FORECASTING GLOBAL CROP FAILURES TO PREPARE CLIMATE-INDUCED FOOD INSECURITY

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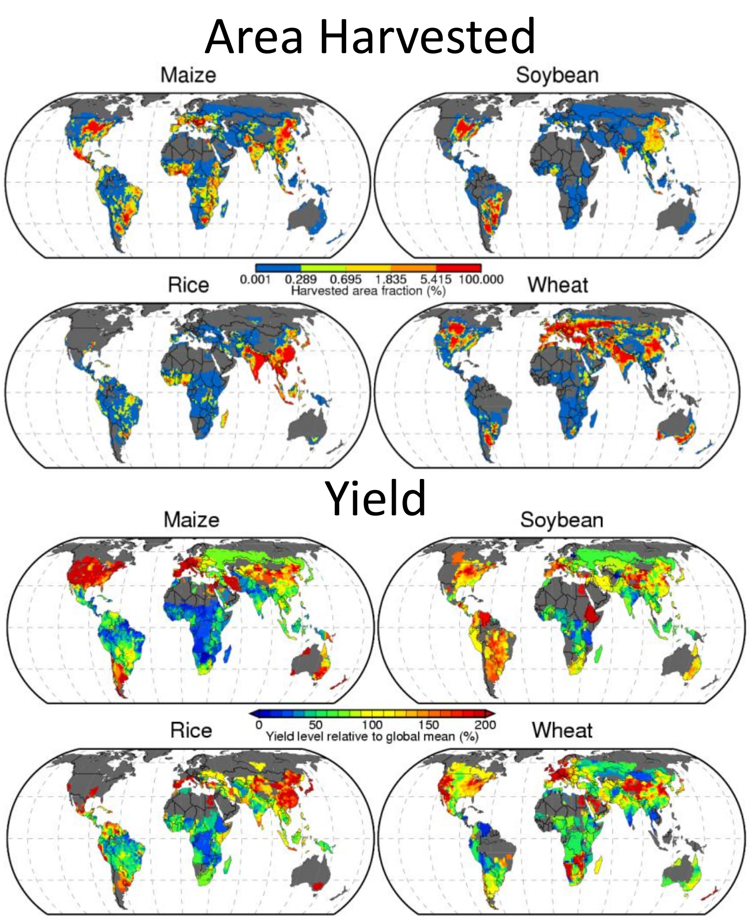
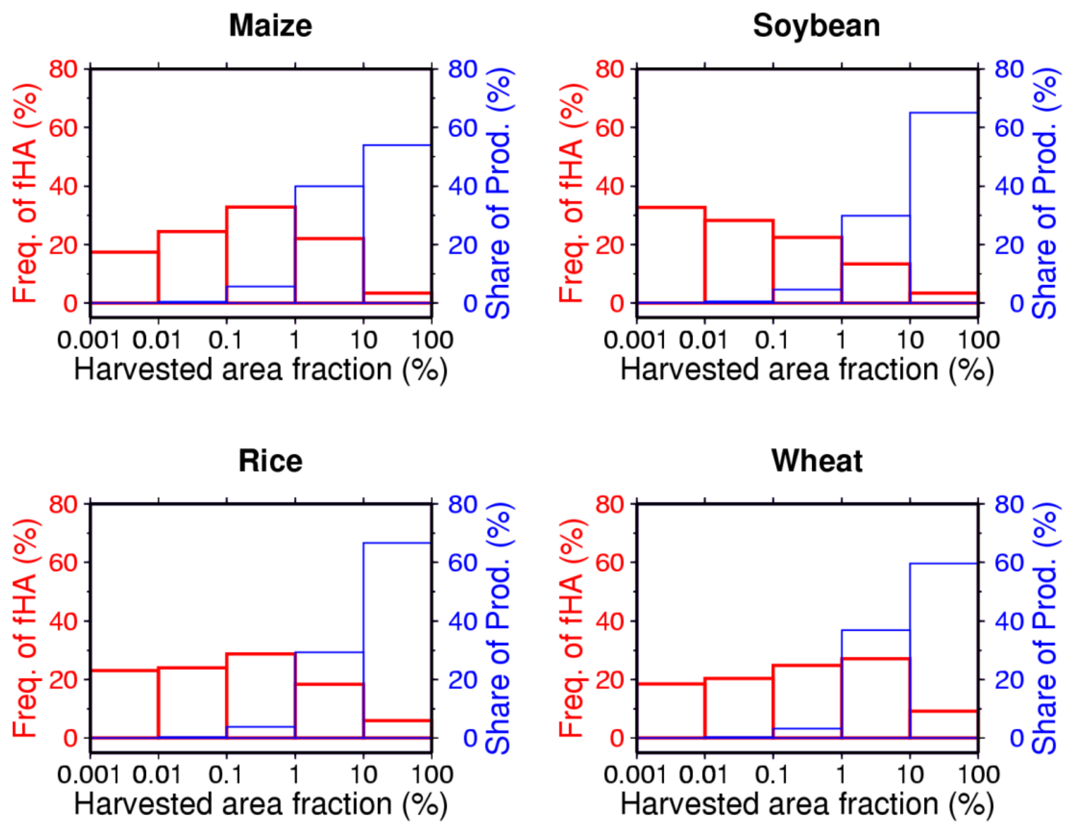
Heterogeneous geo-distribution of crop production

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

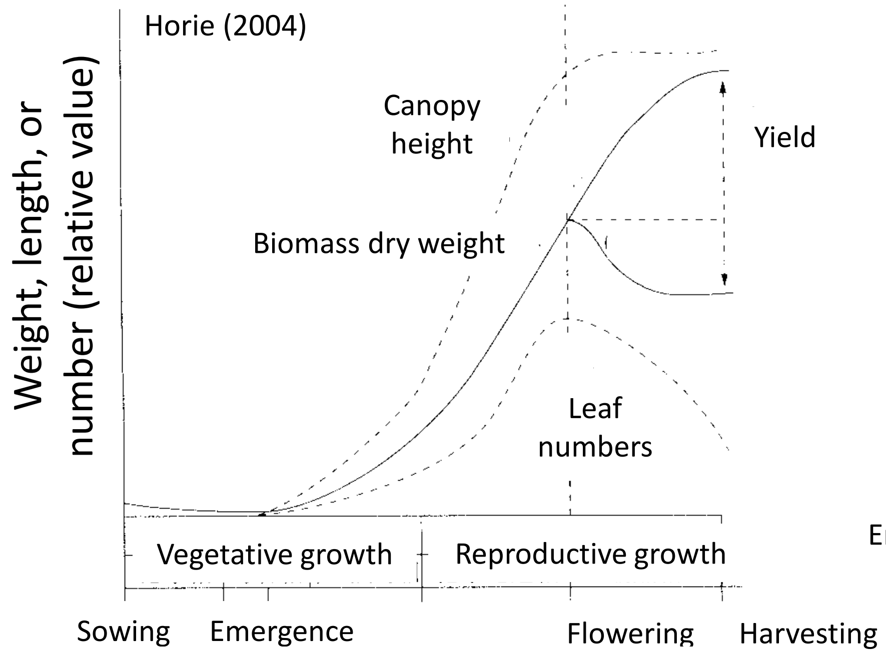
Crop	Area Harvested (Million ha)	Yield (t/ha)	Production (top 3 share) (Million t)	Export Quantity (Million t)	Export/Production (%)
Maize	161	4.1	827 (64%)	102 (74%)	12.3
Soybean	96	1.7	231 (81%)	79 (89%)	34.1
Rice	159	3.7	689 (58%)	29 (63%)	4.2
Wheat	222	3.1	683 (38%)	131 (47%)	19.2

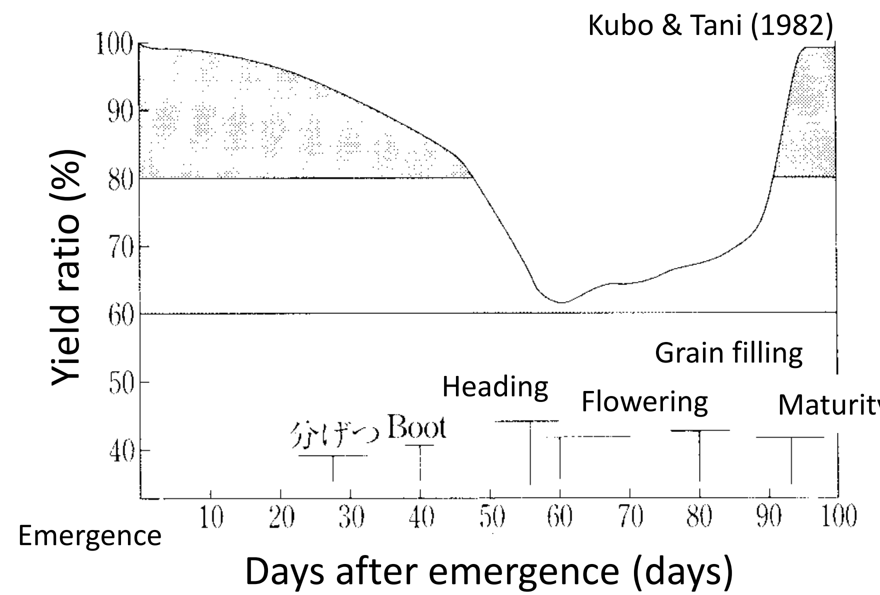


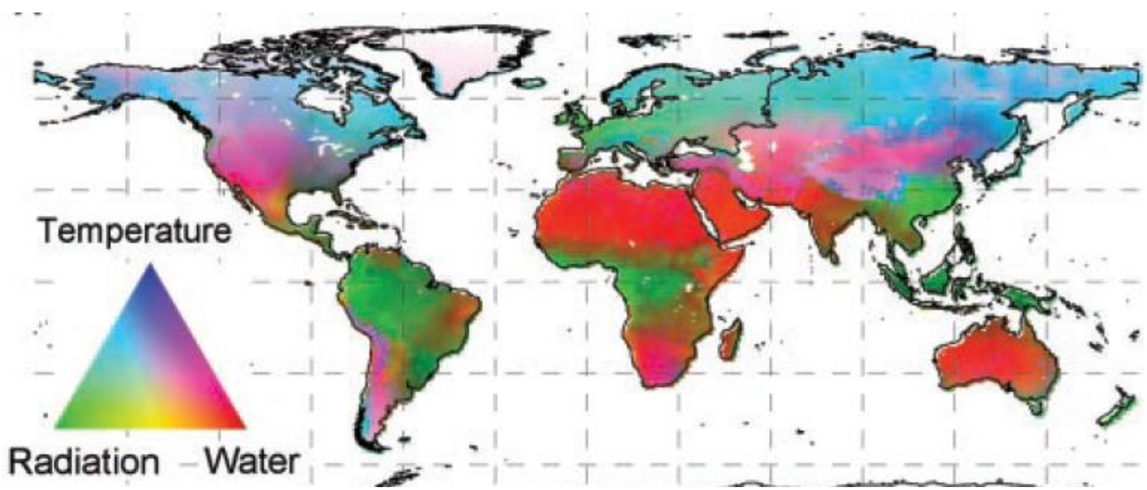


A few grids provide most food!

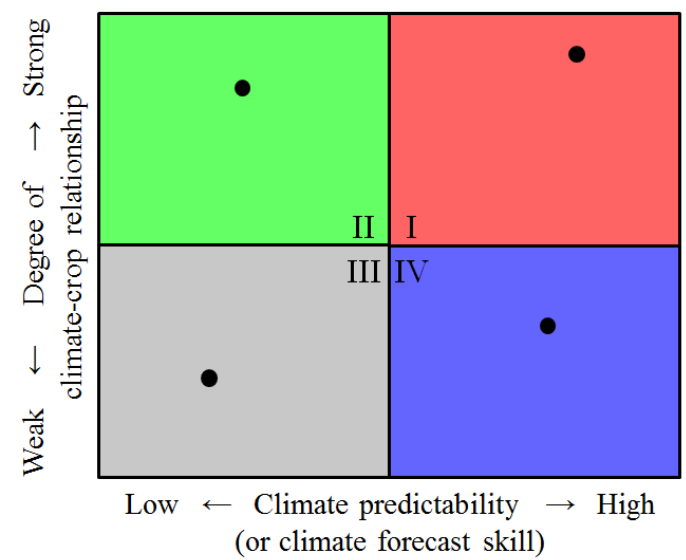
Specific climate variable at specific timing







Nemani et al. (1997) *Science*



Iizumi et al. (in preparation)

Introduction

http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/

EXTREME WEATHER, EXTREME PRICES

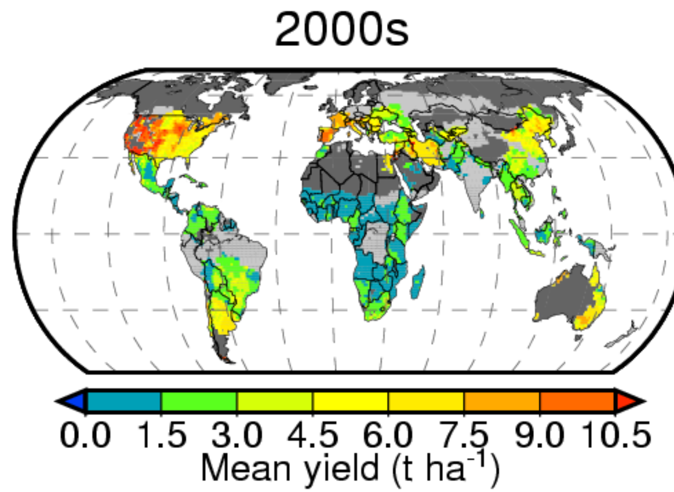
The costs of feeding a warming world

http://www.oxfam.ca/news-and-publications/publications-and-reports/extreme-weather-extreme-prices

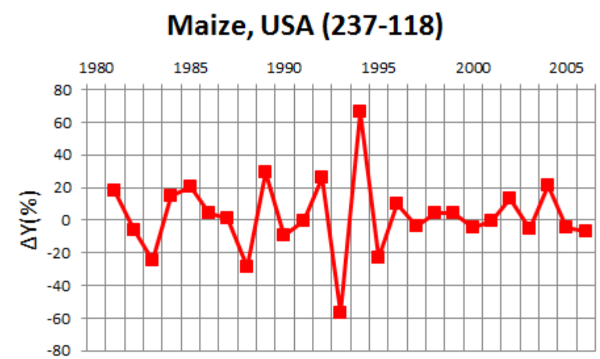
- This situation calls for a global early warning system for food supply anomalies;
- Most crop prediction or famine early warning operate regionally, and few have evaluated the crop prediction skill at the global scale;
- The key question is that of potential utility: how high is the crop prediction skill in capturing the year-to-year yield variation at useful lead times?

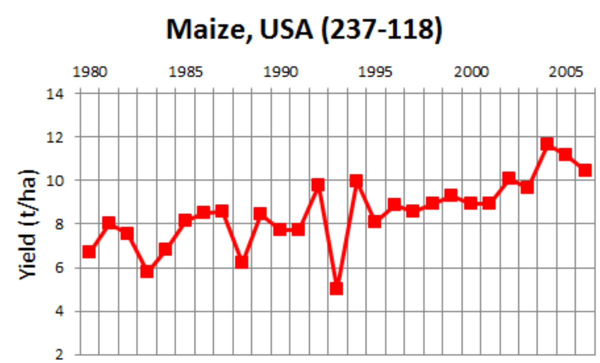
Data and Methods (crop yield)

- Global, gridded historical yield dataset (Iizumi et al., *Global Elol. 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
  - $\Delta Y_t = (Y_t - Y_{t-1}) / Y_{ave} * 100$
  - Same average yield was used for the first 3–yr of the study period
  - Popular in Agro–meteorological fields (e.g., Lobell & Field, 2007, *Environ. Res. Lett.*; Kucharik, 2008, *Agron. J.*)





Data and Methods (crop phenology)

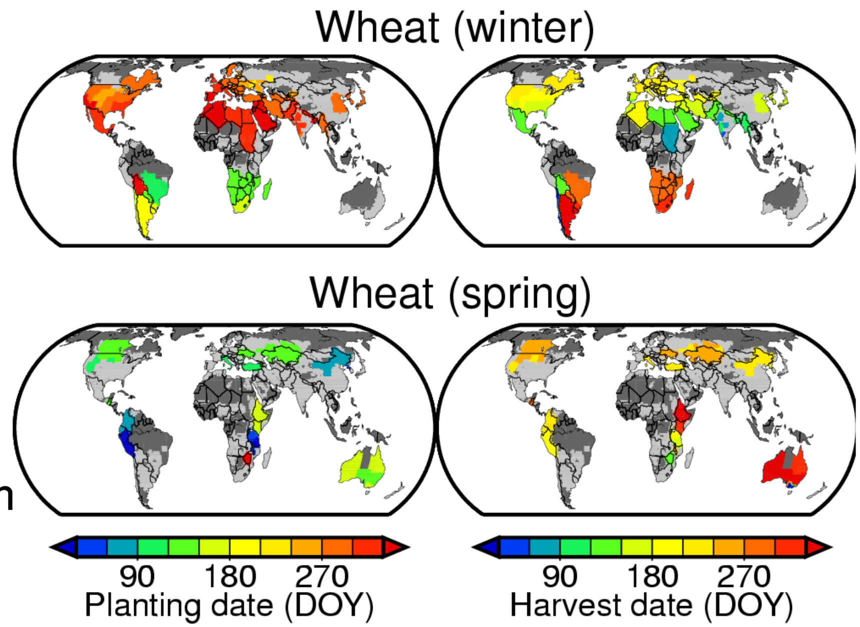
- Global crop phenology dataset

  Sacks et al., 2011, *Global Ecol. Biogeogr.*

  – 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>
<tr><td colspan="6">Winter wheat</td><td colspan="6">Spring wheat</td></tr>
<tr><td rowspan="2">Tillage</td><td colspan="2">Vegetative growth</td><td colspan="3">Reproductive growth</td><td rowspan="2">Tillage</td><td colspan="2">Vegetative growth</td><td colspan="3">Reproductive growth</td></tr>
<tr><td>Planting</td><td></td><td>Flowering</td><td></td><td>Harvesting</td><td>Planting</td><td></td><td>Flowering</td><td></td><td>Harvesting</td></tr>
<tr><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Key growing season</td><td></td><td></td><td></td><td colspan="3">Key growing season</td></tr>
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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

Crop calendar					
Tilling	Vegetative growth		Reproductive growth		
	Planting		Flowering		Harvesting
Timing of **pre-season prediction**	1-mon	2-mon	3-mon	4-mon	5-mon
		Timing of **in-season prediction**	1-mon	2-mon	3-mon

- 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（℃）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.

Hindcasts with reanalysis (upper limit of skill)

- 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?

Random Pre-season Within-season

Sensitivity of yield to temperature and soil moisture

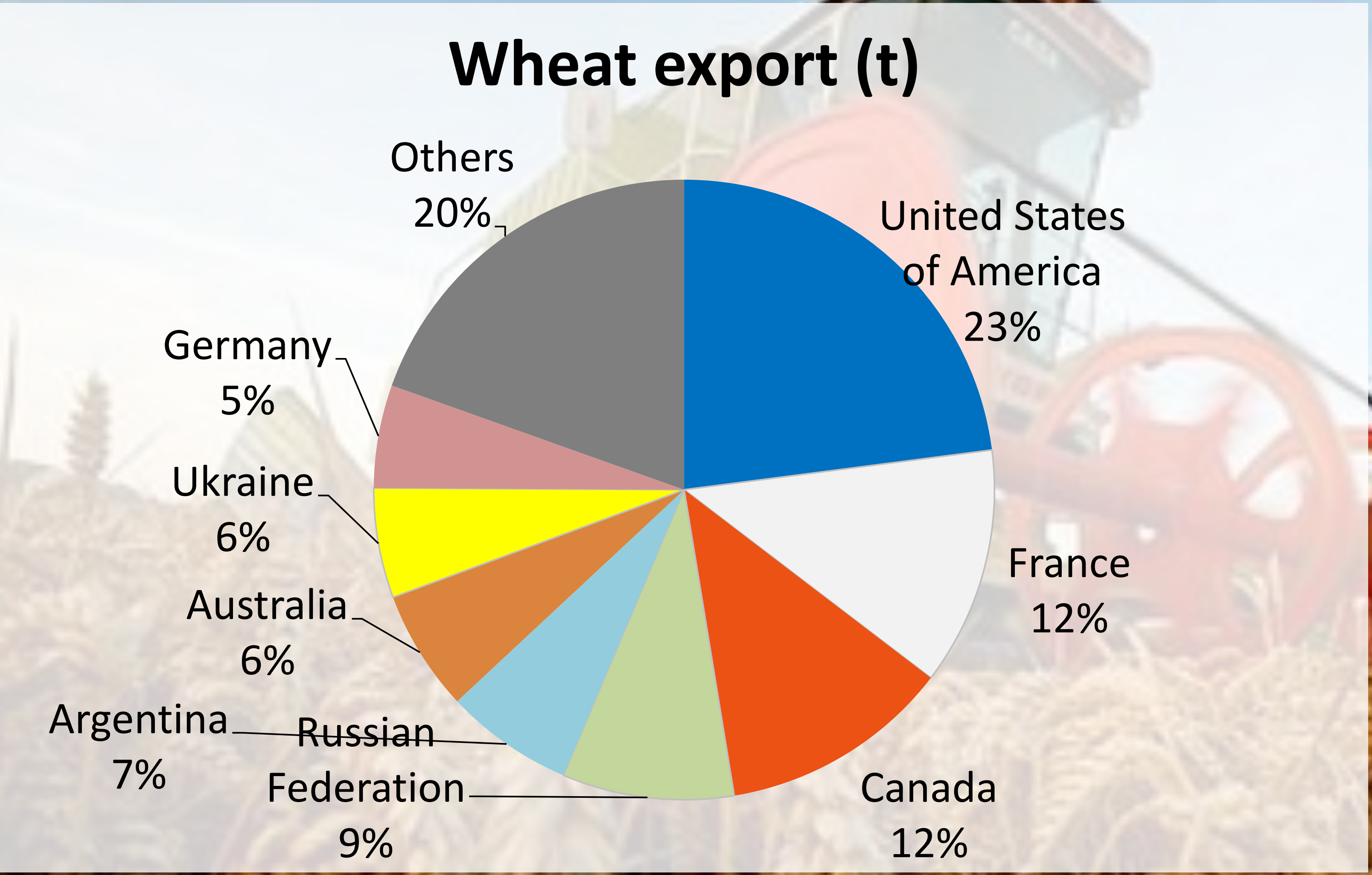
- Weighted average of yield elasticity to temperature and soil moisture (evaluated based on climatological mean values);
- Maize and soybean are water dependent while rice and wheat are more temperature dependent.

Crop prediction skill

(Skillful area)

Observation Within-season Pre-season

Is there further value from prediction for wheat?



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

Crop prediction skill in wheat exporting countries

1st Exporter (23% of world export)

2nd Exporter (12%)

(Skillful area)

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.