mm

Agricultural Research and Extension Sites
Weather Stations

DRAFT 2/05/99
18-yr mean and SD of daily solar radiation and temperature from May 1 to Oct 15 in Lincoln, NE.
To estimate yield potential across NE requires:

- Sufficient spatial coverage
- Sufficient temporal coverage
How to estimate yield potential across NE?

✔ Experimentation
  + directly measured yields
  - limited in spatial and temporal coverage
How to estimate yield potential across NE?

✓ Experimentation
  + directly measured yields
  -- limited in spatial and temporal coverage

✓ Model simulation
  + large spatial and temporal coverage
  + can explore ‘scenarios’
  -- results need to be validated

- Hybrid of CERES-Maize + Generic Dutch crop model.
- Corn specific and growth driven by temperature.
- Mechanistic photosynthesis routine sensitive to temperature & light intensity.
- Growth and maintenance respiration included and sensitive to crop development and temperature.
- Robust in high yielding environments

*Predict silking from total GDD*
Regression of GDD to silking (GDD$_{silking}$) on total GDD (GDD$_{total}$) for 107 commercial maize hybrids from Pioneer Inc. Many points have the same values and thus overlap.
Collection of weather data

49 sites inside NE
12 sites out of NE

Yr/site (in NE)
mean = 14
min = 4 (2 sites)
max = 21 (11 sites)
Simulation of best yields under current practices

- Planting date: NASS* report
- Maturity: NASS report
- Plant pop: 74,000/ha (30,000/acre)

*Nebraska Agric. Statistics Service
Current practices: *best yields*

Grain, Mg/ha

- 10.1 - 10.8
- 10.9 - 11.5
- 11.6 - 12.1
- 12.2 - 12.8
Current practices: best yields

**Grain, Mg/ha**
- 10.1 - 10.8
- 10.9 - 11.5
- 11.6 - 12.1
- 12.2 - 12.8

**Stove, Mg/ha**
- 9.6 - 10.9
- 11.0 - 11.4
- 11.5 - 12.0
- 12.1 - 12.8
Average maize grain yield under irrigation in Nebraska by reporting district from NASS database 1998-2002 and corresponding simulation by Hybrid-Maize model.
Current practices: variation of best yields

SD of grain
- 0.6 - 1.0 Mg/ha
- 1.1 - 1.5
- 1.6 - 2.5

SD of Stover
- 0.4 - 1.1 Mg/ha
- 1.2 - 1.8
- 1.9 - 2.5
To achieving full yield potential: *optimal management*

1. Determine maximum duration of growing season

2. Choose the right hybrid

3. Use optimal plant population

4. Grow under stress-free conditions.
To achieving full yield potential:  

**optimal management**

1. Hybrid-Maize model search for (a) optimal sowing data and (b) the date when grain filling stops. It then derives total available GDD (GDD<sub>available</sub>).

2. Set parameter GDD<sub>total</sub>:  
   
   \[\text{GDD}_{\text{total}} = \begin{cases} 
   \text{GDD}_{\text{available}}, & \text{if } \text{GDD}_{\text{available}} < \text{GDD}_{\text{max}} \\
   \text{GDD}_{\text{max}}, & \text{if } \text{GDD}_{\text{available}} > \text{GDD}_{\text{max}} 
   \end{cases}\]

3. Plant pop = 99,000/ha (40,000/acre)

4. Run under stress-free conditions using other common settings.
Optimal management: gain in season length

- 11 – 19 d
- 20 - 29
- 30 - 38
Optimal management: *gain in yield*

Grain
- 2.6 - 3.5 Mg/ha
- 3.6 - 4.5
- 4.6 - 6.0
Optimal management: *gain in yield*

- **Grain**
  - 2.6 - 3.5 Mg/ha
  - 3.6 - 4.5 Mg/ha
  - 4.6 - 6.0 Mg/ha

- **Stover**
  - 0.9 - 1.5 Mg/ha
  - 1.6 - 2.5 Mg/ha
  - 2.6 - 3.2 Mg/ha
Maize yield potential across NE estimated by Hybrid-Maize model (error bars are SD over time)
Maize yield potential across NE estimated by Hybrid-Maize model in comparison with actual yields (means of 1998-2002)
Maize yield potential simulated by Hybrid-Maize compared to the yield of NE contest winners.
Optimal management:  
*temporal (mean=14 y) variation of yields*

**SD of grain**
- 0.9 - 1.5 Mg/ha
- 1.6 - 2.2
- 2.3 - 3.0

**SD of stover**
- 0.3 - 1.1 Mg/ha
- 1.2 - 1.7
- 1.8 - 2.5
Conclusions

- Model simulation is a powerful tool in understanding maize yield potential in diverse environments.

- Across NE, the current irrigated maize yield is only 56% of the yield potential.

- Achieving that potential requires longer-maturity cultivars (esp. N-W) and higher plant density.

- Temporal variation of maize yield potential increases from S-E to N-W across Nebraska due to greater variation in length of growing season in N-W than S-E.
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Thank you