Environmental Plant Physiology
Introduction

K. Raja Reddy
Krreddy@pss.msstate.edu

Mississippi State University
A Land-Grant Institution
Personal - Family

Sasank Reddy

short bio

- I'm a PhD candidate in the Department of Electrical Engineering at UCLA and a graduate student researcher in the Center for Embedded Networked Sensing. I received my Master's degree in Embedded Computing Systems from UCLA in December 2006. Prior to joining UCLA, I worked at Radiant Systems in Atlanta, Georgia. Furthermore, I did my undergrad at the Georgia Institute of Technology where I majored in Computer Engineering.

contact

- office: 3551 Boelter Hall
- sasank [at] ee [dot] ucla [dot] edu
Personal - Education

**Education:** Ph.D. in Botany with Applied Plant Physiology as a major

**Research areas:** Environmental plant physiology including global change, crop modeling, remote sensing.

**Years at MSU:** 21

**Taught the course since:** 2000
Trends That Shape Our Future
Trends, Signs and Signatures from the Earth
Past, Present and Future World Population

![Graph showing world population over the years](image)
Trends, Signs and Signatures from the Earth
Present and Future World Population Trends

- Population, millions
  - Asia: 2,367
  - China: 1,437
  - India: 1,628
  - Africa: 1,941
  - Europe: 728
  - Latin America: 549
  - North America: 326

- Trends, Signs and Signatures from the Earth
  - 56%
  - 10%
  - 50%
  - 120%
  - -5%
  - 42%
  - 39%
## Maize - Production and Yield – Selected Countries

**Trends, Signs and Signatures from the Earth**

<table>
<thead>
<tr>
<th>Country</th>
<th>Maize production area, %</th>
<th>Maize production, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>China</td>
<td>15%</td>
<td>25%</td>
</tr>
<tr>
<td>Brazil</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Mexico</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>France</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>India</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>Romania</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>Argentina</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.5%</td>
<td>1%</td>
</tr>
</tbody>
</table>

*Year 2004, Area = 147.02 Mha, Production = 721.4 MMt*
Trends, Signs and Signatures from the Earth
Maize - Production and Yield – Selected Countries

### Yield

- **USA**: 156% @ 114 kg yr⁻¹
- **China**: 335% @ 100 kg yr⁻¹
- **Brazil**: 157% @ 47 kg yr⁻¹

### Production

- **USA**: 226% @ 3.90 MMt yr⁻¹
- **China**: 631% @ 2.77 MMt yr⁻¹
- **Brazil**: 364% @ 0.73 MMt yr⁻¹

P = 67%, and A = 46%
# Trends, Signs and Signatures from the Earth

**Wheat - Production and Yield – Selected Countries**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wheat yield, kg ha⁻¹</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>651% @ 88kg yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>80% @ 26 kg yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>210% @ 50 kg yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wheat production, MMt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>539% @ 2.42 MMt yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>76% @ 1.62 MMt yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>555% @ 0.69 MMt yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Trends, Signs and Signatures from the Earth
Rice - Production and Yield – Selected Countries

Year 2004, Area = 151.3 Mha, Production = 605.8 MMt

Rice production area, %
Area
Production

Rice production, %

Area and Production for selected countries:

- USA
- Japan
- Brazil
- Philippines
- Myanmar
- Thailand
- Vietnam
- Bangladesh
- Indonesia
- India
- China

Area and production data for 2004.
Trends, Signs and Signatures from the Earth
Rice - Production and Yield – Selected Countries

Yield
- China: 205% @ 102 kg yr\(^{-1}\)
- Indonesia: 156% @ 77 kg yr\(^{-1}\)
- India: 90% @ 42 kg yr\(^{-1}\)

Production
- China: 232% @ 2.98 MMt yr\(^{-1}\)
- India: 339% @ 2.15 MMt yr\(^{-1}\)
- Indonesia: 132% @ 1.12 MMt yr\(^{-1}\)

P = 60%, and A = 55%
Trends, Signs and Signatures from the Earth

Soybean - Production and Yield – Selected Countries

Year 2004, Area = 91.44 Mha, Production = 204.3 MMt
Trends, Signs and Signatures from the Earth
Soybean - Production and Yield – Selected Countries

USA: 69% @ 26 kg yr⁻¹
Brazil: 103% @ 37 kg yr⁻¹
China: 168% @ 26 kg yr⁻¹

USA: 364% @ 1.35 MMt yr⁻¹
Brazil: @ 0.99 MMt yr⁻¹
China: 183% @ 0.24 MMt yr⁻¹
Trends, Signs and Signatures from the Earth
Cotton - Production and Yield – Selected Countries

Seed cotton yield, kg ha⁻¹

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>409% @ 58 kg yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>72% @ 16 kg yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>141% @ kg yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cotton production, MMt

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>45% @ 0.09 MMt yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>172% @ 0.08 MMt yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>649% @ 0.29 MMt yr⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Trends, Signs and Signatures from the Earth
Global Major Foods – Meat and Poultry Production

Meat and Poultry Production

Meat and Poultry Production Relative Trends

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

Year
Trends, Signs and Signatures from the Earth
Global Major Foods – Per Capita Consumption

<table>
<thead>
<tr>
<th>Year</th>
<th>Consumption, lb/person</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>100</td>
</tr>
<tr>
<td>1970</td>
<td>150</td>
</tr>
<tr>
<td>1975</td>
<td>200</td>
</tr>
<tr>
<td>1980</td>
<td>250</td>
</tr>
<tr>
<td>1985</td>
<td>300</td>
</tr>
<tr>
<td>1990</td>
<td>350</td>
</tr>
<tr>
<td>1995</td>
<td>400</td>
</tr>
<tr>
<td>2000</td>
<td>450</td>
</tr>
</tbody>
</table>

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
Cropland area, Irrigation and Salinization

Percentage change from Year 1985 to 2000

<table>
<thead>
<tr>
<th></th>
<th>Cropland area</th>
<th>Irrigated area</th>
<th>Salinized area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mha</td>
<td>(Percentage)</td>
<td>Mha</td>
</tr>
<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>

S.G. Pritchard and J. S. Amthor, 2005
Crop rotations

Morrow plots: East-central Illinois

Soil organic carbon (%)

Year

1880 1900 1920 1940 1960 1980 2000

Reicosky et al. 2000

Fertility management

Sanborn Field: Central Missouri

Soil organic carbon (%)

Year

1880 1900 1920 1940 1960 1980

Wagner, (1989)

Estimated to 4% in 1888

Wheat, 6 Tons Manure/year

Corn, 6 Tons Manure/year

Continuous Wheat

Continuous Corn

Crop rotations Fertility management

Wheat, 6 Tons Manure/year

Corn, 6 Tons Manure/year

Continuous Wheat

Continuous Corn

Reicosky et al. 2000
## Trends, Signs and Signatures from the Earth
Population, cereal yield, arable and irrigated area, N use

<table>
<thead>
<tr>
<th>Year</th>
<th>Relative values (1961=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cereal yield</td>
</tr>
<tr>
<td>1955</td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
</tbody>
</table>

### 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 6.4 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.
- Increase in the number of crops per hectare per year (mostly practiced in tropics, requires access to irrigation, high input use, short season cultivars, and others such as labor, pest and disease control may be a problem).
- 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 (CO2, CH4, N2O etc.)
- Temperatures
- Glaciers, oceans and sea-levels
- Precipitation patterns and drought intensities
- Extreme events
- Higher ozone and UV-B radiations
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
Past and Current Levels in GHG Concentrations, Rates of Change and Atmospheric Lifetime

<table>
<thead>
<tr>
<th>Global warming gases</th>
<th>Ozone depleting chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>CO₂</td>
</tr>
<tr>
<td>Pre-industrial</td>
<td>about 280</td>
</tr>
<tr>
<td>concentration (1850)</td>
<td>ppm</td>
</tr>
<tr>
<td>Current Concentration</td>
<td>386 ppm</td>
</tr>
<tr>
<td>in 2008</td>
<td></td>
</tr>
<tr>
<td>Rate of change</td>
<td>1.43 ppm/yr</td>
</tr>
<tr>
<td>Atmospheric lifetime</td>
<td>5 to 200 years</td>
</tr>
</tbody>
</table>
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 ºC</td>
<td>0.8-2.6 ºC</td>
<td>2.4-6.4 ºC</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>
Trends, Signs and Signatures from the Earth
Spatial and temporal trends in climate

Day of the Year
Phoenix, AZ, USA
Stoneville, MS, USA
Maros, Indonesia
Hyderabad, India

Temperature, °C

Spatial and temporal trends in climate
Trends, Signs and Signatures from the Earth
Present and Projected Temperature Changes

- Hyderabad
- Stoneville, MS
- Stoneville, MS + Projected climate
- Hyderabad + Projected climate
- Optimum temperature for Rice

Day of the year
Temperature, °C

0 60 120 180 240 300 360
Climate Change and Crop Productivity
Some Considerations

• As human population expands and demand upon natural resources increases, the need to manage the environments in which people live becomes more important, but also more difficult.

• 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, land and water management and invasive species dominance.
Climate Change and Crop Productivity
Some Considerations

- Land and water management is especially critical as the use of upstream watersheds can drastically affect large numbers of people living in downstream watersheds.
- 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.
- An integrated approach that stresses both the importance of participatory planning and the institutional and technical constraints and opportunities is therefore necessary.
Environmental Stresses and Plant Growing Conditions
Environmental and Cultural Factors Limiting Potential Yields

- Atmospheric carbon dioxide
- Solar radiation
- Temperature (including extremes)
- Water (irrigation and rainfall)
- Wind
- Nutrients (N, P, K, and other nutrients)
- Others, Ultra-violet radiation, ozone etc.,
- Growth regulators (such as PIX)
## Area of Total World Land Surface Subject to Environmental Limitations of Various Types

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Area of world soil subject to limitation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>27.9</td>
</tr>
<tr>
<td>Shallow soil</td>
<td>24.2</td>
</tr>
<tr>
<td>Mineral excess or deficiency</td>
<td>22.5</td>
</tr>
<tr>
<td>Flooding</td>
<td>12.2</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>3.1</td>
</tr>
<tr>
<td>None</td>
<td>10.1</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
<tr>
<td>Temperature</td>
<td>14.8 (over laps with other stresses)</td>
</tr>
</tbody>
</table>
Objectives

• The objectives of this course are to learn plant responses to abiotic stresses, particularly plant growth and development, and to learn modeling methodologies on how to integrate those plant processes under multiple stress conditions.

• At the end, the students are expected to:

  ✓ understand individual as well as interactive abiotic stress effects on photosynthesis, respiration, growth, development and finally yield.

  ✓ understand on how to develop methodologies to integrate multiple stress factor effects on various plant/canopy processes.
Chapter 1

- Atmospheric carbon dioxide
- Solar radiation
- Temperature (Including extremes)
- Water
- Wind
- Nutrients
- Other factors such as ozone
- Plant growth regulators
- The facilities and tools
Chapter 2

Photosynthesis and the environment

- The Environmental productivity Index (EPI) concept.
- The photosynthesis - Species variability.
- Photosynthesis and aging process.
- Respiration.
Chapter 3

Crop growth and development

• Phenology

• Growth of various organs and whole plants.

• The concept of environmental productivity index in quantifying crop growth and development in response to the environment.
Chapter 4

Scaling of processes from leaves to whole plant, canopies or ecosystems.

Chapter 5

Special topics include:

• Plant growth regulators – PIX.
• Remote sensing and environmental plant physiology.
Suggested reading:


