Long-Term Trajectories: Crop Yields, farm land, and irrigated agriculture

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Global Cereal Yield Trends, 1965-2011
(tyranny of linear growth rates)

Maize yield slope = 65 kg ha\(^{-1}\) y\(^{-1}\)
Rice yield slope = 52 kg ha\(^{-1}\) y\(^{-1}\)
Wheat yield slope = 40 kg ha\(^{-1}\) y\(^{-1}\)

Source: FAOSTAT
Global analysis of crop yield trends

- Since 1965, yield trends of major cereal crops best-fit linear increase models in all countries, and these rates are not fast enough to meet demand on existing farmland.

- No evidence of exponential rate of gain.

- 31% of total global production of major cereal crops comes from countries in which rate of yield increase has markedly decreased or plateaued.

- For maize since 1965, rate of return on yield-enhancing research has fallen 75%.


Bottom line: rate of yield gain must accelerate to avoid massive expansion of crop production area at expense of natural systems. Good land-use policies also needed.
Food production capacity on existing farmland

- Estimated by yield gap on current farmland (see Global Yield Gap Atlas: www.yieldgap.org)
- Essential for each country and region to evaluate robust food security scenarios
  - To identify likely trade trajectories
  - Export opportunities versus import-dependence
- Important to inform policies and to help prioritize R & D investments at national, regional and global scales
Yield potential, yield gap, and determining factors

- **Yield Potential**: Determined by:
  - Radiation
  - Temperature
  - Water supply

- **Actual field yield**: Limited by:
  - Nutrients
  - Insects, weeds
  - Diseases
  - etc......

**Yield gap**

Grain yield (Mg ha⁻¹)

Yield Potential: Irrigated or rainfed
Current rainfed yields, yield potential, yield gaps, and national production capacity at 80% of rainfed yield potential in Argentina (Modified from Merlosa et al., 2015)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Current yield</th>
<th>Yield Potential</th>
<th>Yield gap</th>
<th>Current yield as % of yield potential</th>
<th>Crop area</th>
<th>National production capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>2.7</td>
<td>3.9</td>
<td>1.2</td>
<td>68</td>
<td>17.6</td>
<td>55</td>
</tr>
<tr>
<td>Wheat</td>
<td>3.0</td>
<td>5.2</td>
<td>2.2</td>
<td>59</td>
<td>4.5</td>
<td>19</td>
</tr>
<tr>
<td>Maize</td>
<td>6.8</td>
<td>11.6</td>
<td>4.8</td>
<td>59</td>
<td>3.7</td>
<td>34</td>
</tr>
</tbody>
</table>

If all Argentine farmers produced at 80% of rainfed yield potential, the increase in total production of soybean, wheat, and maize represents 9, 4, and 9% of current global maize exports, respectively.
Screen shots from Global Yield Gap Atlas showing rainfed maize yield potential and temporal variability (CV) aggregated to climate zone and national spatial scales.
Importance of irrigated agriculture to global food security

• Reduces pressure to expand crop production area: 40% of global food production on <20% of crop area

• Crops produced with irrigation have both high and reliable yields, even in semi-arid regions with substantial climate variability
  – In fact, irrigation is a powerful climate change adaptation option where sustainable water resources can support it

• High, consistent yields promote agricultural development in regions where rainfed crop production is risky due to variable climate
  – Central and western Nebraska example: irrigated crop production attracts investments in infrastructure, agricultural equipment manufacturing, seed and input suppliers, crop consultants, and value-added enterprises such as food processing, livestock feeding operations, and slaughterhouses that otherwise could not be justified
  – Much of Sub-Saharan Africa crop production area is like west/central NE
Maize yield stability (CV) versus yield level in US Corn Belt: based on county average maize yields in NE and IA from 2000-2009

Grain Yield (t/ha)

Coefficient of variation (%)

harsh rainfed maize environments as in much of Sub-Saharan Africa

Is irrigated agriculture sustainable?

• Yes, where water withdrawals do not exceed recharge capacity over the medium- to long-term and water quality is maintained
• Requires good governance of surface and groundwater resources
• The Nebraska Natural Resource Districts provide a useful model of successful governance based on local control

Can current irrigated crop area be maintained?

• Several major aquifers are in decline: Ingo-Gangetic plains, North China Plain, portions of the High Plains Aquifer, California Central Valley. Lack of good governance is the problem. But even with good governance, total area under irrigation is likely to decline to a more sustainable level
• Substantial opportunities to expand irrigated area exist in Sub-Saharan Africa and parts of Latin America, and improved irrigation water use efficiency will increase the area that can be irrigated with a given sustainable water supply
• Overall best guess: current global irrigated area can be maintained but not increased significantly
What is scope for improving water use efficiency?

• Improved crop and soil management
• Better irrigation system equipment and technologies
• Crop genetic improvement
Analytical framework to benchmark and evaluate maize water productivity (WP) of in farmers’ fields

- Growing-season water supply includes stored soil moisture at planting, in-season rainfall, and irrigation (if applied).
- WP boundary-function is the best possible yield that can be achieved with a given water supply.
- Mean WP function is what can be achieved with best management practices and irrigation technologies.

Growing-water supply (in)

Grain yield (bu ac⁻¹)

WP boundary-function slope = 11 bu acre-in⁻¹

Mean WP function slope = 8 bu-in⁻¹

x-intercept ≈ 4 in

(a) Improved crop mgt

(b) Improved irrigation mgt

(c)
Applying the framework to farmer-reported data in Nebraska

Figures at left show the relationship between:

(a) Grain yields and seasonal water supply from 777 field-years from the Tri-Basin Natural Resource District (NRD). Average rainfed yields for the three counties in this NRD were obtained from USDA-NASS (2005–2007).

(b) Disaggregated by irrigation system type, or

(c) As actual yield and simulated yield with optimal irrigation based on crop simulation in combination with weather records and crop management data from a subset of 123 fields.

In all three panels, dashed and solid black lines are the boundary- and mean water productivity functions from the previous slide.

Horizontal dashed lines indicate average simulated yield potential (Yp) with current crop management in the Tri-Basin NRD (15.4Mgha⁻¹).

Based on these data, water use could be reduced by 33% with little impact on yield if all farmers adopted pivot irrigation and improved irrigation timing based on real-time weather and soil water status.

From Grassini et al., 2011b.
• Continued, steady progress towards hybrids and cultivars with greater overall stress resistance can be expected from brute-force breeding informed by bioinformatics, molecular markers, and spatial analysis of targeted environments.

• The potential for biotechnology to give a quantum leap in drought tolerance and water use efficiency has not been fulfilled and is unlikely in foreseeable future because these traits are under complex genetic control.

• Overall rate of yield advance will depend on continued large R & D investments in genetic improvement and agronomic technologies (see next slide for US maize).
1966-2010 USA corn yield trends as supported by improvements in genetics, agronomic practices, and agricultural equipment

linear rate of gain = 1.86 bu ac\(^{-1}\) yr\(^{-1}\)

1.2% of trend-line yield in 2012

- Improved balance in N, P, K fertilization
- Multi-location hybrid testing in 1000s of on-farm strip trials
- Expansion of irrigated area
- Electronic auto-steer
- Precision planters
- Transgenic (Bt) insect resistance
- Integrated pest management
- Conservation tillage and soil testing
- Increased N fertilizer rates

Summary Points

• While there is tremendous potential to close current yield gaps on existing farm land, doing so will not likely reduce expansion of crop production area without well-coordinated national policies regarding land use change.

• Likewise, there is enormous potential to improve water use efficiency of irrigated agriculture, but effective policies and regulations are needed to ensure that water resources are not being depleted or degraded.

• Future improvements can be expected from continued innovations in both agronomic practices and genetics. However, current seed company business models are in question given rush to merge for all multi-national seed companies and a substantial reduction in the "rate of yield growth return" on investment.

• Appropriate business models have yet to be developed to take advantage of "big data" on crop management, soils and climate, and advances in computing power, remote sensing, communication technologies, and simulation models.

• Urgent need for increased investment in agricultural R & D coupled with improved prioritization to increase effectiveness and efficiency of that investment; ruthless focus on both productivity and environmental goals is required.