FORECASTING GLOBAL CROP FAILURES TO PREPARE CLIMATE-INDUCED FOOD INSECURITY

Toshichika Iizumi\textsuperscript{1}, Hirofumi Sakuma\textsuperscript{2}, Masayuki Yokozawa\textsuperscript{1}, Jing-Jia Luo\textsuperscript{3}, Andrew J. Challinor\textsuperscript{4} and Toshio Yamagata\textsuperscript{2}

\textsuperscript{1}National Institute for Agro-Environmental Sciences  
\textsuperscript{2}Research Institute for Global Change, JAMSTEC  
\textsuperscript{3}Australian Bureau of Meteorology  
\textsuperscript{4}University of Leeds
Heterogeneous geo-distribution of crop production

Table. World area harvested, average yield, production, and export quantity for four crops in 2008.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area Harvested (Million ha)</th>
<th>Yield (t/ha)</th>
<th>Production (top 3 share) (Million t)</th>
<th>Export Quantity (Million t)</th>
<th>Export/Production (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>161</td>
<td>4.1</td>
<td>827 (64%)</td>
<td>102 (74%)</td>
<td>12.3</td>
</tr>
<tr>
<td>Soybean</td>
<td>96</td>
<td>1.7</td>
<td>231 (81%)</td>
<td>79 (89%)</td>
<td>34.1</td>
</tr>
<tr>
<td>Rice</td>
<td>159</td>
<td>3.7</td>
<td>689 (58%)</td>
<td>29 (63%)</td>
<td>4.2</td>
</tr>
<tr>
<td>Wheat</td>
<td>222</td>
<td>3.1</td>
<td>683 (38%)</td>
<td>131 (47%)</td>
<td>19.2</td>
</tr>
</tbody>
</table>

A few grids provide most food!
Specific climate variable at specific timing

- Weight, length, or number (relative value)
- Biomass dry weight
- Canopy height
- Leaf numbers

Emergence
Sowing
Vegetative growth
Reproductive growth
Flowering
Harvesting

Kubo & Tani (1982)

Nemani et al. (1997) *Science*

Horie (2004)

Iizumi et al. (in preparation)

Nemani et al. (1997) *Science*

Degree of Strong climate-crop relationship

Weak

Low Climate predictability High (or climate forecast skill)

I
II
III
IV
This situation calls for a global early warning system for food supply anomalies;

Most crop prediction or famine early warning operate regionally, and few have evaluated the crop prediction skill at the global scale;

The key question is that of potential utility: how high is the crop prediction skill in capturing the year-to-year yield variation at useful lead times?
Data and Methods (crop yield)

- Global, gridded historical yield dataset (Iizumi et al., *Global Ecol. Biogeogr.*, in review)
  - covers the period 1982–2006
  - derived by aligning county yield statistics with yield proxy from satellites

- Removal of technological yield trend to derive climate–crop relationship
  - $\Delta Y_t = \frac{(Y_t - Y_{t-1})}{Y_{ave}} \times 100$
  - Same average yield was used for the first 3–yr of the study period

![Map of global yield data]

![Graph of maize yield in USA (1980-2005)]
Data and Methods (crop phenology)

- Global crop phenology dataset
  - Type of cropping system
    - Maize (major/secondary)
    - Soybean (major)
    - Rice (major/secondary)
    - Wheat (winter/spring)
  - Share of production by cropping system
    - Average yield of winter wheat 2 t/ha (100t) and spring wheat 4 t/ha (500t) is not 3 t/ha, but 3.7 t/ha
  - Specification of key growing season for each cropping system

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Winter wheat</th>
<th>Spring wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vegetative growth</td>
<td>Reproductive growth</td>
</tr>
<tr>
<td></td>
<td>Planting</td>
<td>Flowering</td>
</tr>
<tr>
<td>Jun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key growing season**
Data and Methods

- 2m air temperature and soil moisture (surface 10cm) data
  - Seasonal forecasts from SINTEX-F and JRA-25 reanalysis, both monthly basis
  - Lead time ranges from 3 to 5 month for pre-season prediction and 1 to 3 month for within-season prediction

-- Multiple linear regression models:
  - $\Delta Y_t = \Delta T_t + \Delta SW_t + \varepsilon$
  - $\Delta T_t = T_t - T_{t-1} \; ; \; \Delta SW_t = SW_t - SW_{t-1}$
  - $Y$ is yield (t/ha), $T$ and $SW$ is key growing season mean temperature (°C) and soil moisture (mm), suffix t indicates year (N=24);
  - One model for each cropping system (then calculate weighted average yield);
  - Regression coefficients were determined by Bayesian calibration method.
• Over 16% (r=.404, p<.05) of year-to-year yield variation can be explained by temperature and soil moisture alone. Such “skillful” area produces 28 to 40% of world production in 2000.
Within-season prediction

• Skillful area of within-season prediction produces 3 to 10% of world production.
• Prediction achieved limited part of the potential...
• Amount of production produced in “skillful” area decreases as lead time increases.
Are these predictions better than random?
Sensitivity of yield to temperature and soil moisture

• Weighted average of yield elasticity to temperature and soil moisture (evaluated based on climatological mean values);
• Maize and soybean are water dependent while rice and wheat are more temperature dependent.
Crop prediction skill

Observation

Within-season Pre-season
Is there further value from prediction for wheat?

Wheat is the world's third most produced cereal crop, but covers more land area worldwide than any other crop!

### Wheat export (t)

- **United States of America**: 23%
- **France**: 12%
- **Canada**: 12%
- **Argentina**: 7%
- **Russia**: 9%
- **Ukraine**: 6%
- **Australia**: 6%
- **Germany**: 5%
- **Others**: 20%
Crop prediction skill in wheat exporting countries

1st Exporter (23% of world export)  2nd Exporter (12%)

3rd Exporter (12%)  6th Exporter (6%)
Summary

• Skill of seasonal forecast–based crop prediction is significantly better than that of random forecast for temperature–dependent crops (rice and wheat);

• Skill decreases as lead time increases, but the pre–season prediction skill for wheat remains similar to the within–season in two major exporting countries;

• There is value to be obtained from seasonal forecasts for global food security applications, but the current crop prediction achieve only the limited part of the potential.

• Global crop predictions have a potential to inform about climate–induced wheat yield drops that could be triggers of embargos from major exporting countries food agencies several months to nearly half a year before harvest.