Monitoring the Vulnerability and the need for Adaptation Planning for Food Security

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Outline

- Past and future trends in population, food production and climate change perturbations.
- Global environmental change and its impact on agriculture production systems.
- Role of crop simulation models in addressing future food security and climate change.
Issues of 21st Century, Particularly in Developing Countries

- Meeting food demands for the growing population.
- Reducing the risks of soil and ecosystem degradation.
- Minimizing the risks of eutrophication and contamination of natural waters.
- Decreasing the net emissions CO$_2$ and other greenhouse gases.
Trends That Shape Our Future
Trends, Signs and Signatures from the Earth
Past, Present and Future World Population

World Population

Year
Population in Billions

0 500 1000 1500 2000
Trends, Signs and Signatures from the Earth
Past, Present and Future World Population Trends

Population, millions

<table>
<thead>
<tr>
<th>Region</th>
<th>2000</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia (less China and India)</td>
<td>1,419</td>
<td>2,351</td>
</tr>
<tr>
<td>China</td>
<td>1,275</td>
<td>1,395</td>
</tr>
<tr>
<td>India</td>
<td>1,016</td>
<td>1,531</td>
</tr>
<tr>
<td>Africa</td>
<td>796</td>
<td>1,803</td>
</tr>
<tr>
<td>Europe</td>
<td>728</td>
<td>631</td>
</tr>
<tr>
<td>Latin America</td>
<td>520</td>
<td>768</td>
</tr>
<tr>
<td>North America</td>
<td>315</td>
<td>448</td>
</tr>
</tbody>
</table>

% Change:
-66% 9.4% 51% 127% -13% 48% 42%
Global Major Foods: Meat and Poultry production and consumption

1961 and 2007: Million t
Poultry = 9 and 87
Meat = 71 and 286

Selected fruits = 1.95 lb/year
Vegetables = 3.21 lb/year
Meat and Poultry = 0.65 lb/year
Flour and Cereals = 2.70 lb/year
Trends, Signs and Signatures from the Earth

Maize: Production and Yield - Selected Countries

- USA: 142% @ 121.0 kg yr\(^{-1}\)
- China: 357% @ 91.9 kg yr\(^{-1}\)
- Brazil: 184% @ 52.6 kg yr\(^{-1}\)

Production
- USA: 263% @ 5.23 MMt yr\(^{-1}\)
- China: 743% @ 2.91 MMt yr\(^{-1}\)
- Brazil: 471% @ 0.93 MMt yr\(^{-1}\)

\(P = 67\%, \text{ and } A = 46\%\)
Trends, Signs and Signatures from the Earth
Rice: Production and Yield - Selected Countries

Year

Rice yield, t ha\(^{-1}\)
0 1 2 3 4 5 6 7 8

USA, 70 kg yr\(^{-1}\)
Indonesia, 77 kg yr\(^{-1}\)
Japan, 32 kg yr\(^{-1}\)
China, 102 kg yr\(^{-1}\)
India, 42 kg yr\(^{-1}\)
Thailand, 21 kg yr\(^{-1}\)

World 2004 average = 3.97 t ha\(^{-1}\)

World, 53 kg yr\(^{-1}\)

Trends, Signs and Signatures from the Earth
Rice: Production and Yield - Selected Countries
Trends, Signs and Signatures from the Earth
Management Practices on Soil Quality

Crop rotations

Morrow plots: East-central Illinois

Fertility management

Sanborn Field: Central Missouri

Soil organic carbon (%)

Reicosky et al. 2000
### Trends, Signs and Signatures from the Earth

**Cropland area, Irrigation and Salinization**

<table>
<thead>
<tr>
<th>Country</th>
<th>Cropland area</th>
<th>Irrigated area</th>
<th>Salinized area</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>124.0</td>
<td>54.4 (22%)</td>
<td>7-8 (14%)</td>
</tr>
<tr>
<td>India</td>
<td>161.8</td>
<td>54.8 (31%)</td>
<td>10-30 (50%)</td>
</tr>
<tr>
<td>USA</td>
<td>177.0</td>
<td>22.4 (13%)</td>
<td>4.5 -6 (15%)</td>
</tr>
<tr>
<td>USSR</td>
<td>204.1</td>
<td>19.9 (2%)</td>
<td>2.5-4.5 (21%)</td>
</tr>
<tr>
<td>World</td>
<td>1364.2</td>
<td>271.7 (21%)</td>
<td>62-82 (37%)</td>
</tr>
</tbody>
</table>

**Percentage change from Year 2000**

<table>
<thead>
<tr>
<th>Country</th>
<th>Cropland area</th>
<th>Irrigated area</th>
<th>Salinized area</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>USA</td>
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<td></td>
</tr>
<tr>
<td>USSR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Percent change since 1985**

S.G. Pritchard and J. S. Amthor, 2005
Trends, Signs and Signatures from the Earth
Population, Cereal Yield, Arable and Irrigated Area, N Use

2000 values are:
Cereal yield = 2.25
Arable area = 1.09
Irrigated area = 1.98
Population = 1.97
Fertilizer use = 4.33
Feeding 10 Billion Mouths

- We must develop the capacity to feed 10 billion people within the next 40 to 50 years.

- The average world current cereal yield is about 3 tons per ha for about 6 billion people.

- We need about 4 tons per ha for 8 billion (33% more than the current), and 5 tons per ha for 10 billion (67% more than the current).
Routes to Greater Food Production

- Increase in the area of land under cultivation.

- Displacement of lower yielding crops by higher yielding ones (done since the dawn of domestication).

- **Efficiency of crop production in terms of:**
  - Per unit of land area (yield per ha)
  - Per unit of time
  - Per unit of inputs such as fertilizers, water and labor etc.
Here Comes the Greatest Challenge of our Time, The Global Climate Change
Trends, Signs and Signatures from the Earth

- Greenhouse gases (CO$_2$, CH$_4$, N$_2$O etc.)
- Temperatures
- Glaciers, oceans and sea-levels
- Precipitation patterns and drought intensities
- Extreme events
- Higher ozone and UV-B radiation
Trends, Signs and Signatures from the Earth
Global Carbon Emissions and Fluxes

Preindustrial -1850 = 286 ppm
Current, 2005 = 380 ppm
Difference = 94 ppm

Preindustrial -1850 = 0.005 billion Mt.
Current, 2005 = 7.99 billion Mt.
Difference = 7.93 billion Mt.

Preindustrial -1850 = 501 Tg C
Current, 2005 = 1467 Tg C
Difference = 967 Tg
### Global warming gases

<table>
<thead>
<tr>
<th>Period</th>
<th>CO₂</th>
<th>Methane</th>
<th>Nitrous oxide</th>
<th>CFC-11</th>
<th>HFC-23</th>
<th>Perfluoromethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-industrial concentration</td>
<td>about 280 ppm</td>
<td>about 700 ppb</td>
<td>about 270 ppb</td>
<td>0</td>
<td>0</td>
<td>40 ppt</td>
</tr>
<tr>
<td>(1850)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Concentration in 2008</td>
<td>386 ppm</td>
<td>1857 ppb</td>
<td>321 ppb</td>
<td>244 ppt</td>
<td>18 ppt</td>
<td>74 ppt</td>
</tr>
<tr>
<td>Rate of change</td>
<td>1.43 ppm/yr</td>
<td>7.0 ppb/yr</td>
<td>0.8 ppb/yr</td>
<td>-1.4 ppt/yr</td>
<td>0.55 ppt/yr</td>
<td>1 ppt/yr</td>
</tr>
<tr>
<td>Atmospheric lifetime</td>
<td>5 to 200 years</td>
<td>12 years</td>
<td>114 years</td>
<td>45 years</td>
<td>260 Years</td>
<td>&gt;50,000 years</td>
</tr>
</tbody>
</table>

### Ozone depleting chemicals
CFCs are commonly used as refrigerants, solvents, and foam blowing agents. The most common CFCs are CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115.
Trends, Signs and Signatures from the Earth
Future trends in global carbon dioxide concentration and associated climate change, if no interventions are made

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>2025</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide concentration</td>
<td>405-460 ppm</td>
<td>445-640 ppm</td>
<td>720-1020 ppm</td>
</tr>
<tr>
<td>Global mean temperature change from the year 1990</td>
<td>0.4-1.1 °C</td>
<td>0.8-2.6 °C</td>
<td>2.4-6.4 °C</td>
</tr>
<tr>
<td>Global mean sea-level rise from the year 1990</td>
<td>3-14 cm</td>
<td>5-32 cm</td>
<td>26-59 cm</td>
</tr>
</tbody>
</table>
Climate Change and Crop Productivity

Photosynthesis - Leaf Water Potential

Midday Leaf Water Potential, MPa

Photosynthesis, mg CO₂ m⁻² s⁻¹

PPF, 1600 µmol m⁻² s⁻¹

700 µl l⁻¹ CO₂

350 µl l⁻¹ CO₂

Well-watered  Water stressed
Climate Change and Crop Productivity

Temperature and CO2 - Rice Yield

Baker and Allen, 1993
Climate Change and Crop Productivity

Rice Growing Areas and Variety trial Experiments
Growing season temperatures from those locations listed in the previous slide and with an additional 5°C added to those temperatures relative to optimum and marginal conditions.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

Ambient temperature: 25.36°C = 8.26 t/ha
Ambient plus 5°C: 30.36°C = 5.51 t/ha, 33%
Climate Change and Crop Productivity
Temperature and Cotton Growth

4-week old cotton seedlings

20/12  25/17  30/22  35/27  40/32 °C
Climate Change and Crop Productivity
Temperature and CO₂ - Cotton Reproductive Growth

![Graph showing the relationship between temperature and fruit production efficiency in cotton. The x-axis represents temperature in °C, ranging from 24 to 34. The y-axis represents fruit production efficiency in g kg⁻¹ Dry Weight, ranging from 0 to 400. Two lines are depicted: one for 700 µL L⁻¹ and one for 350 µL L⁻¹ CO₂. The graph shows a decrease in fruit production efficiency with increasing temperature.](image-url)
High Temperature Effects on Cotton
Heat-blasted Flower Buds and Flowers
San Joaquin Valley, California, USA

Figure 7. Heat-blasted squares in California’s San Joaquin Valley.
(Photo: R. Vargas)
Climate Change and Crop Productivity
Temperature and CO2 – Rangeland C4 Grass: Big Bluestem

Vegetative Weight and Seed Weight

![Graph showing the effect of temperature and CO2 levels on vegetative biomass and seed weight.]

- Vegetative biomass (g plant⁻¹)
  - 360 ppm
  - 720 ppm
- Seed weight (g plant⁻¹)
  - 1.5% °C⁻¹
  - 8.4% °C⁻¹
Climate Change and Crop Productivity

Long-term Temperatures across Regions

Day of the Year

Temperature, °C

Phoenix, AZ, USA
Stoneville, MS, USA
Maros, Indonesia
Hyderabad, India

Stoneville, MS, USA
Issues of 21\textsuperscript{st} Century, Particularly in Developing Countries

- Meeting food demands for the growing population.
- Reducing the risks of soil and ecosystem degradation.
- Minimizing the risks of eutrophication and contamination of natural waters.
- Developing scientific capacity and system tools to assess the impacts of climate change on food and fiber security.
Can We Use Crop Models for Regional and Global Food and Fiber Security and Assist in Policy Decisions?

- Simple models can’t simulate complex problems.
- Robust and process-rich models are needed to study the impacts of climate change perturbation on agro-ecosystem goods and services.

Liang et al. 2009
Crop Model Applications for Natural Resource Management

✓ Farm management (e.g. planting, irrigation, fertilization and harvest scheduling).

✓ Resource management (e.g. several Govt. agencies and private comp. use).

✓ Climate change and policy analysis.

✓ Production forecasts (e.g. global, regional and local forecasts).

✓ Research and development (e.g. research priorities and guide fund allocations).

✓ Turning information into knowledge (e.g. information overflow in every area including agricultural research).
Crop Model Applications for Adaptation to Global Climate Change

- What production strategies have the least risk of economic loss?

- How can natural resource quality be best managed while achieving production goals?

- What are the consequences of climate change on production, gaseous emissions, pest populations, etc.?

- What would be the effect of regional drought on agricultural-based energy production?

- What are the adaptation and mitigation approaches to agricultural production in 21st Century?
Crop Model Applications for Climate Change Scenarios: A Case Study
Potential as Well as Stress Interactions

![Graph showing Lint yield, lbs/acre vs. Year (1960 to 2060)]

- **CO₂ effect**

![Bar chart showing Lint Yield (kg ha⁻¹) for different climate change scenarios (Hot/Dry, Hot/Wet, Cold/Dry, Cold/Wet, Normal) from 1980 to 1992]

- Current, Current with elevated CO₂, Future
Crop Model Applications for Climate Change Scenarios: A Case Study

Planting date Adaptations

![Bar chart showing yield changes over days from 1 May. The chart compares current and future yield scenarios.]
Climate Change and Crop Productivity
Some Considerations

- Climate change has no boundaries, and can’t be viewed in isolation.

- We should consider other stresses on food production systems such as population dynamics, habitat destruction and fragmentation, land-use changes, biodiversity and invasive species dominance.

- The current and projected changes in climate are unprecedented, and the ecosystems including managed ecosystems such as agriculture may not cope with the changes projected in climate.
Climate Change and Crop Productivity
Some Considerations

- Except limiting the causes of climate change, there are no other long-term strategies.
- For a shorter-term, we must develop crop varieties which can withstand changes projected in climate to meet the growing demands for food.
- We must also develop models that provide adequate warning or guidance for policy makers.
- Everybody and every nation should participate in the process. Opportunities are there for everyone.
We will be > 10 billion by 2050 in a much different climate than what we have today

We need to produce enough goods and services in a sustainable way

We need tools to provide information to policy makers
“You can’t eat the potential yield, but need to raise the actual by combating the stresses”

Norman E. Borlaug
Nobel Peace Laureate

“You can’t build peace on empty stomachs”

John Boyd Orr
Nobel Peace Laureate
First FAO Director General

Questions?