Environmental Plant Physiology

Summary

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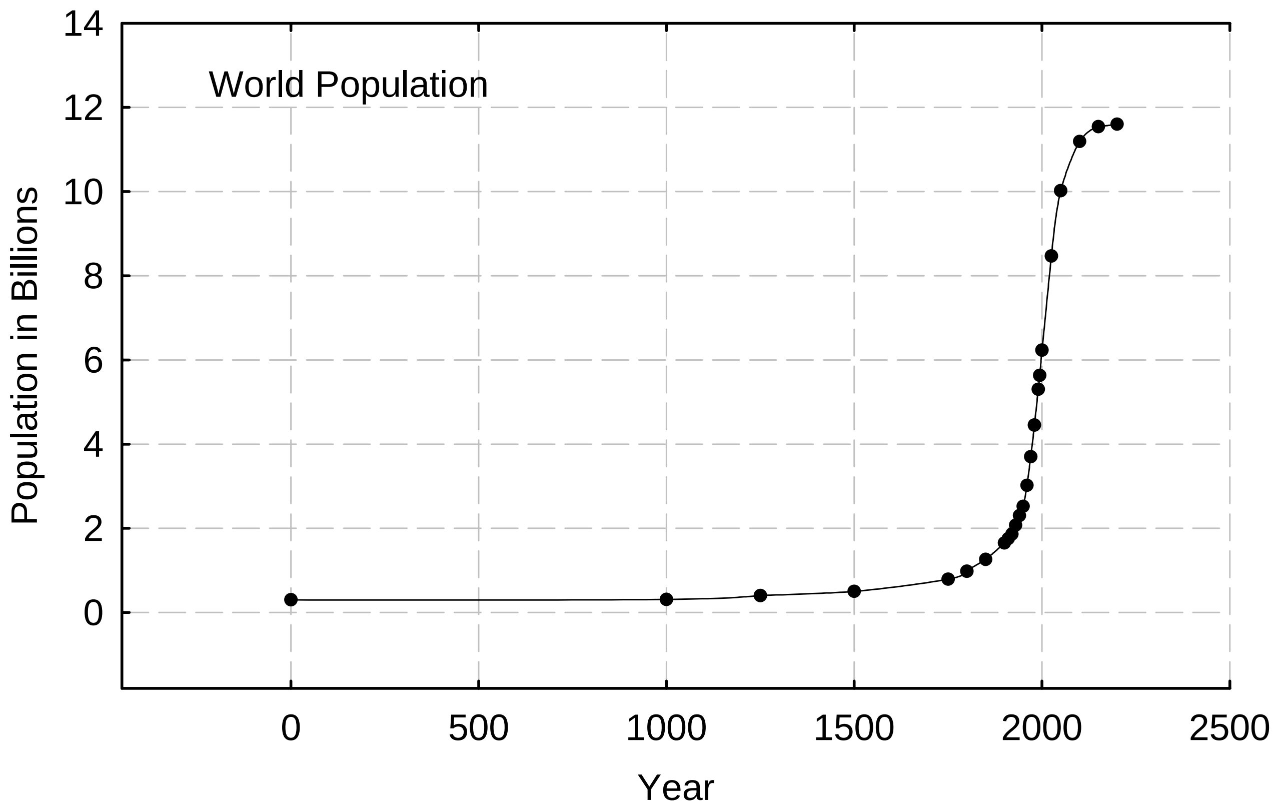
Environmental Plant Physiology
Objectives

- 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.

Trends That Shape Our Future

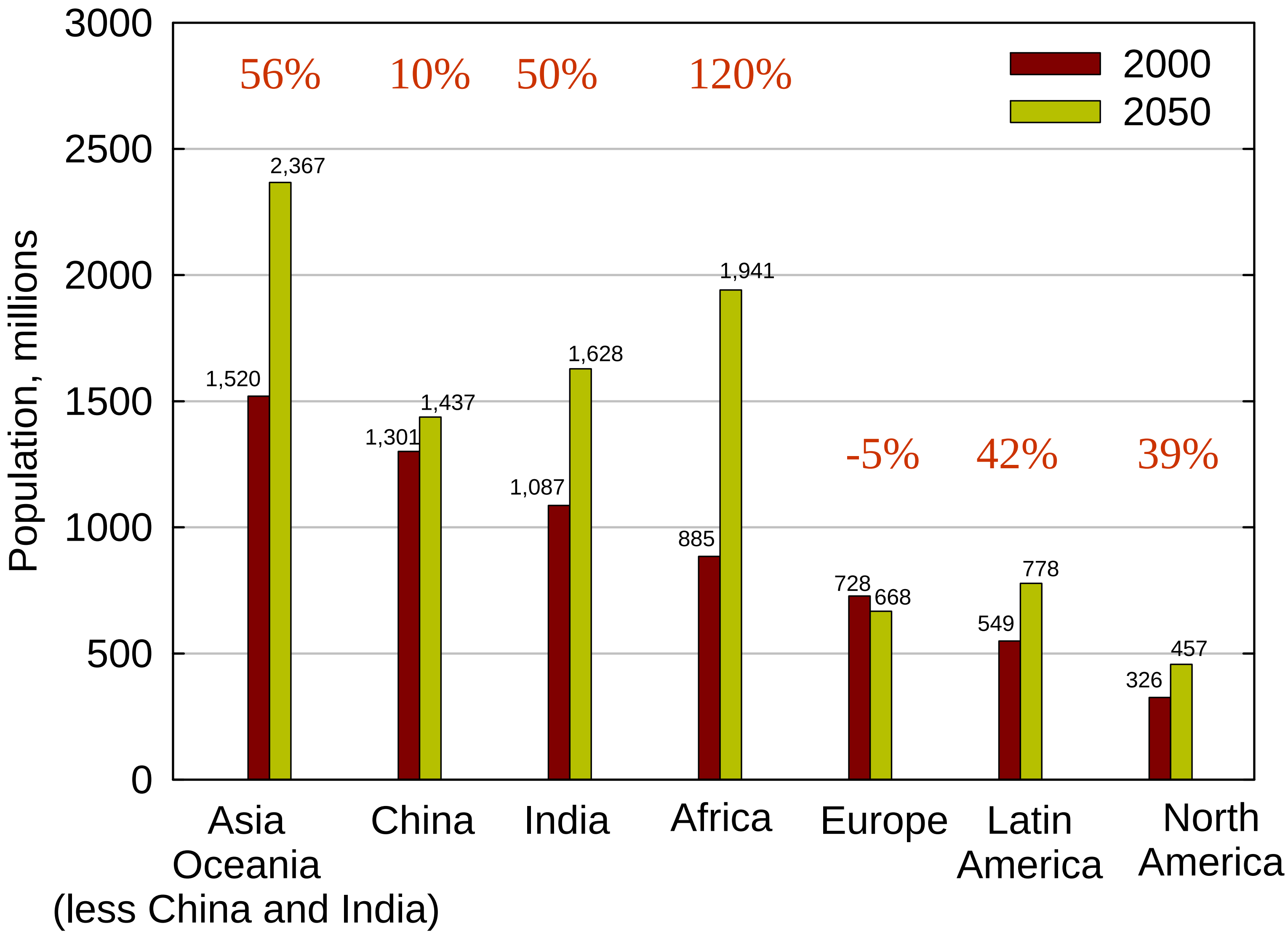
Trends, Signs and Signatures from the Earth

Past, Present and Future World Population



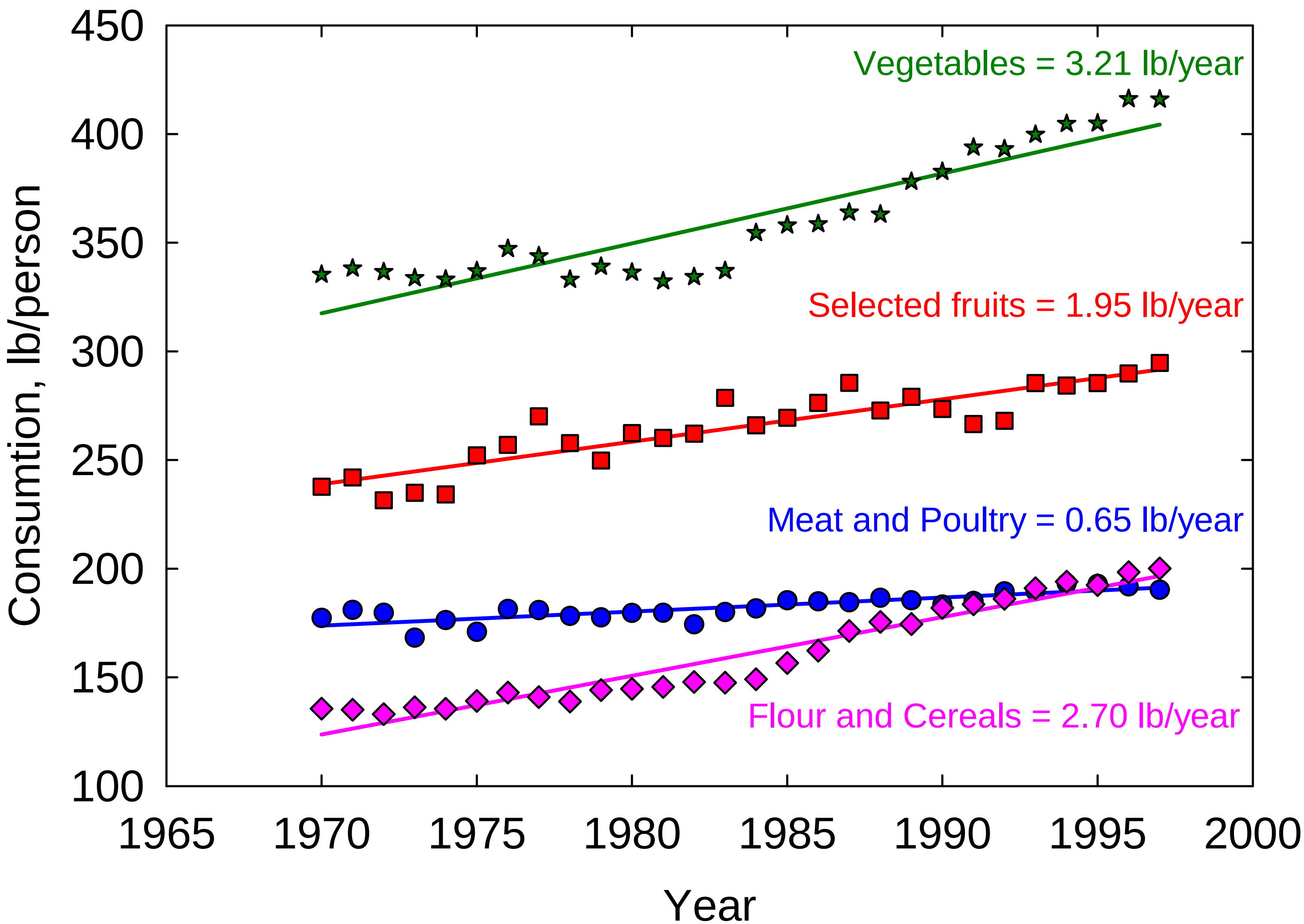
Trends, Signs and Signatures from the Earth

Present and Future World Population Trends



Trends, Signs and Signatures from the Earth

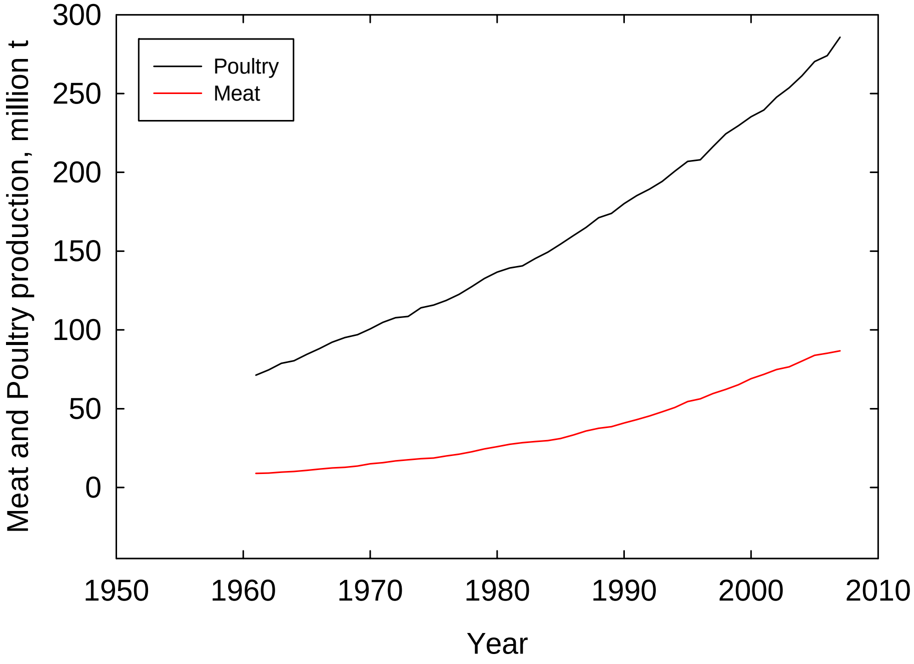
Global Major Foods – Per Capita Consumption



Trends, Signs and Signatures from the Earth

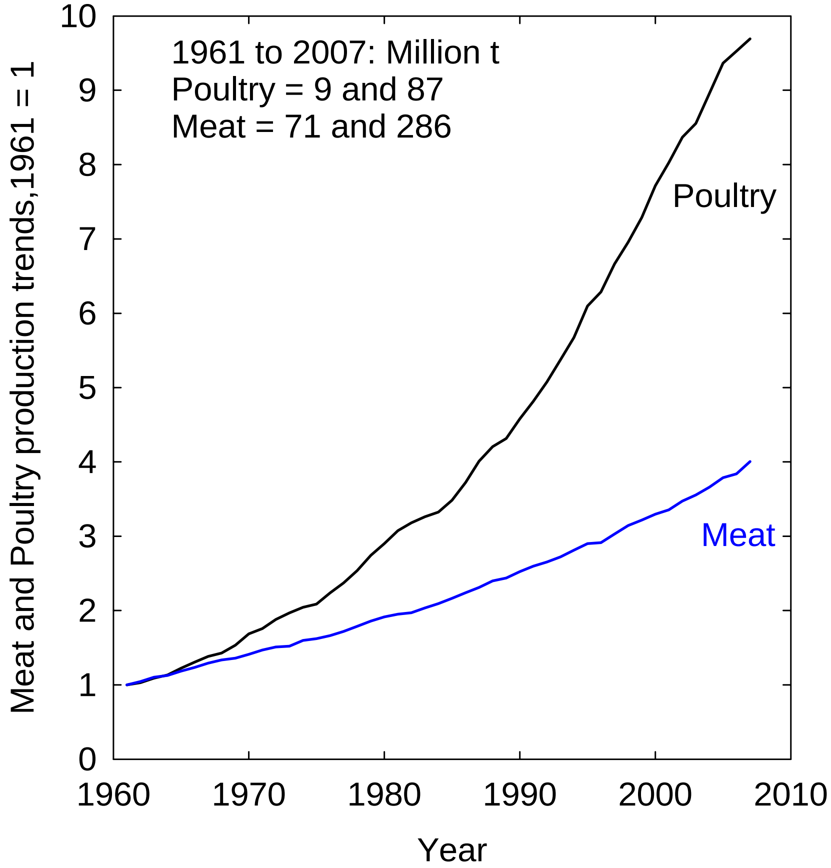
Global Major Foods – Meat and Poultry Production

Meat and Poultry Production



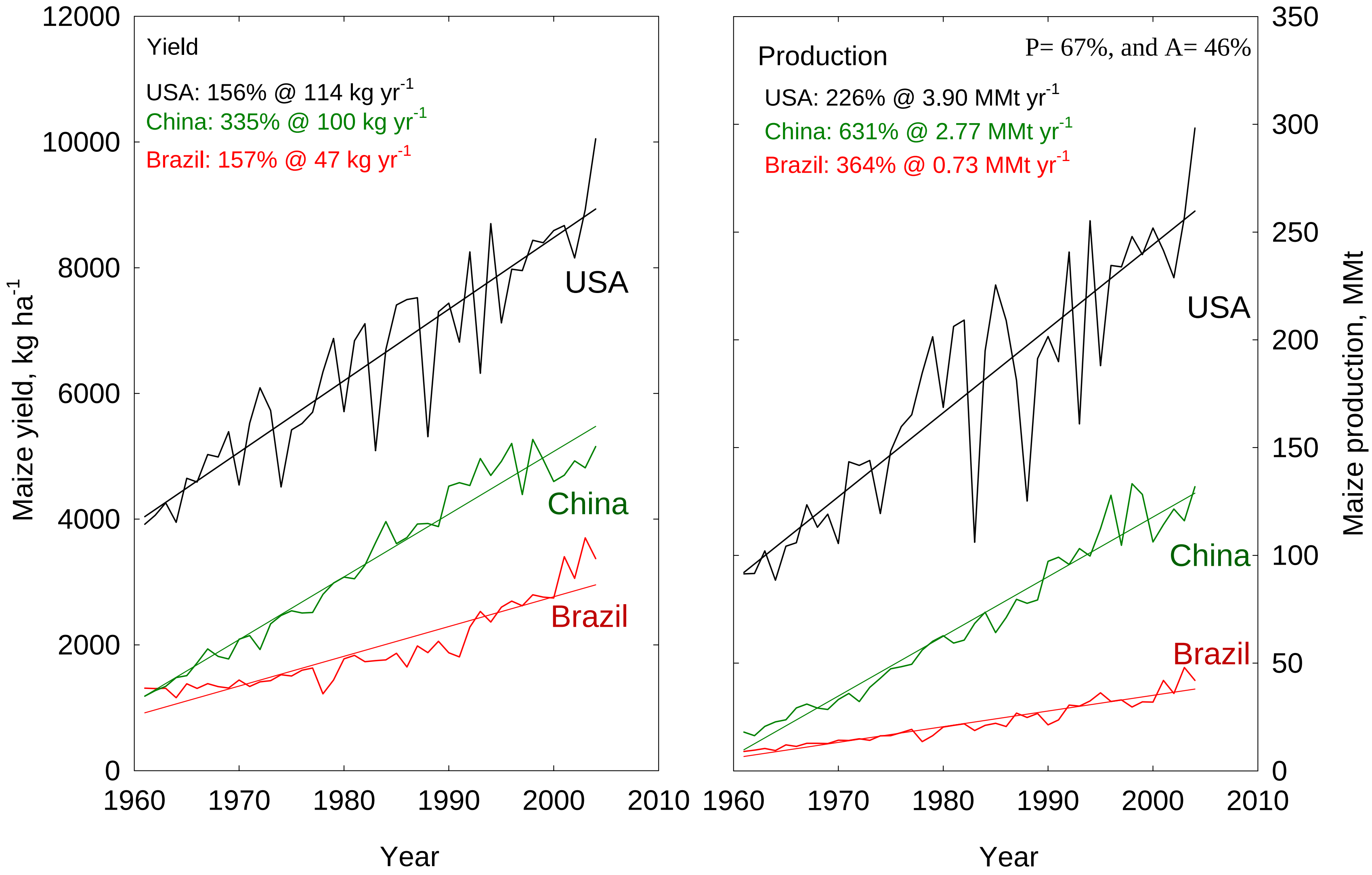
Meat and Poultry Production

Relative Trends



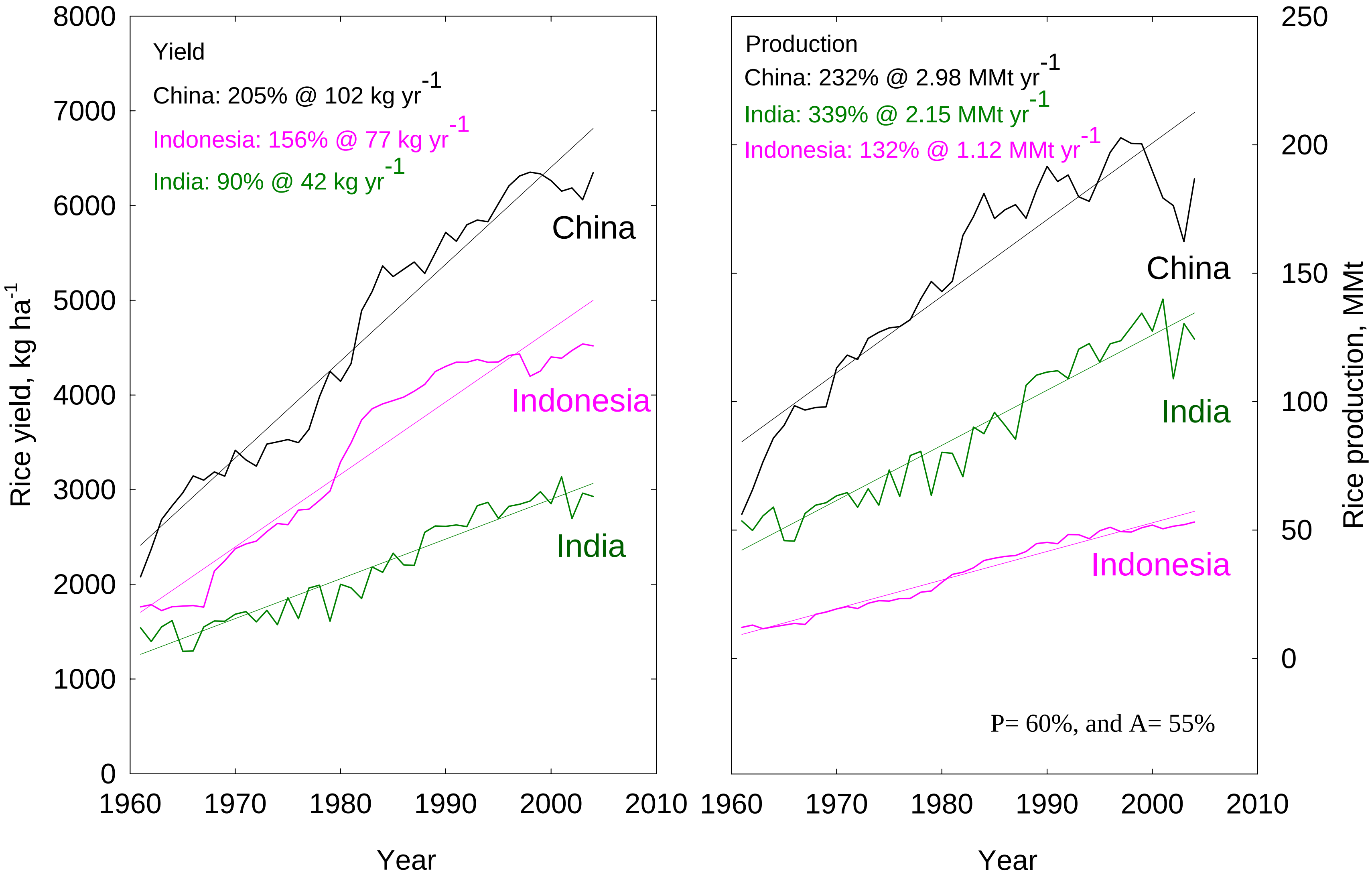
Trends, Signs and Signatures from the Earth

Maize - Production and Yield – Selected Counties



Trends, Signs and Signatures from the Earth

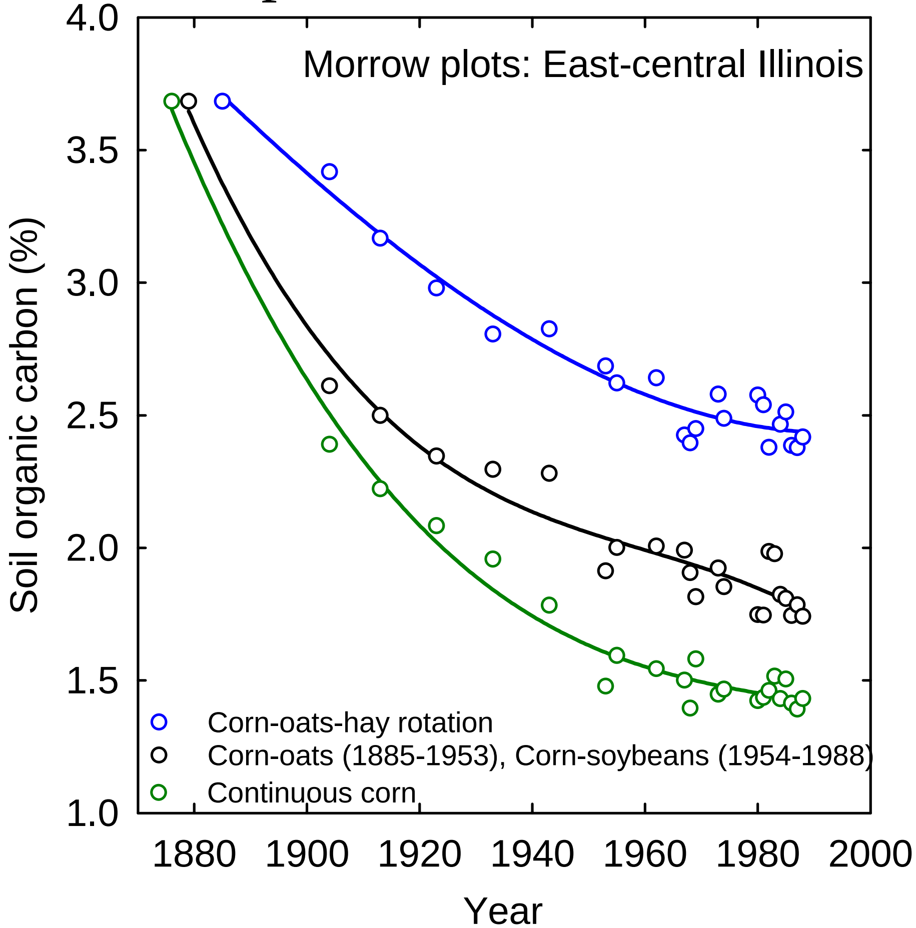
Rice - Production and Yield – Selected Counties



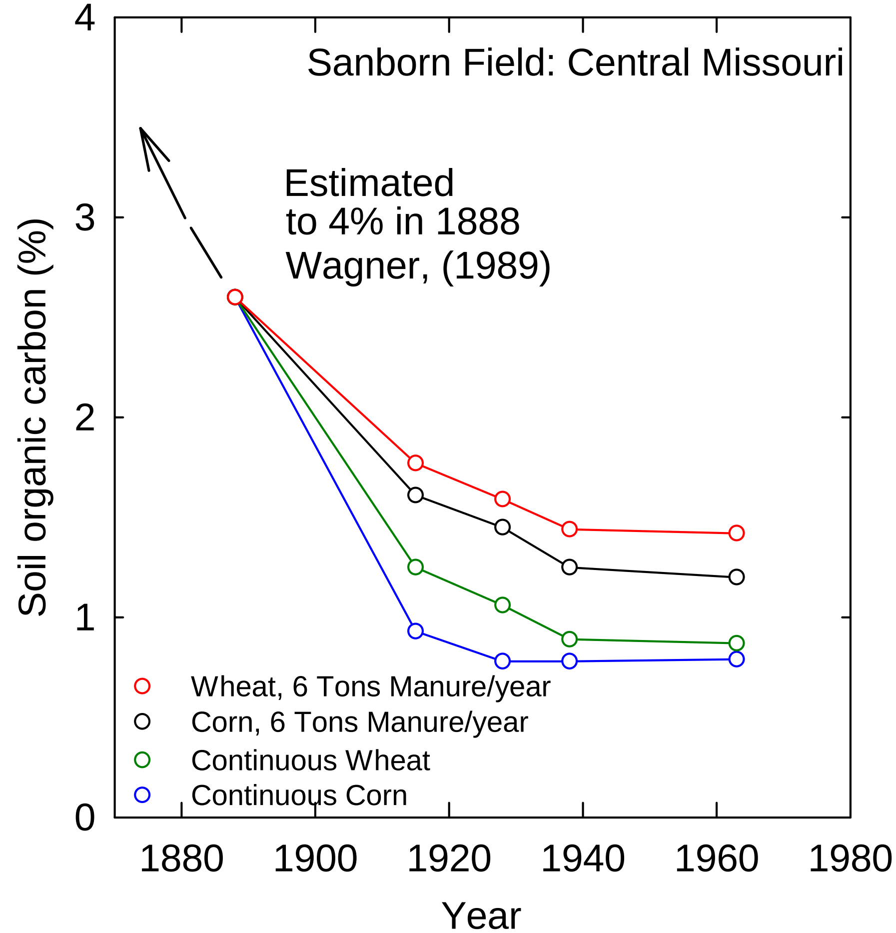
Trends, Signs and Signatures from the Earth

Management Practices

Crop rotations



Fertility management



Reicosky et al. 2000

Trends, Signs and Signatures from the Earth

Cropland area, Irrigation and Salinization

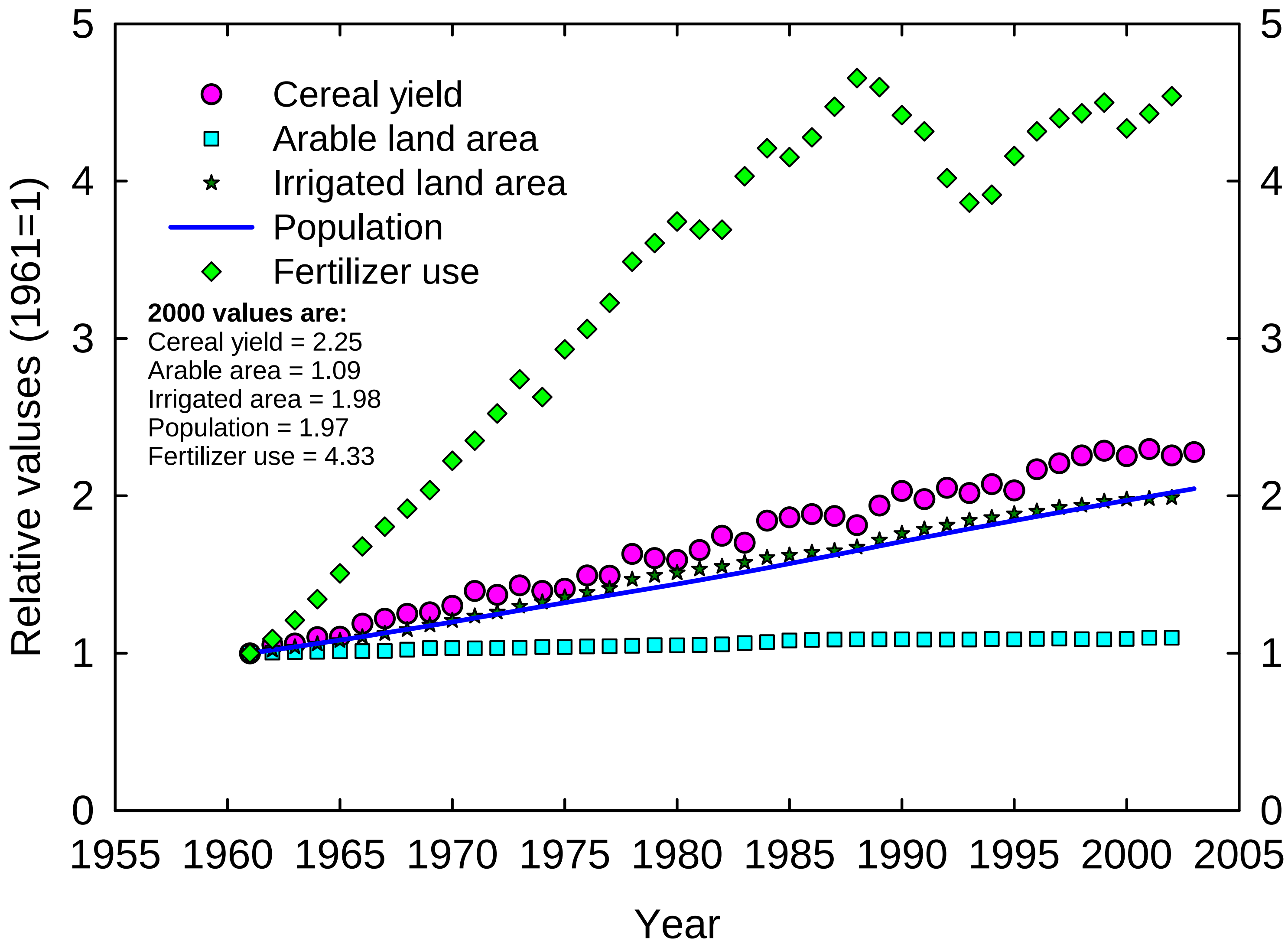
Year 2000

	Cropland area	Irrigated area	Salinized area
	---------------------------- Mha	-------------------------------	
China	124.0	54.4 (22%)	7-8 (14%)
India	161.8	54.8 (31%)	10-30 (50%)
USA	177.0	22.4 (13%)	4.5 -6 (15%)
USSR	204.1	19.9 (2%)	2.5-4.5 (21%)
World	1364.2	271.7 (21%)	62-82 (37%)

Percent change since 1985

Trends, Signs and Signatures from the Earth

Population, cereal yield, arable and irrigated area, N use



Feeding 10 Billion Mouths

We must develop the capacity to feed 10 billion people within in 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).

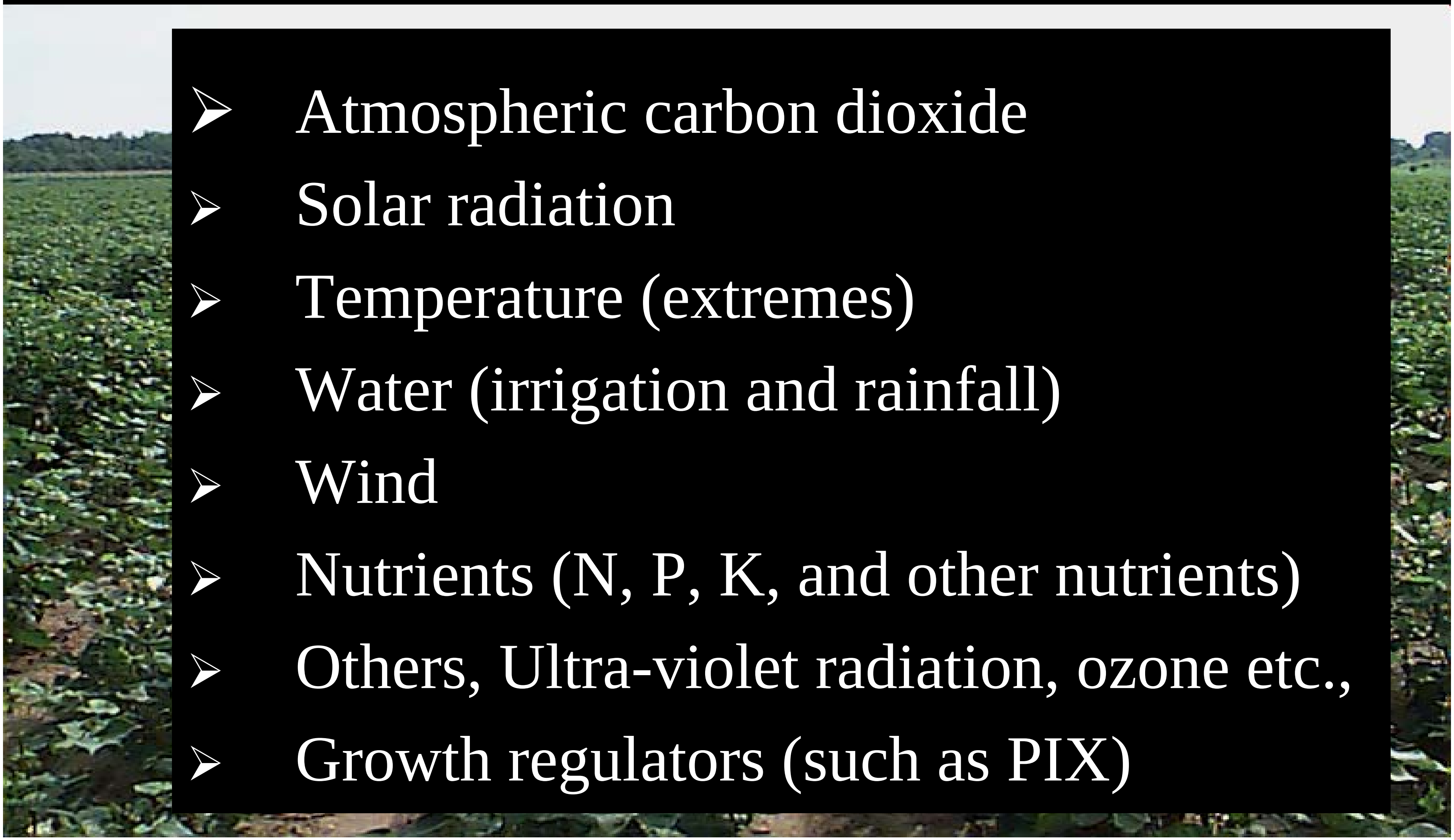
Routes to Greater Food Production

- Increase in the area of land under cultivation.
- 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

Environmental Stresses and Plant Growing Conditions

Environmental and Cultural Factors Limiting Potential Yields



- Atmospheric carbon dioxide
- Solar radiation
- Temperature (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

Limitation	Area of world soil subject to limitation (%)
Drought	27.9
Shallow soil	24.2
Mineral excess or deficiency	22.5
Flooding	12.2
Miscellaneous	3.1
None	10.1
Total	100
Temperature	14.8 (over laps with other stresses)

Environmental Plant Physiology

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

Environmental Plant Physiology

Chapter 2

Photosynthesis and the environment

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

Environmental Plant Physiology

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.

Environmental Plant Physiology

Chapter 4

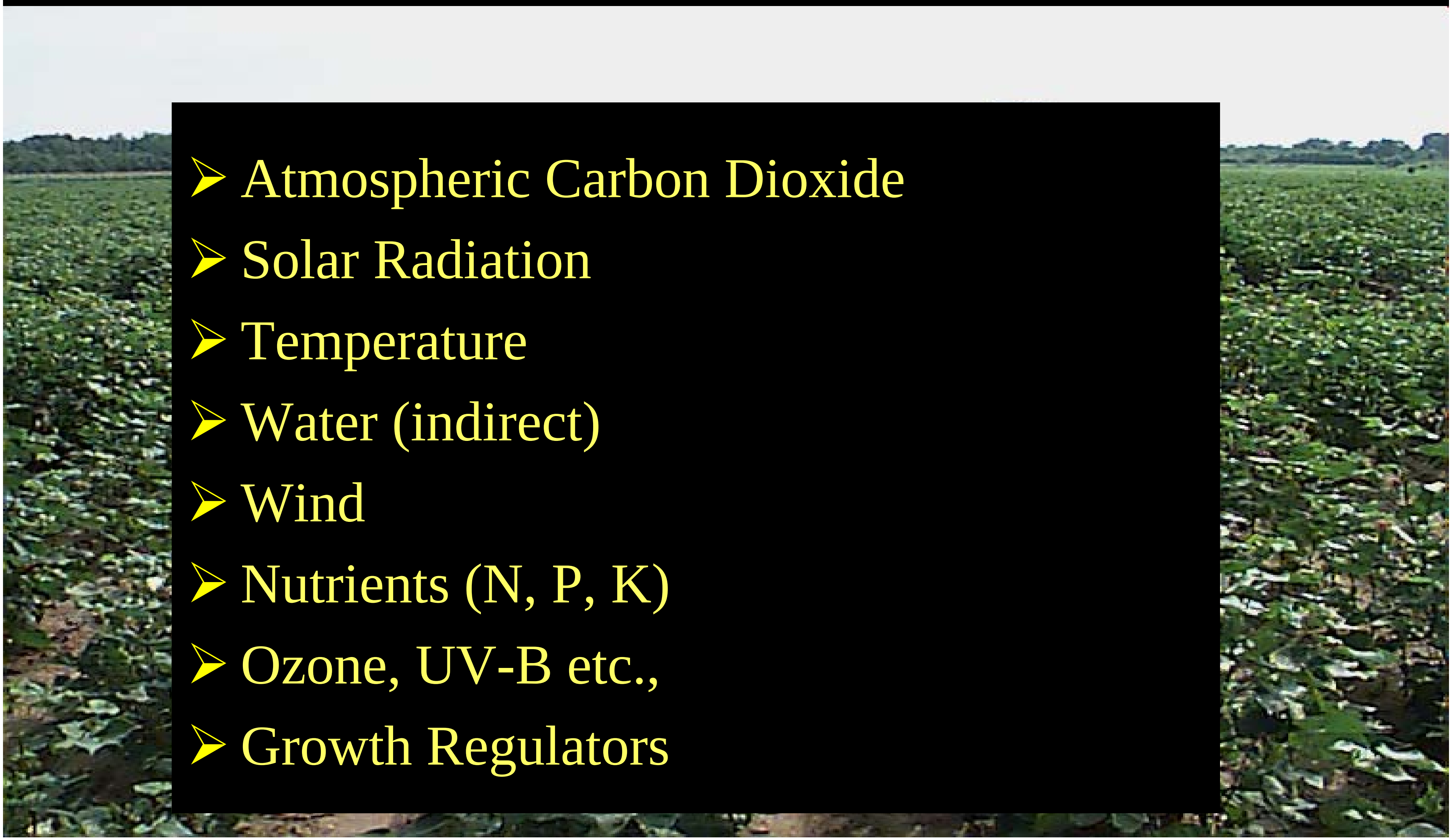
Scaling of processes from leaves to whole plant, canopies or ecosystems.

Chapter 5

Special topics include:

- Remote sensing and environmental plant physiology.

Environmental limiting crop growth, development and yield



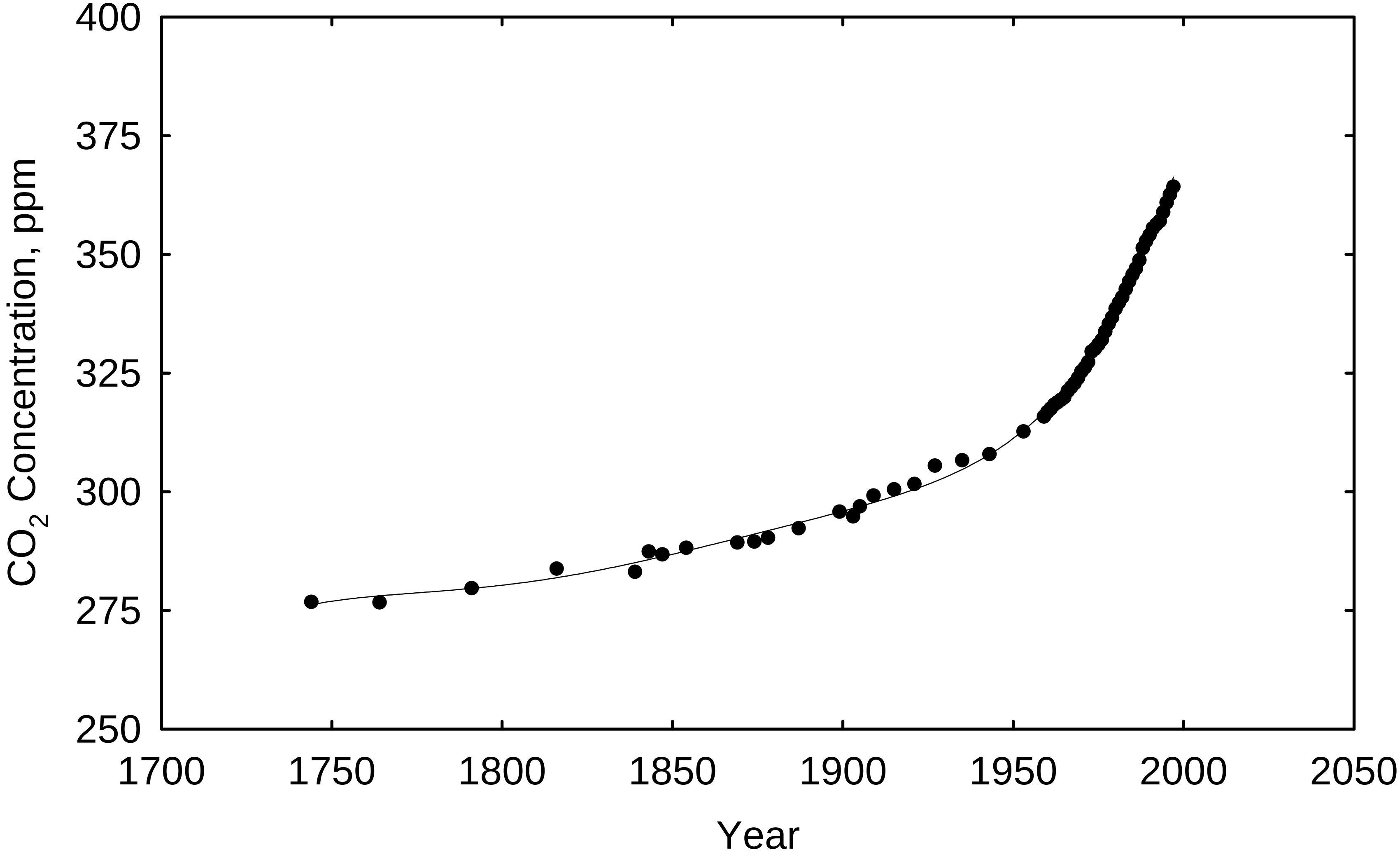
- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

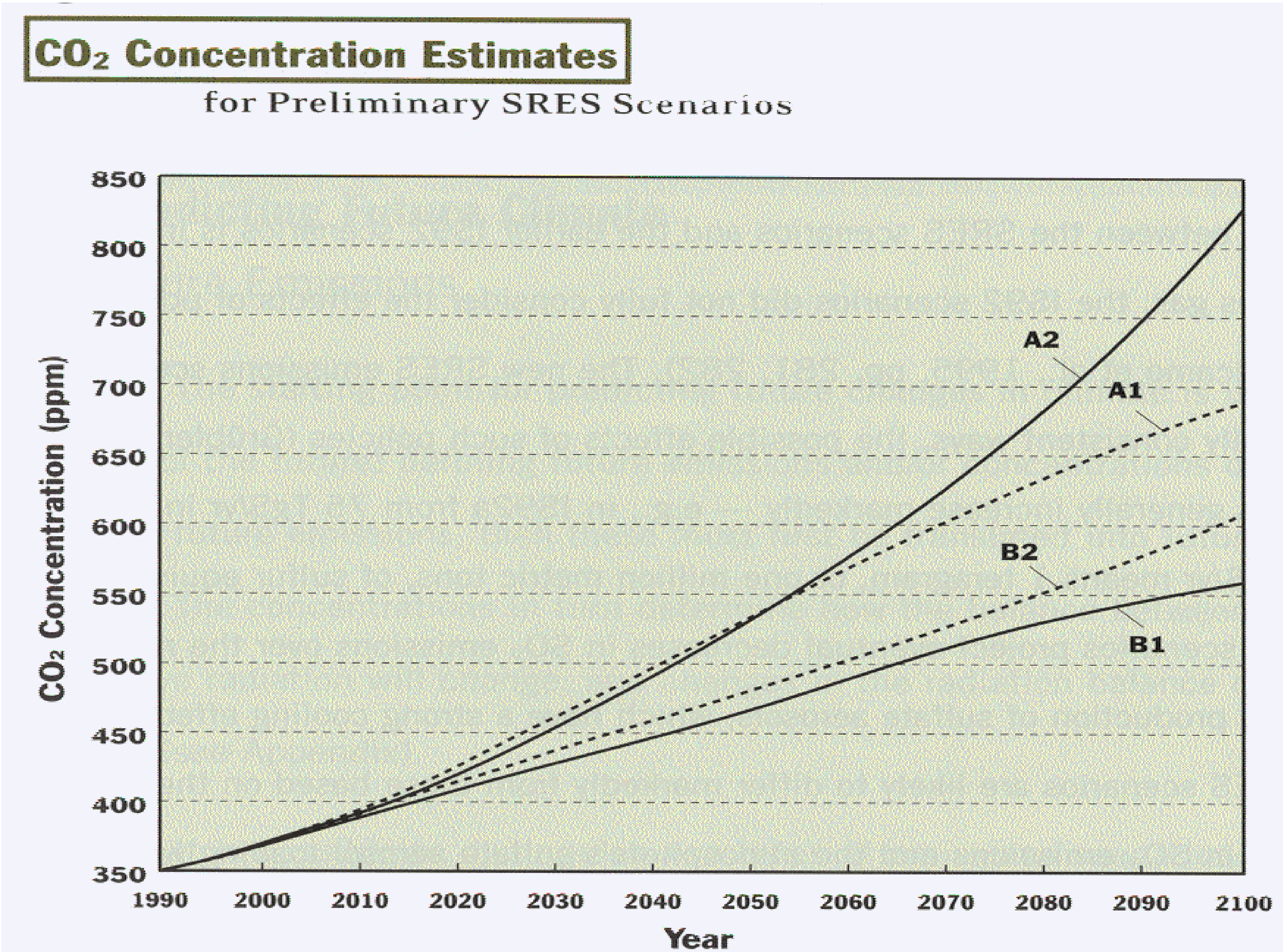
Environmental limiting crop growth, development and yield

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Global Carbon Dioxide Concentrations

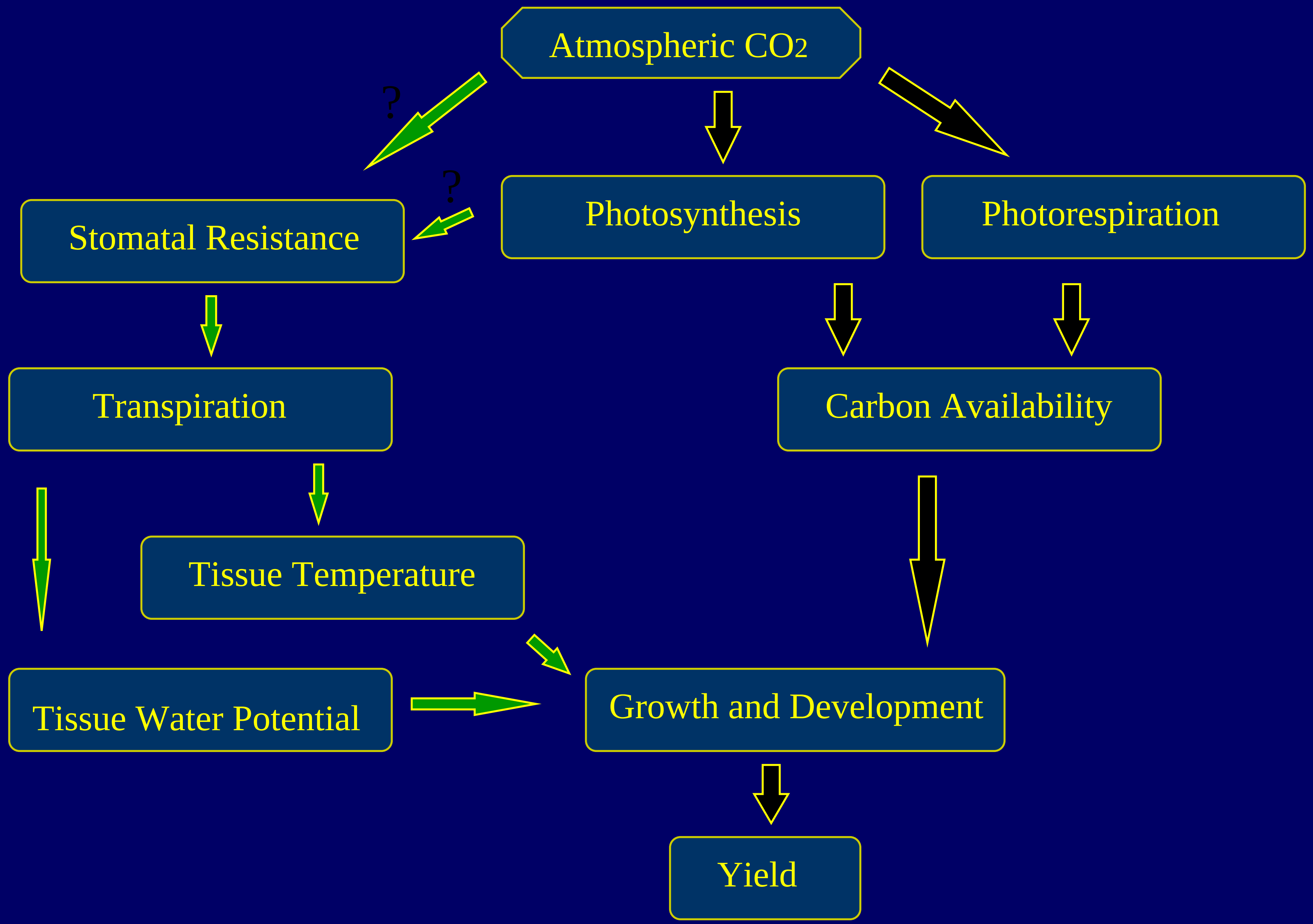
Trends over the last two centuries



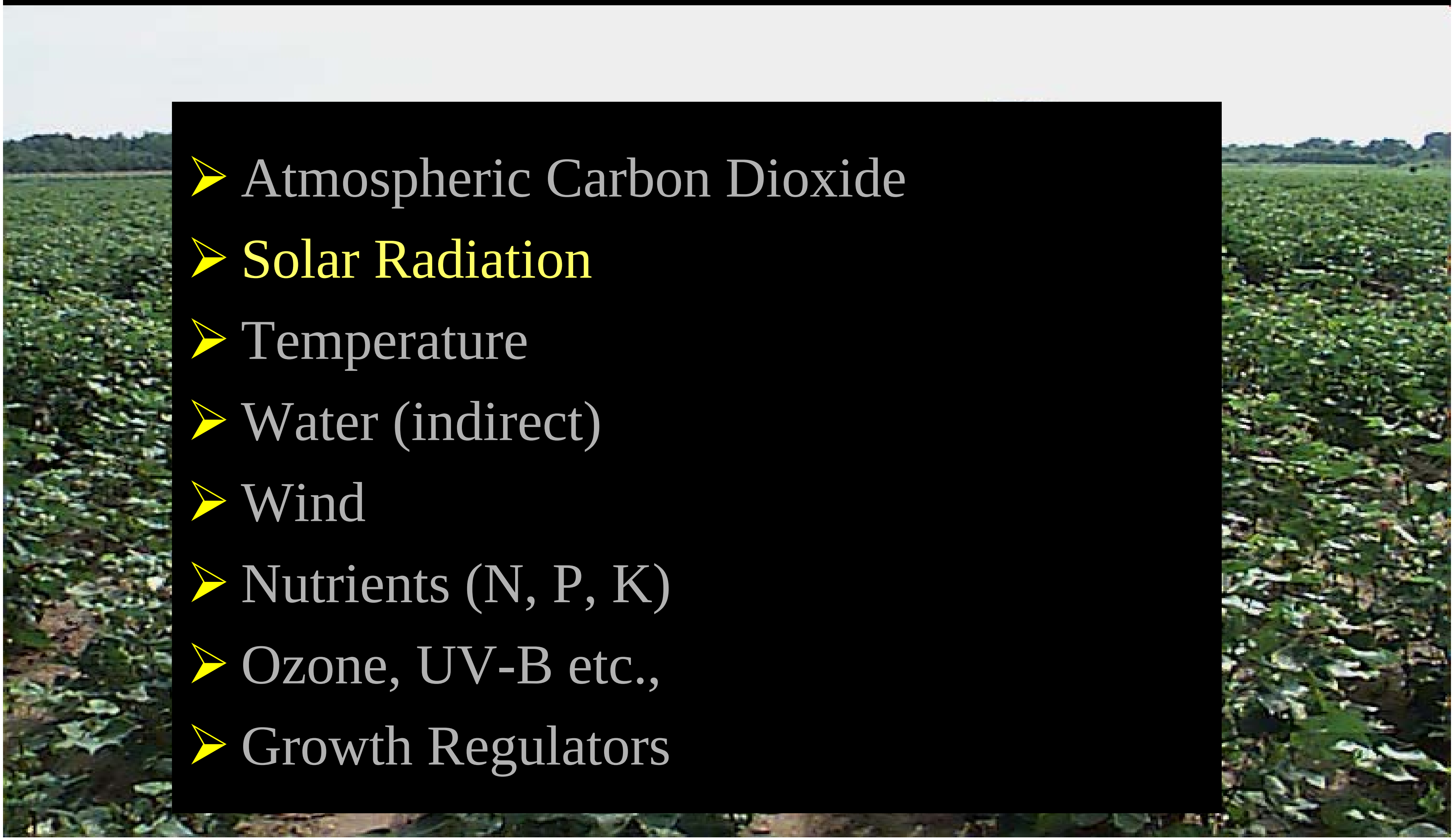


CO2 Concentration Estimates
for Preliminary SRES Scenarios
850
800
750
700
650
600
550
500
450
400
350
CO2 Concentration (ppm)
A2
A1
B2
B1
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year

A Hierarchy of Plant Responses to CO_2



Environmental limiting crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

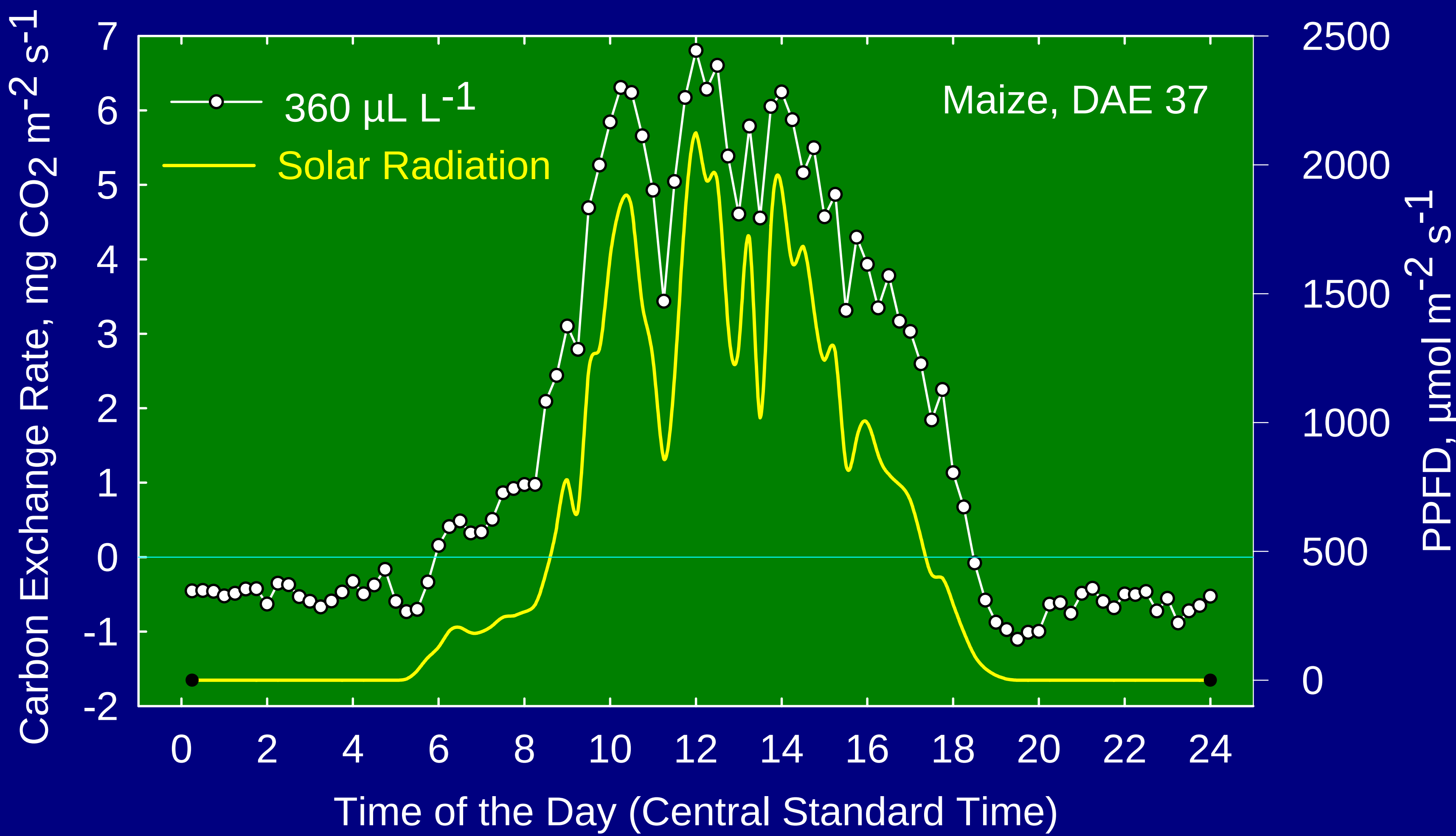
Radiation and Plant Life

Table 1.6. Effect of radiation on plant life. (Ross 1981)

Spectral region	Wavelength (nm)	Percent of solar radiant energy	Photo-synthetic	Effects of radiation		
				Photo-morphogenetic	Photo-destructive	Thermal
Ultraviolet	290 – 380	0 – 4	Insignificant	Slight	Significant	Insignificant
Photosynthetically active range (PhAR)	380 – 710	21 – 46[a]	Significant	Significant	Slight	Significant
Infrared	750 – 4000	50 – 79[a]	Insignificant	Significant	Insignificant	Significant
Longwave radiation	4000 – 100000		Insignificant	Insignificant	Insignificant	Significant

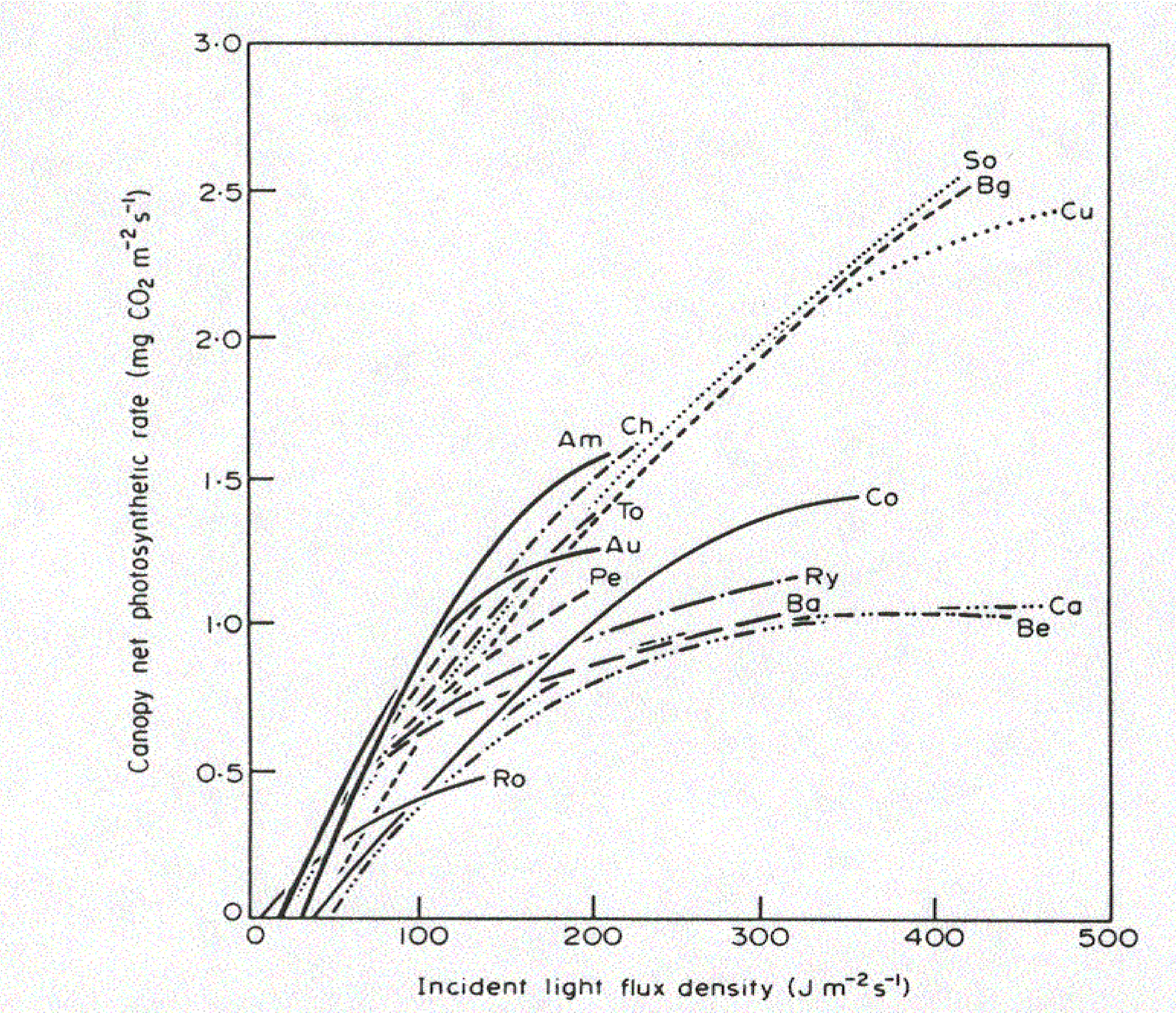
[a] Depending on position of sun and degree of cloud cover.

Net Photosynthesis and Available Light Intensity



Photosynthesis and Solar Radiation

Species variability



Am – Amaranthus

Au – Aubergine

Ba – Barley

Be – Bean

Bg – Bermudagrass

Ca – Cabbage

Ch – Chrysanthimum

Co – Cotton

Cu – Cucumber

Pe – Pepper

Ro – Rose

Ry – Ryegrass

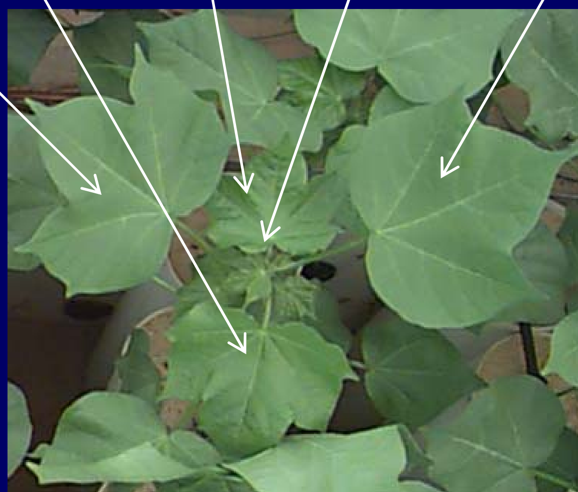
So – Sobean

To - Tomato

Leaf and canopy development and aging process

Leaf

5-day
Emerging leaf
12-day
2-day
8-day



About to abscise

Canopies

Emergence

Squaring

Flowering

Mature crop

Solar Radiation and Dry Matter Production

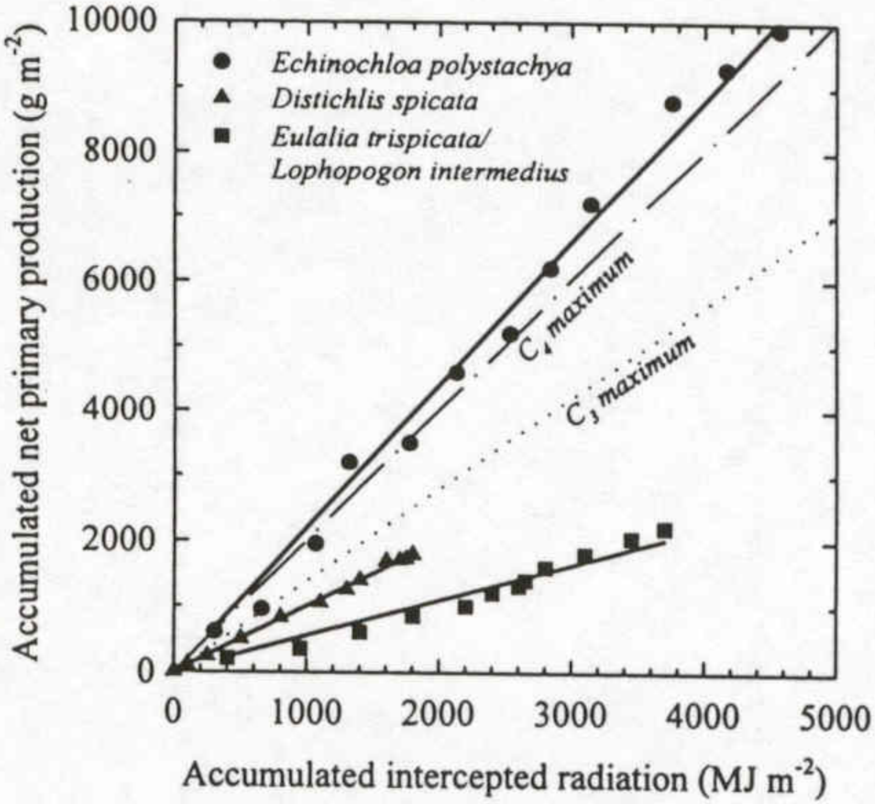


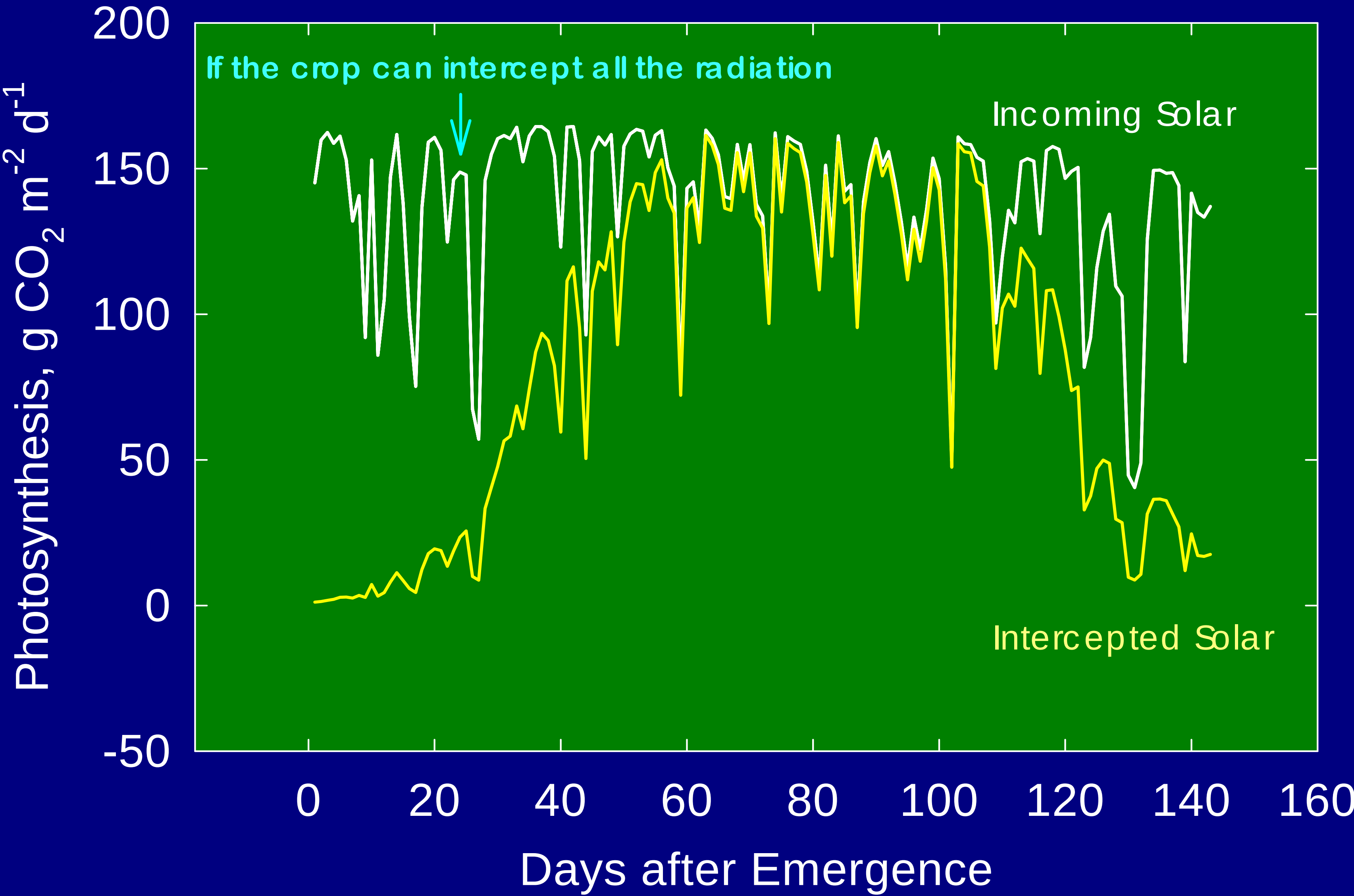
Figure 1 Accumulated monthly mean values of net primary production plotted against the accumulated quantity of total solar radiation (all wavelengths) intercepted by the same communities. Solid lines are the best-fitting straight lines to the illustrated data points. Data are for: (●) monotypic stands of *Echinochloa polystachya* on the Amazon floodplain near Manaus, Brazil (Piedade *et al.*, 1991); (▲) monotypic stands of *Distichlis spicata* on saline grassland close to Mexico City (Jones *et al.*, 1992); and (■) mixed C_4 grass stands codominated by *Eulalia trispicata* and *Lophopogon intermedius* in moist savanna near Hat Yai, Thailand (Kamnalrut and Evenson, 1992). The broken lines indicate the maxima suggested for the two photosynthetic types (after Monteith, 1978). Data redrawn from Piedade *et al.* (1991) and Jones *et al.* (1992).

Effects of Multiple Environmental Factors on Crop Growth and Developmental Aspects

- Introduced Environmental Productivity Index (EPI) concept.
- Photosynthesis
- Crop Phenology or Development
- Crop Growth
- Reproductive Biology

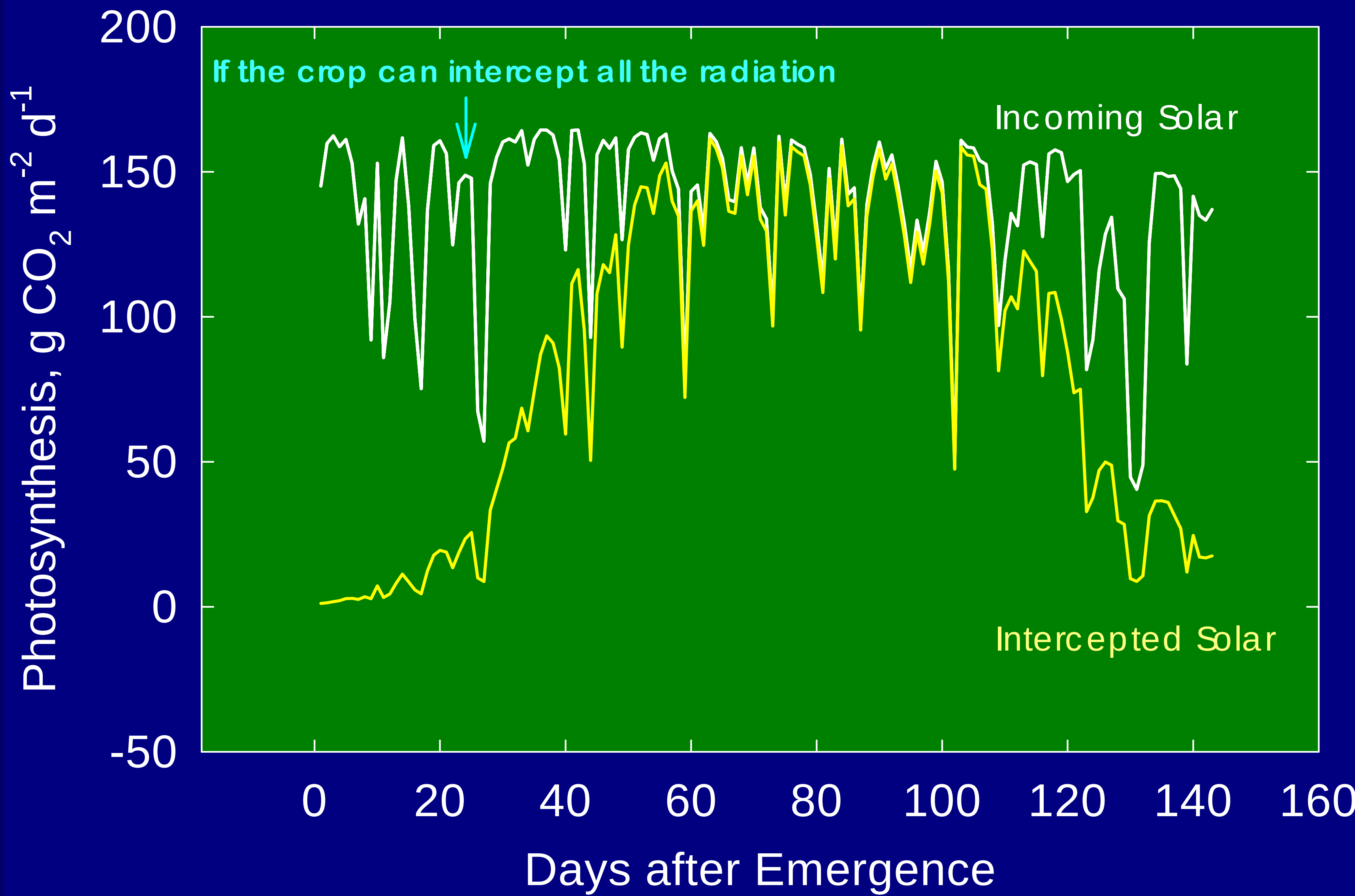
Canopy Photosynthesis - Growing Season

Accounting for environmental factors using EPI concept



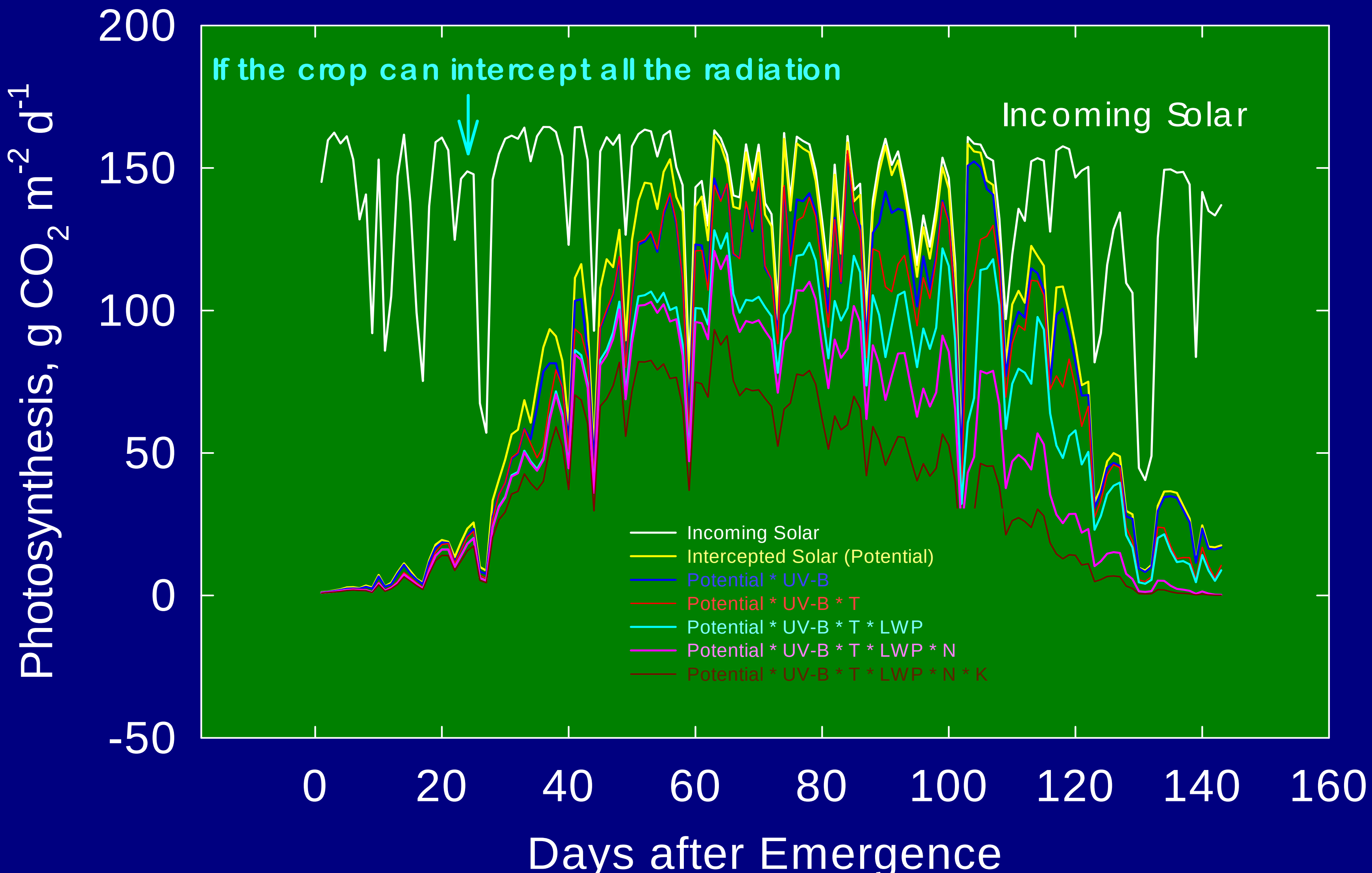
Canopy Photosynthesis - Growing Season

Accounting for environmental factors using EPI concept



Canopy Photosynthesis - Growing Season

Accounting for environmental factors using EPI concept



Radiation Totals for the 1992 Growing season Mississippi State – North Farm

Variable	Amount, MJ
Total Incoming Radiation	2842
Intercepted Radiation	1551
Percent Intercepted	55

Photosynthesis – EPI Concept
Accounting for Individual factors

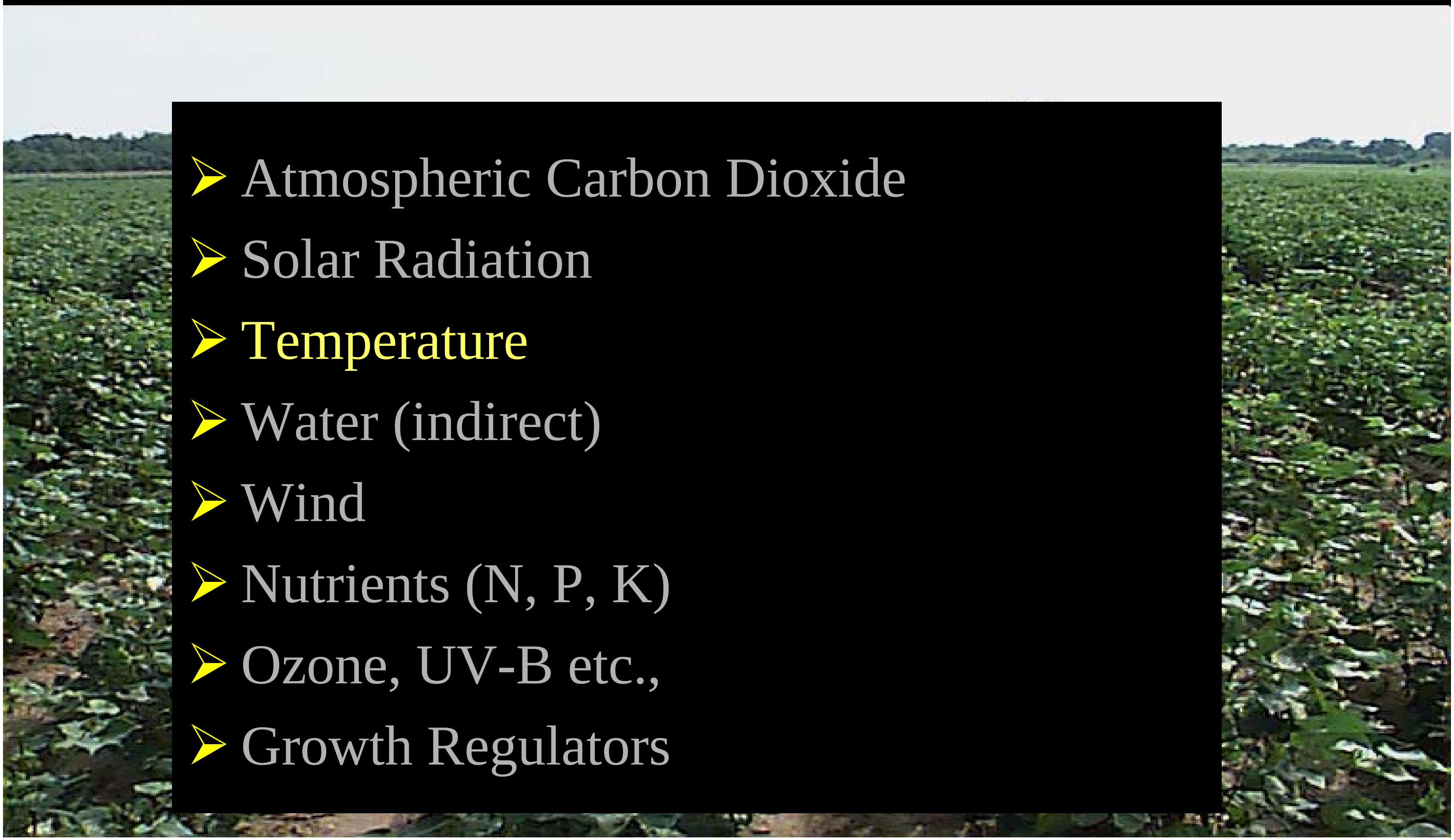
Variable	Amount, g CO2 m^{-2} $season^{-1}$
Incoming R	19644
Intercepted R	11441 (100%)
Int. R * UV-B	10448 (9%)
Int. R.* T	10139 (11%)
Int. R.* W	9783 (14%)
Int. R.* N	8986 (21%)
Int. R * K	10841 (5%)

Photosynthesis – EPI Concept
Accounting for Multiple Factors

Variable	Amount, g CO2 m^{-2} $season^{-1}$
Incoming R	19644
Intercepted R	11441 (100%)
Int. R* UV-B	10230 (9%)
Int. R* UV-B*T	9153 (20%)
Int. R* UV-B*T*W	7551 (34%)
Int. R*UV-B*T*W*N	6292 (55%)
Int. R*UV-B*T*W* K	4576 (60%)

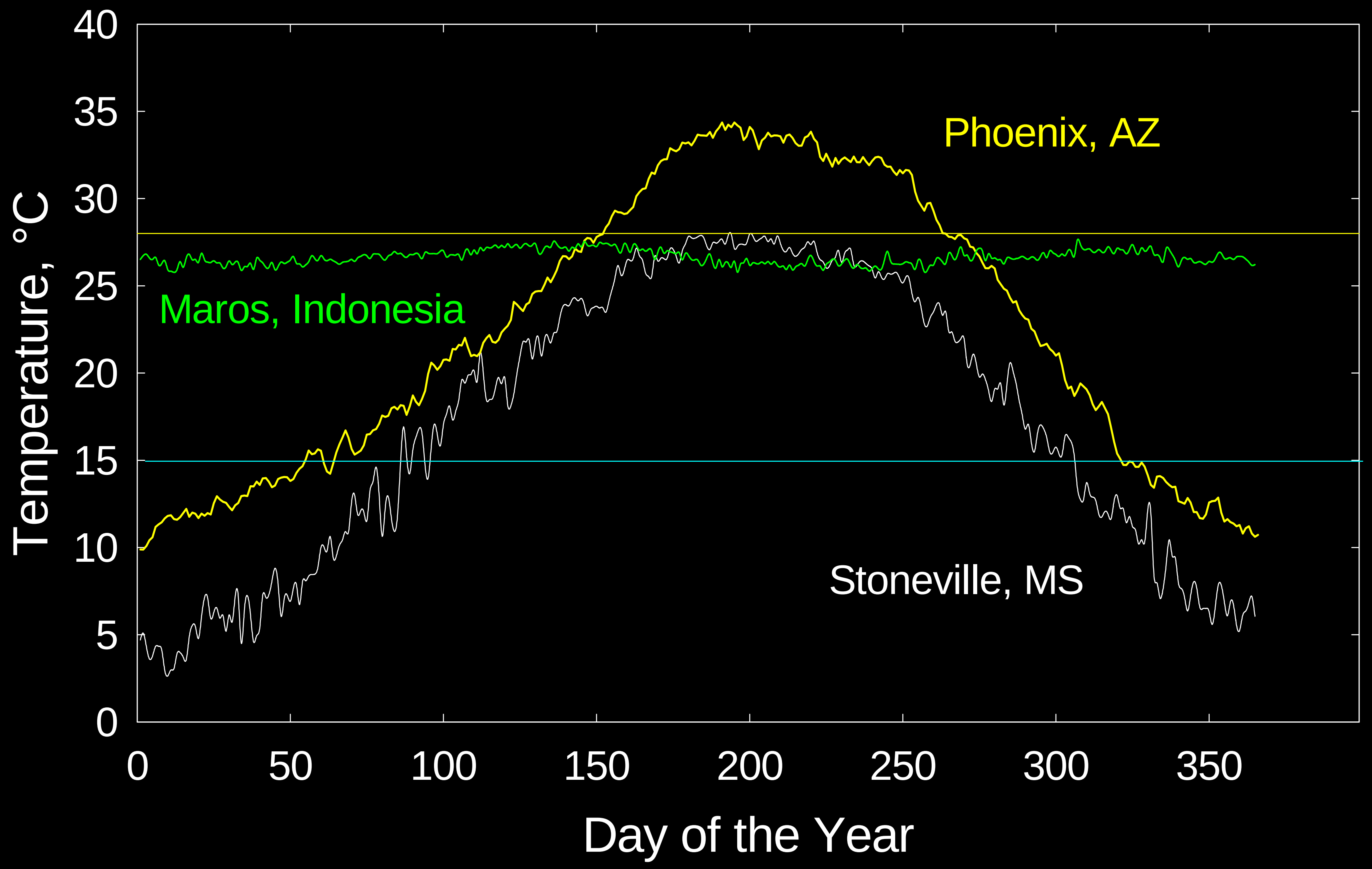
Actual amount

Environmental limiting crop growth, development and yield

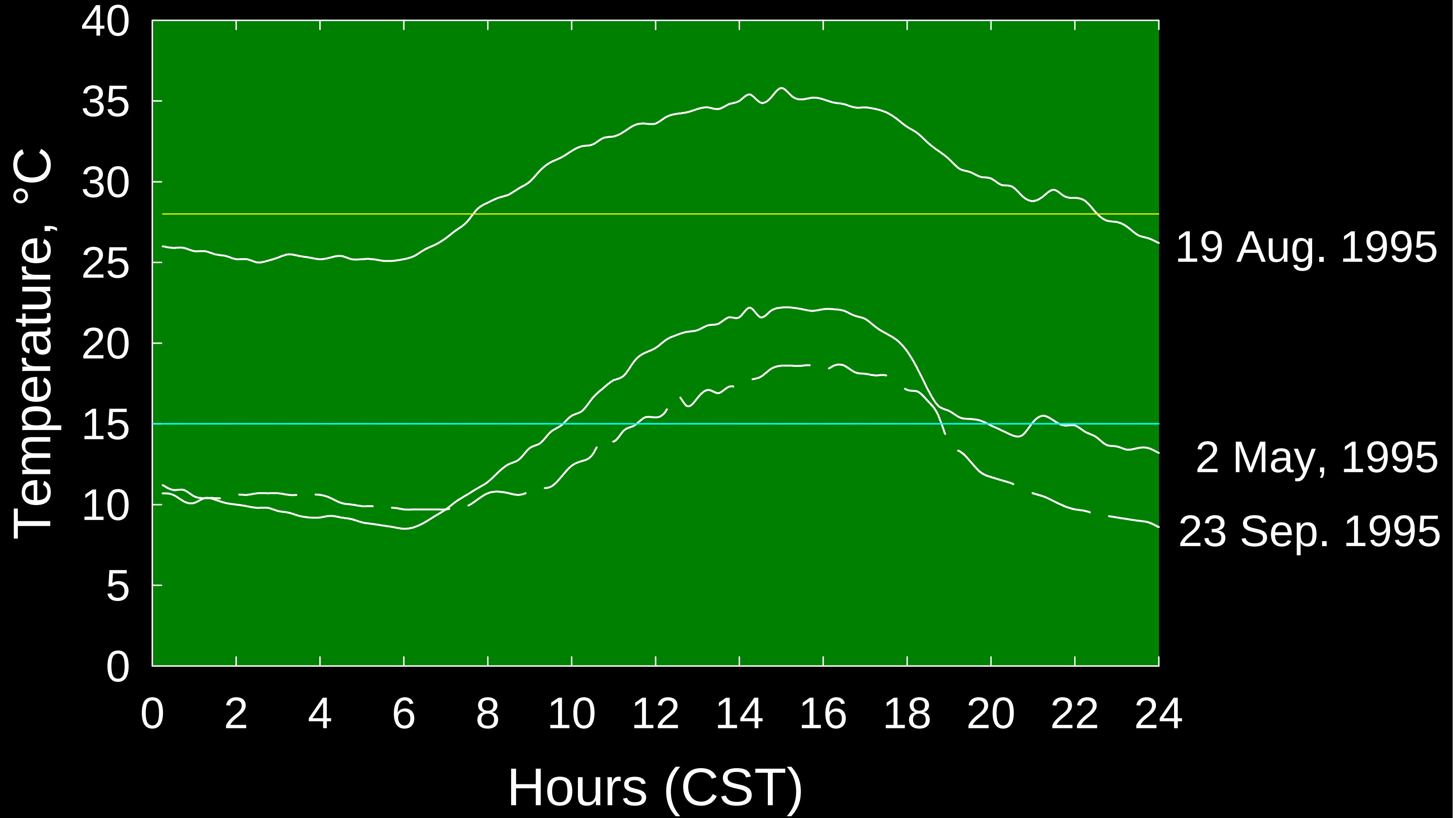


- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Long-Term Average Temperatures



Temperature Conditions - Diurnal Trends
Mississippi State, MS - 1995



Central **Temperature Estimates** Plus Extremes
for the Preliminary SRES Scenarios

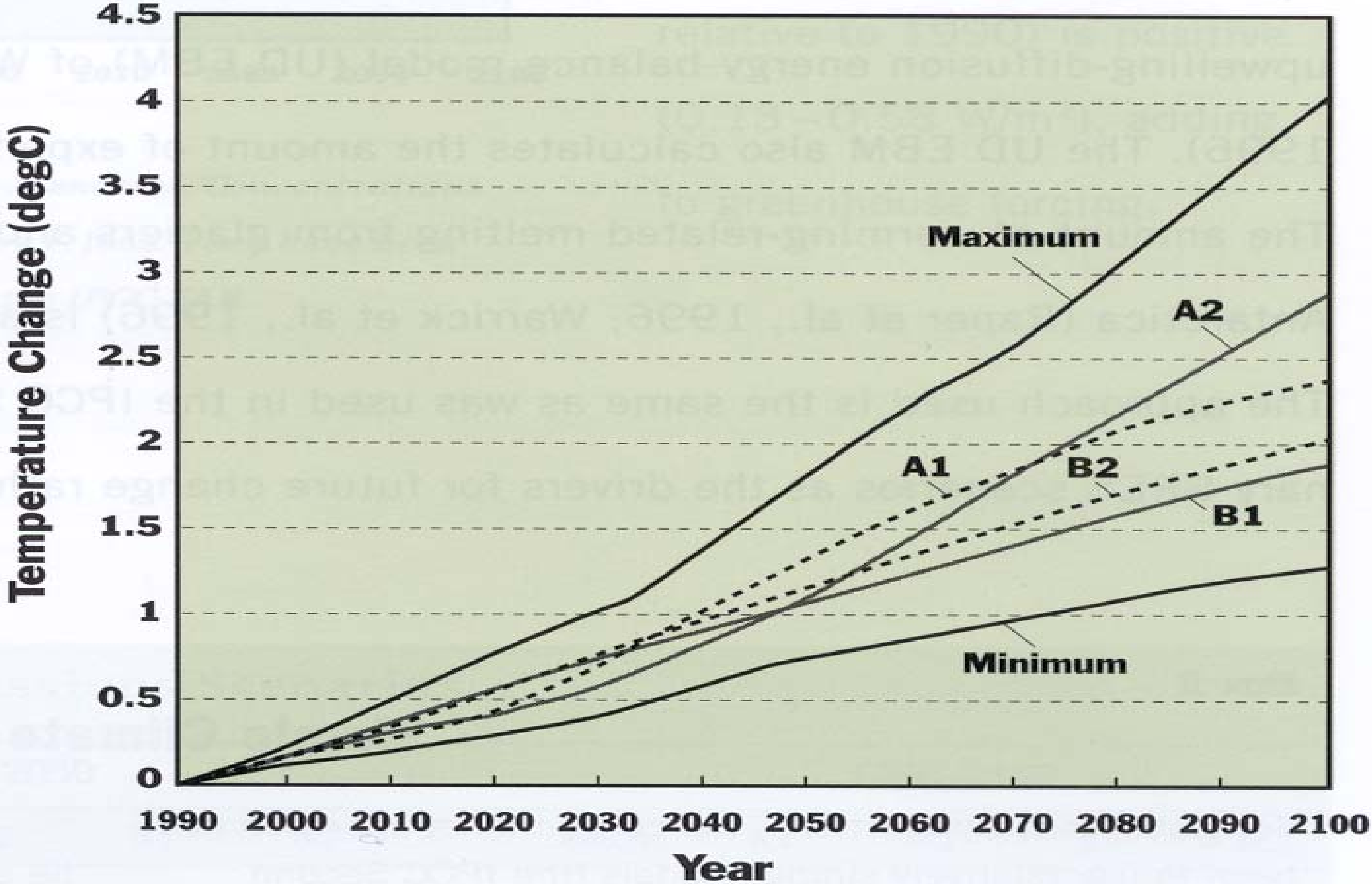
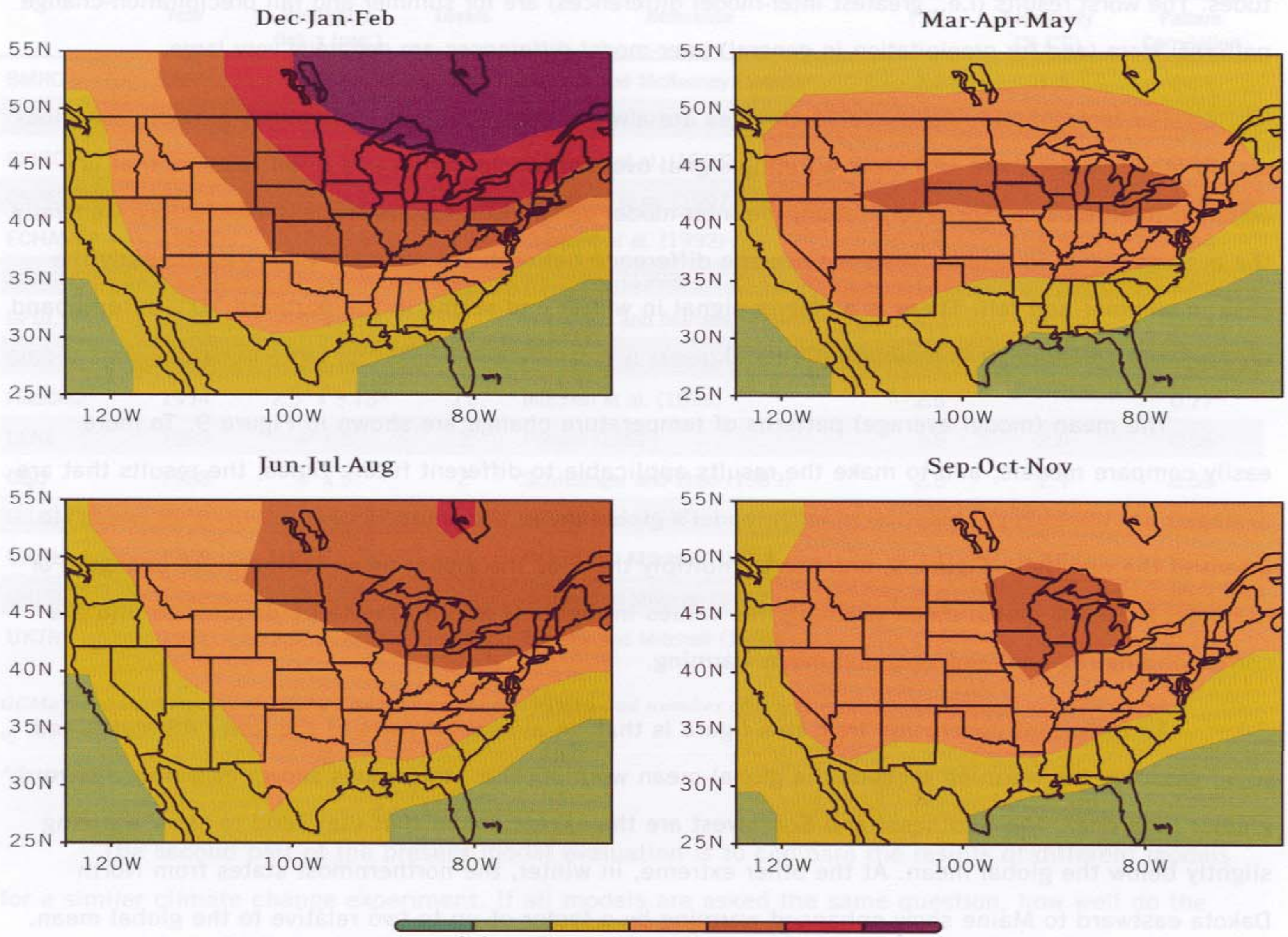


Figure 9

Relative Temperature Changes Mean of 15 Models



Environment Factors

Temperature:

- Strongly Affects:
  - -- *Phenology*
  - -- *Vegetative growth, LAI, LAD*
  - -- *Fruit Growth and Retention*
  - -- *Respiration*
  - -- *Water-loss and Water-Use*
- Moderately Affects:
  - -- *Photosynthesis on a canopy basis*

High-temperature Injury

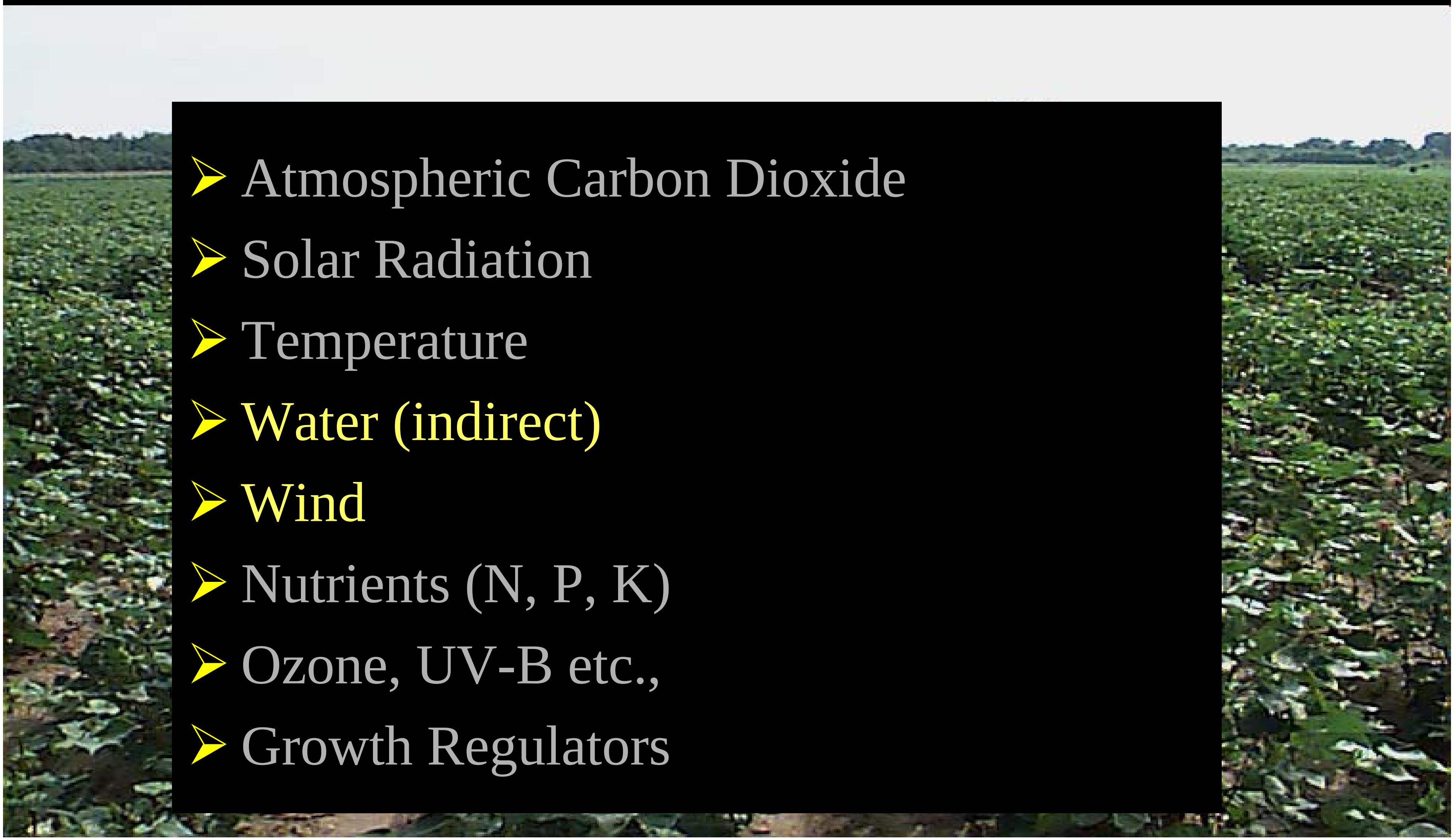
Heat-blasted Cotton Squares

California's San Joaquin Valley

Figure 7. Heat-blasted squares in California's San Joaquin Valley. (Photo: R. Vargas)

Heat-blasted Cotton Flowers and Squares – Arizona

Environmental limiting crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Water

Water plays essential roles in plants as a:

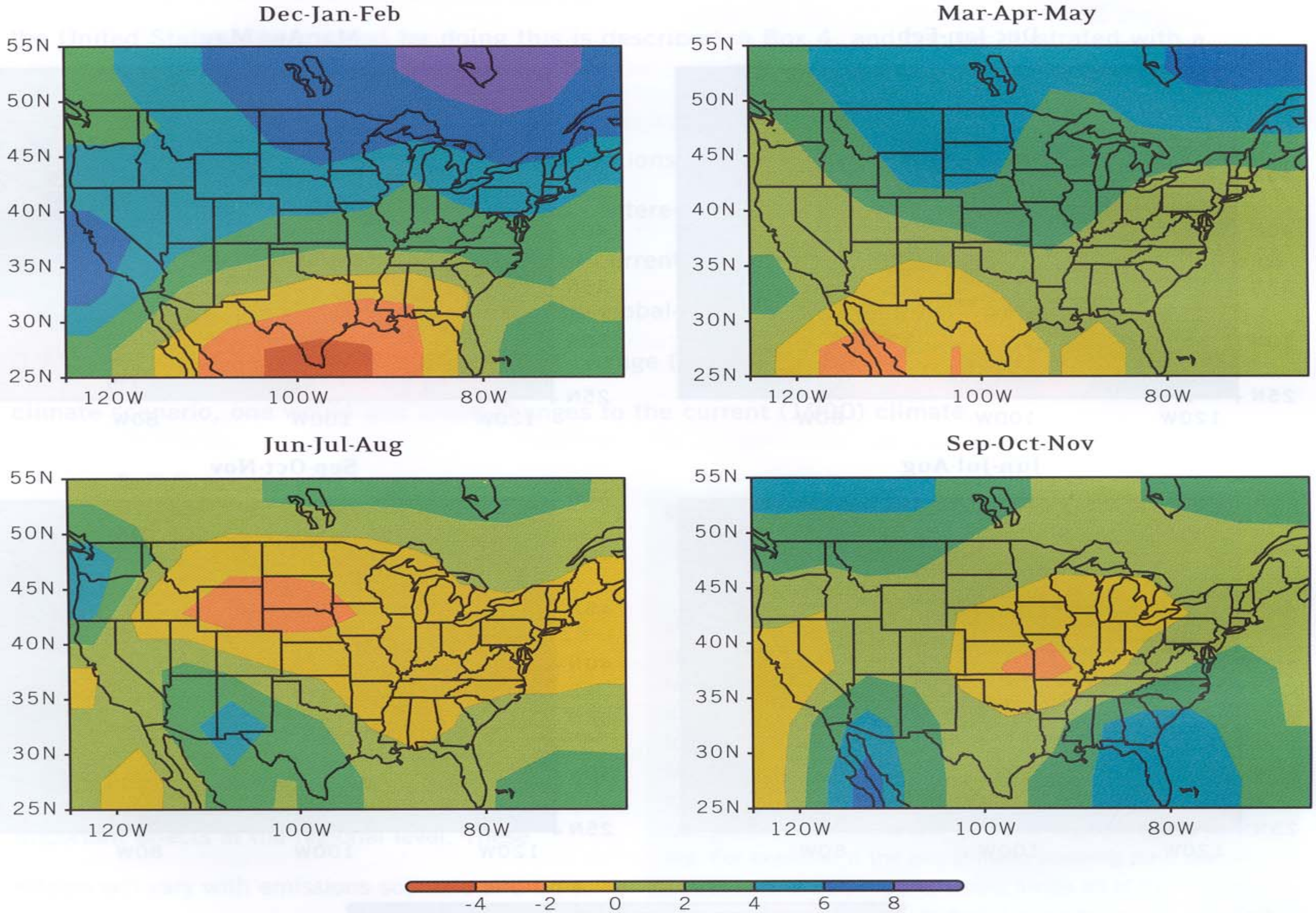
- Constituent
- Solvent
- Reactant in various chemical processes
- Maintenance of turgidity

The physiological importance of water is reflected in its ecological importance.

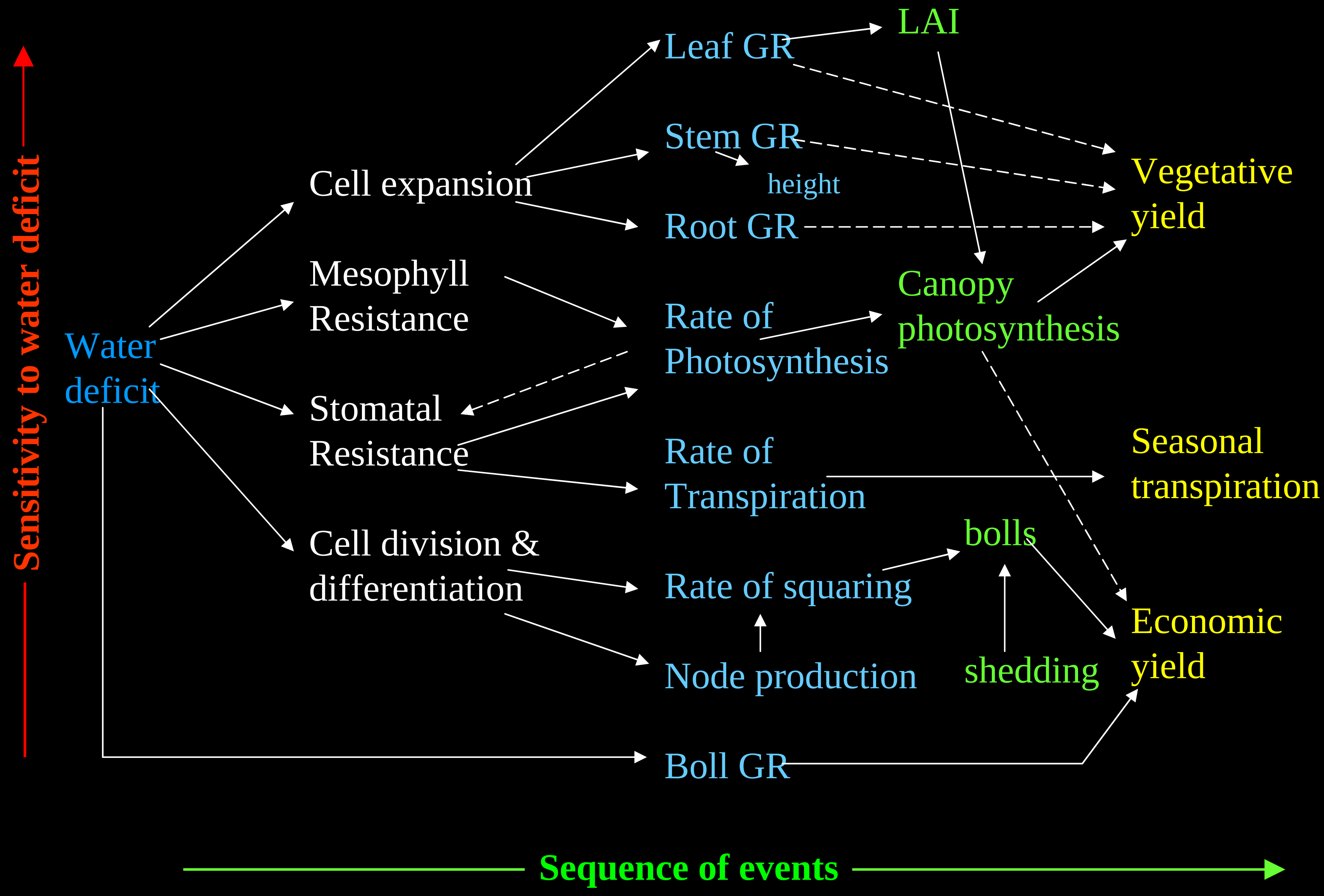
The distribution plants over the earth's surface is controlled by the availability of the water (amount and seasonal distribution of precipitation) where ever temperature permits growth.

Figure 10

Relative Precipitation Changes (%/°C) Mean of 15 Models



Role of water in cotton



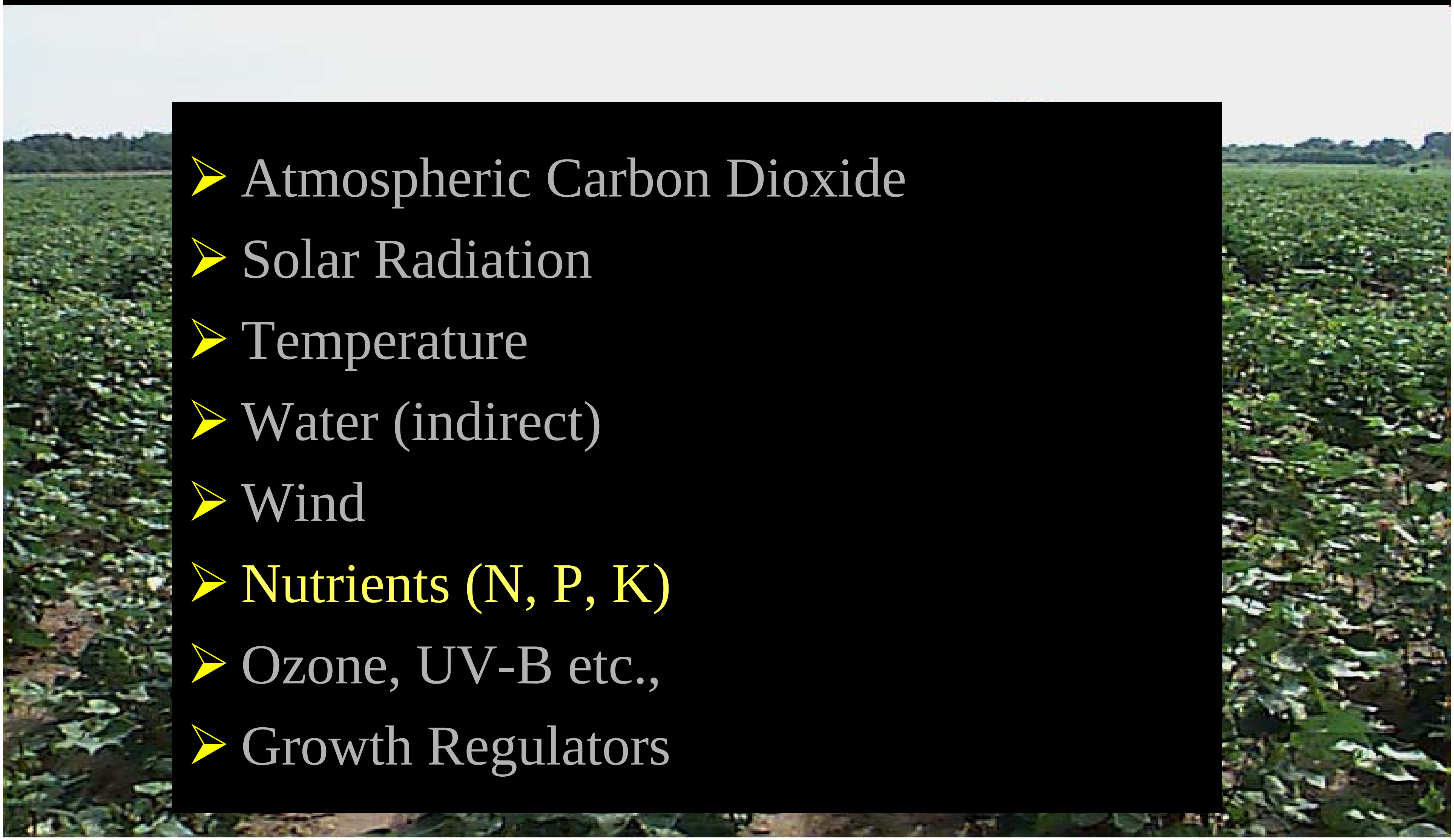
Environment Factors

Water Deficits:

- Strongly affects:
  - -- *Vegetative growth, LAI, LAD*
  - -- *Fruit Growth and Retention*
  - -- *Water-loss and Water-Use*
  - -- *Photosynthesis*
- Moderately affects certain phenological events:
  - -- *Phenology (leaf development)*

Environment – Wind and Hail

Environmental limiting crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
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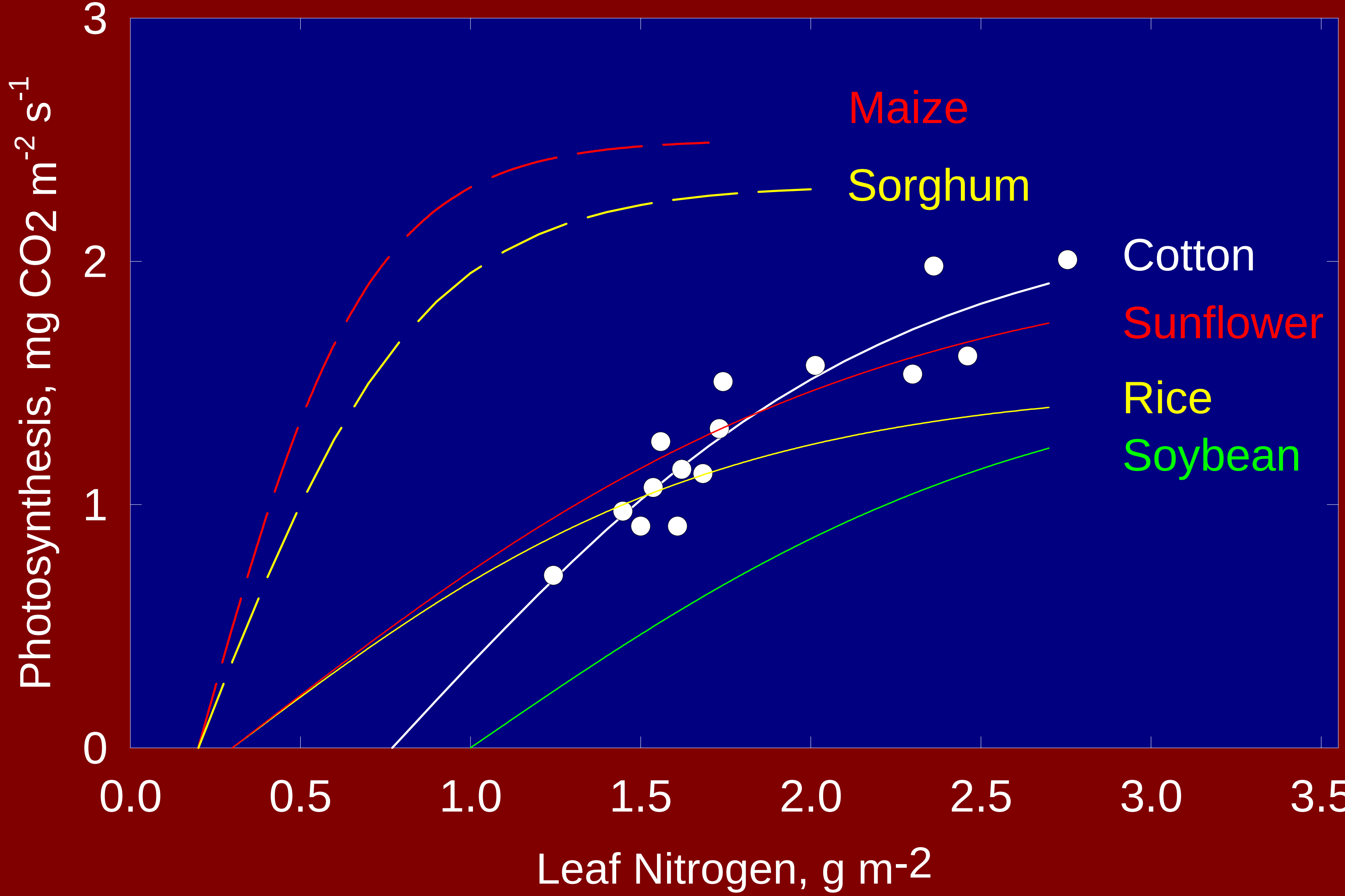
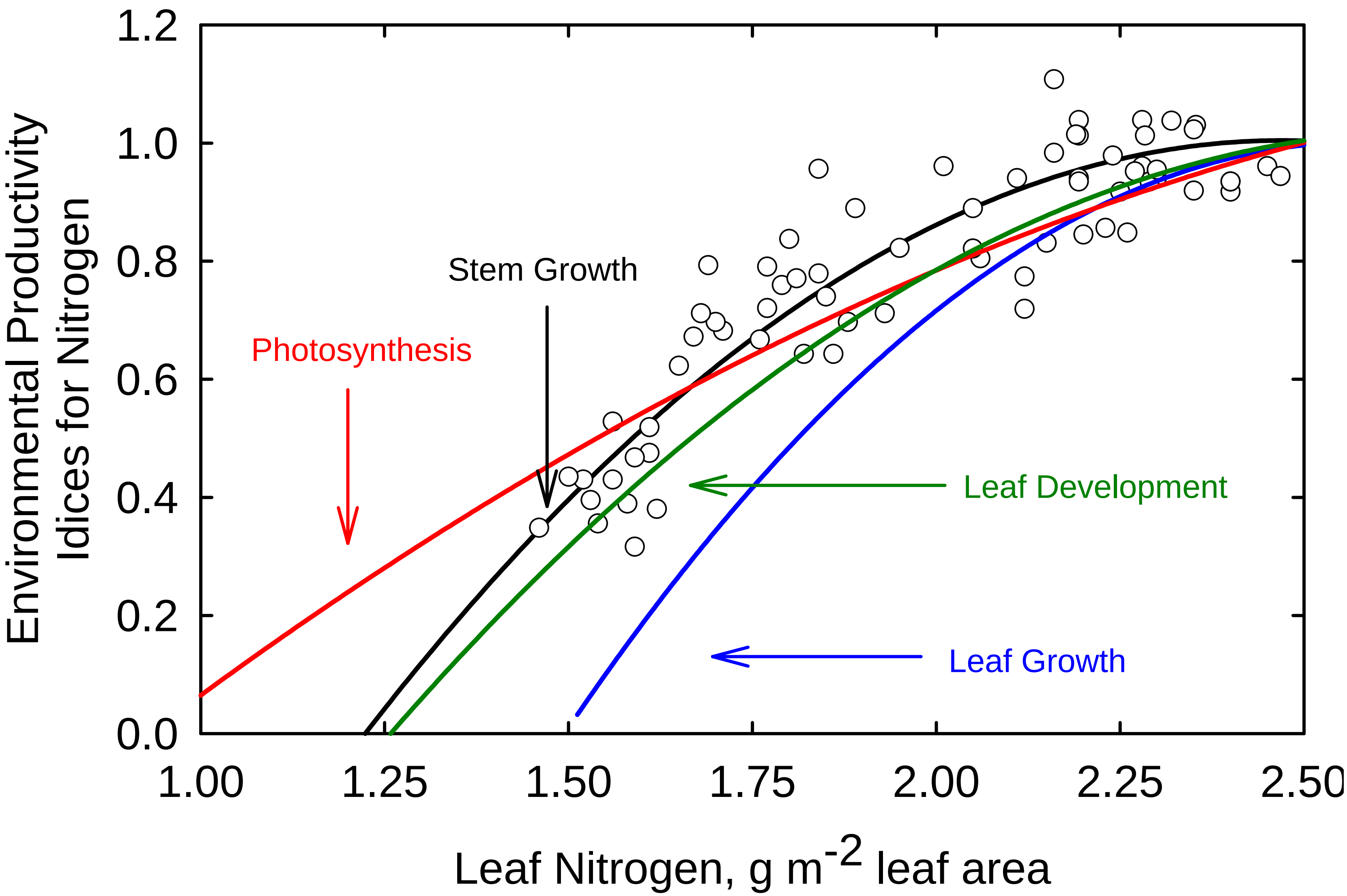
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Photosynthesis - Variability Among Species

Response to Leaf Nitrogen



Environment - Nitrogen



Environment - Nitrogen

Parameter	Percent Reduction from the Optimum (2.5 g N/m^{-2} or 4.5%)			
Leaf N, g m^{-2}	Photosynthesis	Stem growth	Leaf growth	Leaf Development
2.5	100	100	100	100
2.0	12	14	18	12
1.5	53	60	>99	68
1.2	76	--	--	--

Environment - Nitrogen

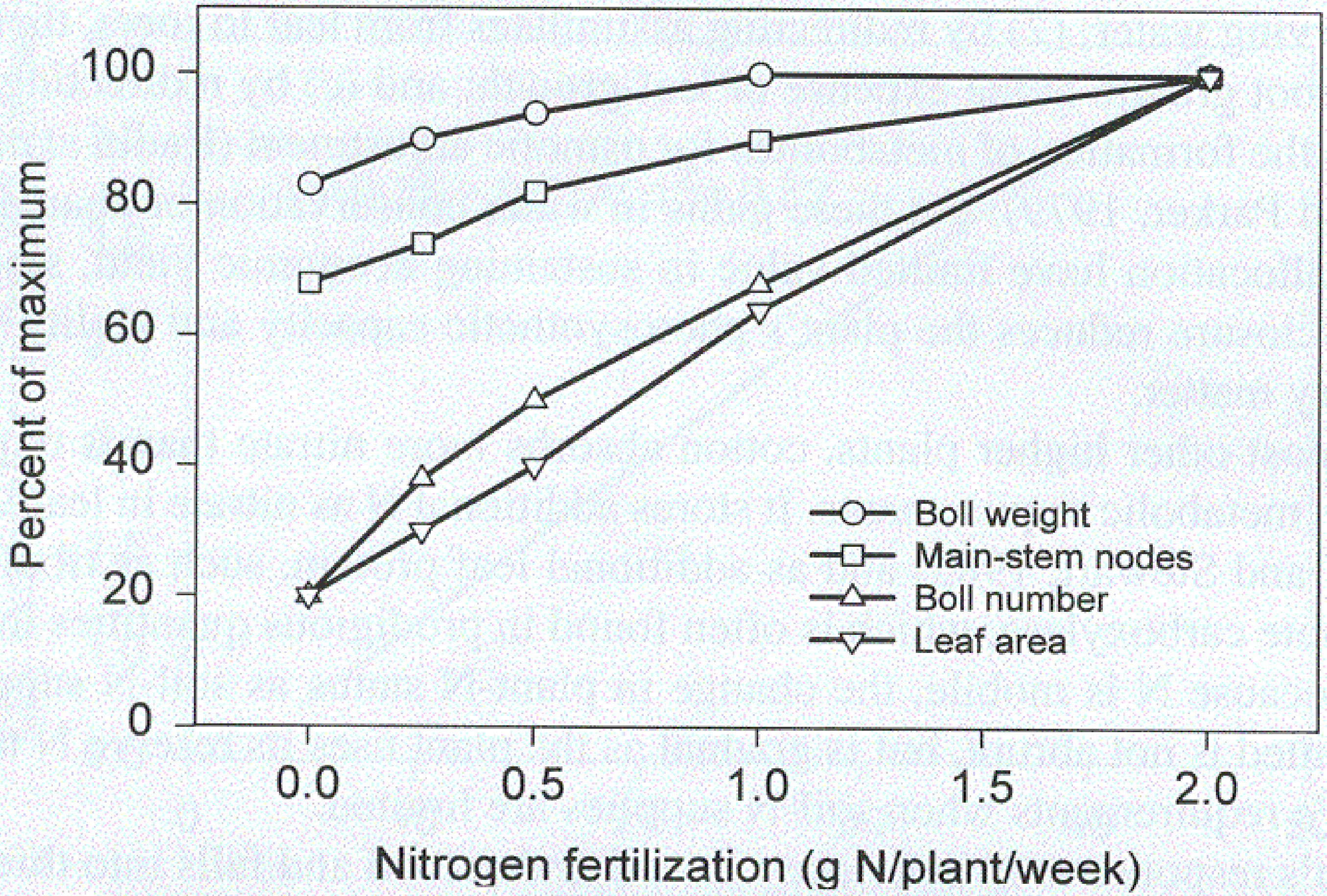


Figure 2 The effect of N on number of main-stem nodes, boll number per plant, leaf area, and boll weight (Jackson and Gerik, 1990).

Environment Factors

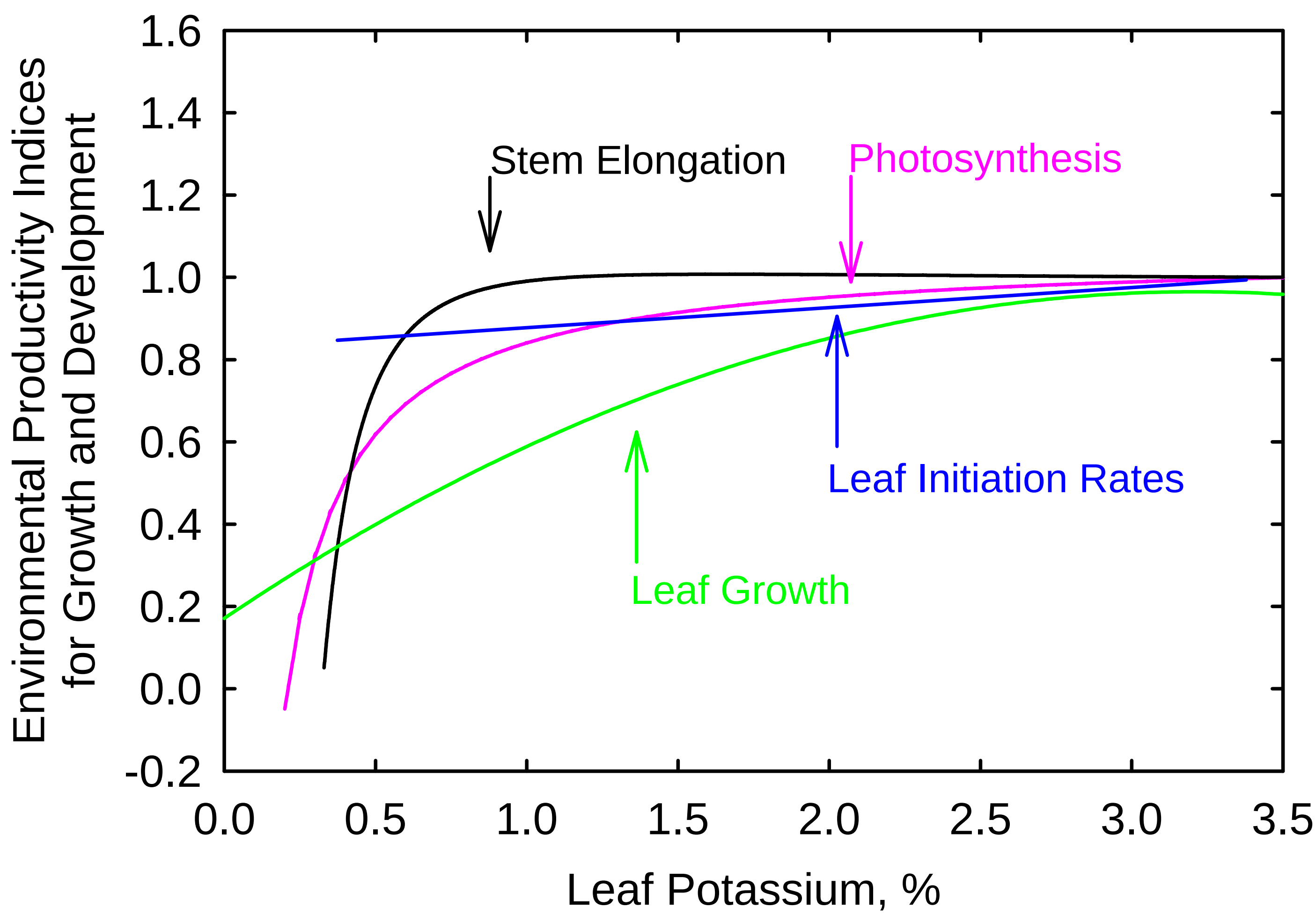
Fertilizers Deficits - Potassium:

- Strongly Affects:
  - -- *Leaf growth, LAI, LAD*
  - -- *Fruit Retention*

- Moderately Affects:
  - -- *Photosynthesis*
  - -- Stem growth

Environment - Nutrients

Potassium - Cotton Growth and Development
Environmental Productivity Indices



Environment Factors

Ultraviolet-B Radiation:

- Strongly Affects:
  - -- *Photosynthesis*
  - -- *Stem growth*
- Moderately Affects:
  - -- *Leaf growth*
  - -- *Leaf aging*
- No Effects:
  - -- *Phenology*

Environmental limiting crop growth, development and yield

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Solar Radiation and Plant Life

For plants, radiation is:

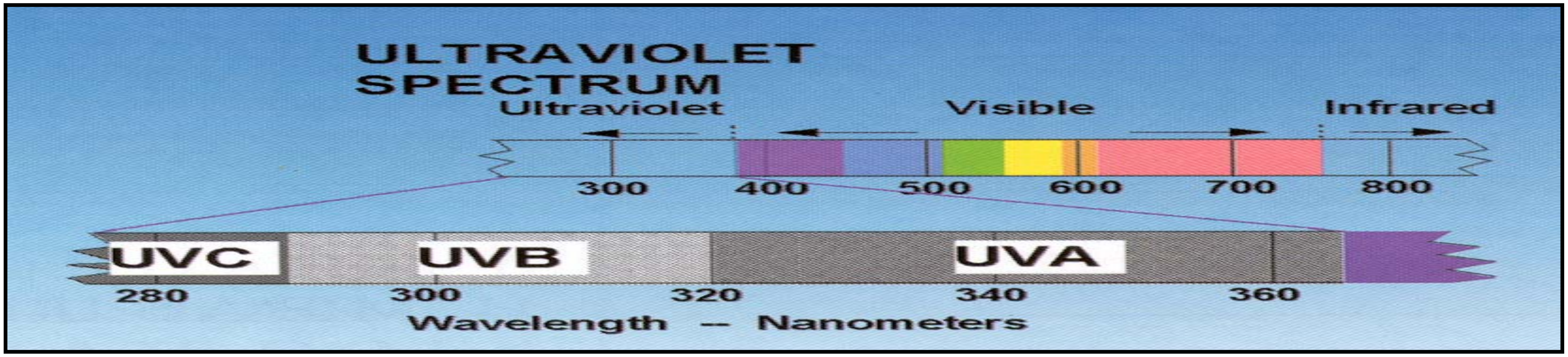
- A source of energy (photoenergetic effect).
- Stimulus for development (photocybernetic effect).
- Stress factor (photodestructive effect).

Effects of Radiation on Plant Life

Spectral Region	Wavelength nm	%	Photo-synthe-sis	Effects		
				Photo morpho-genetic	Photo destru-ctive	Thermal
Ultraviolet	290-380	0-4	IS	Slight	S	IS
PAR	380-710	21-46	S	S	Slight	S
Infrared	750-4000	50-79	IS	S	IS	S
Longwave	4000-100000		IS	IS	IS	S

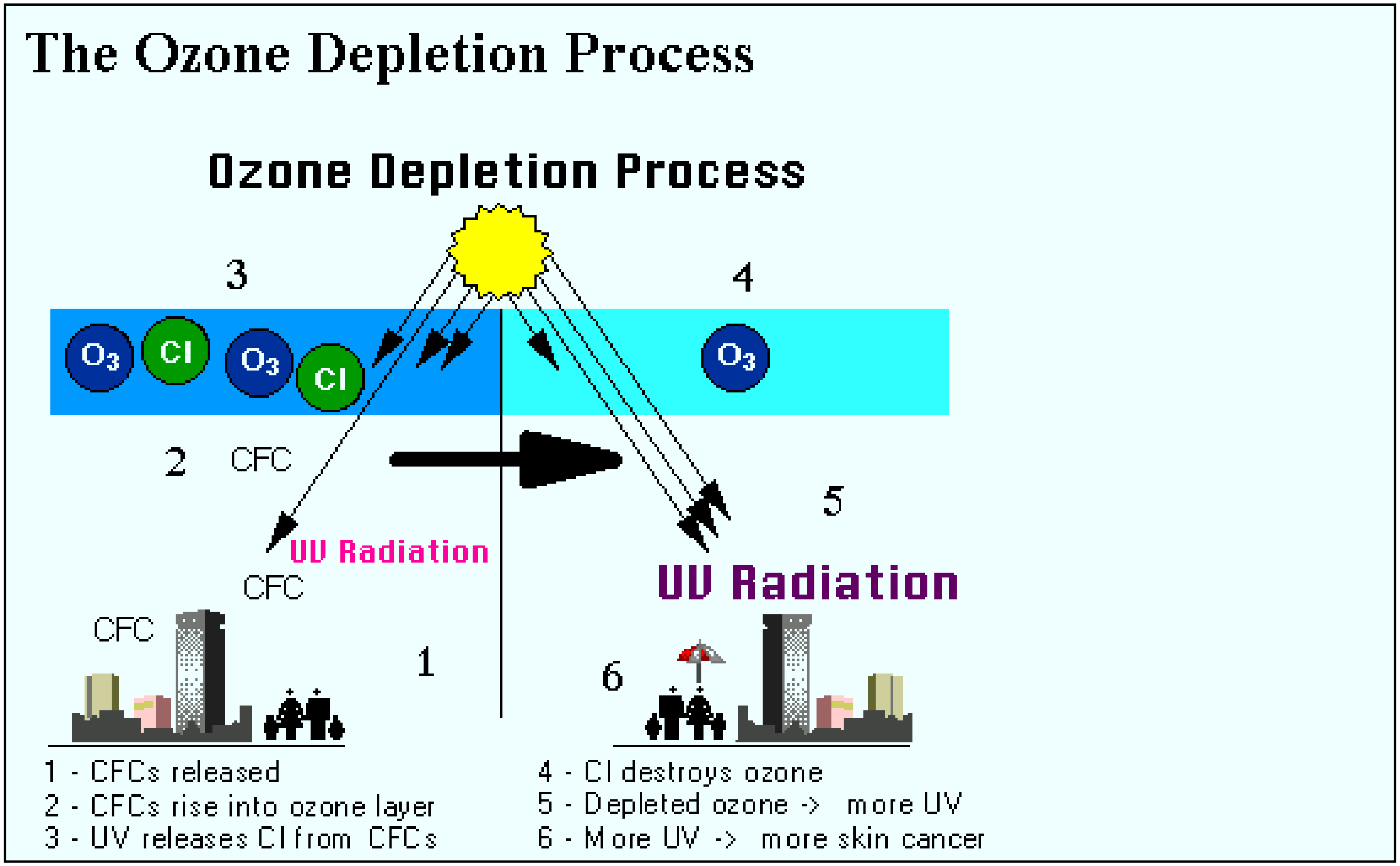
IS = Insignificant, S = Significant

Ultraviolet Radiation

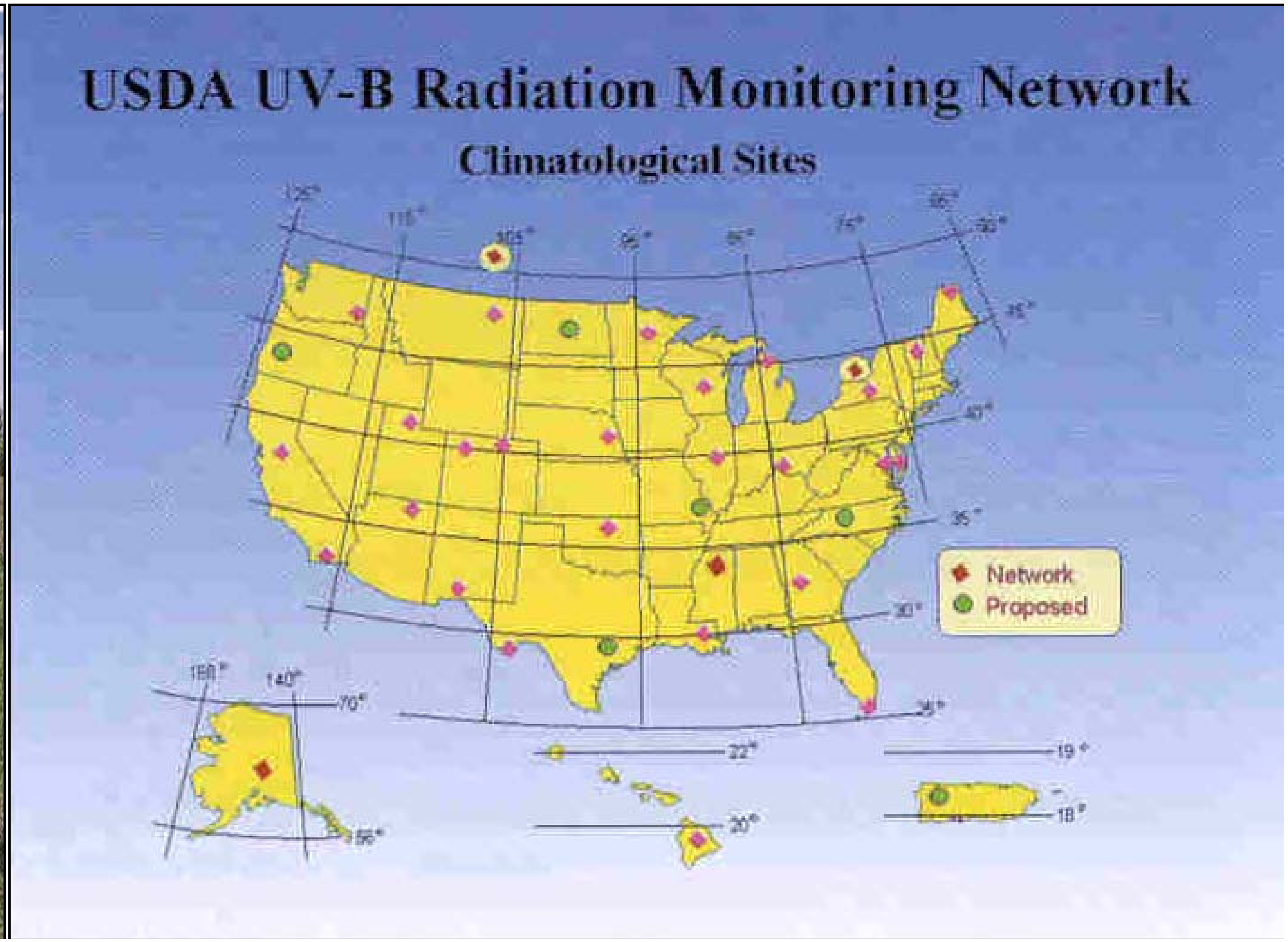


- **UVC: <280), UVB: 280-320, and UVA: 320-400.**
- UVA is not absorbed by ozone.
- UVB is mostly absorbed by ozone, although some reaches the Earth.
- UVC is completely absorbed by ozone and normal oxygen.

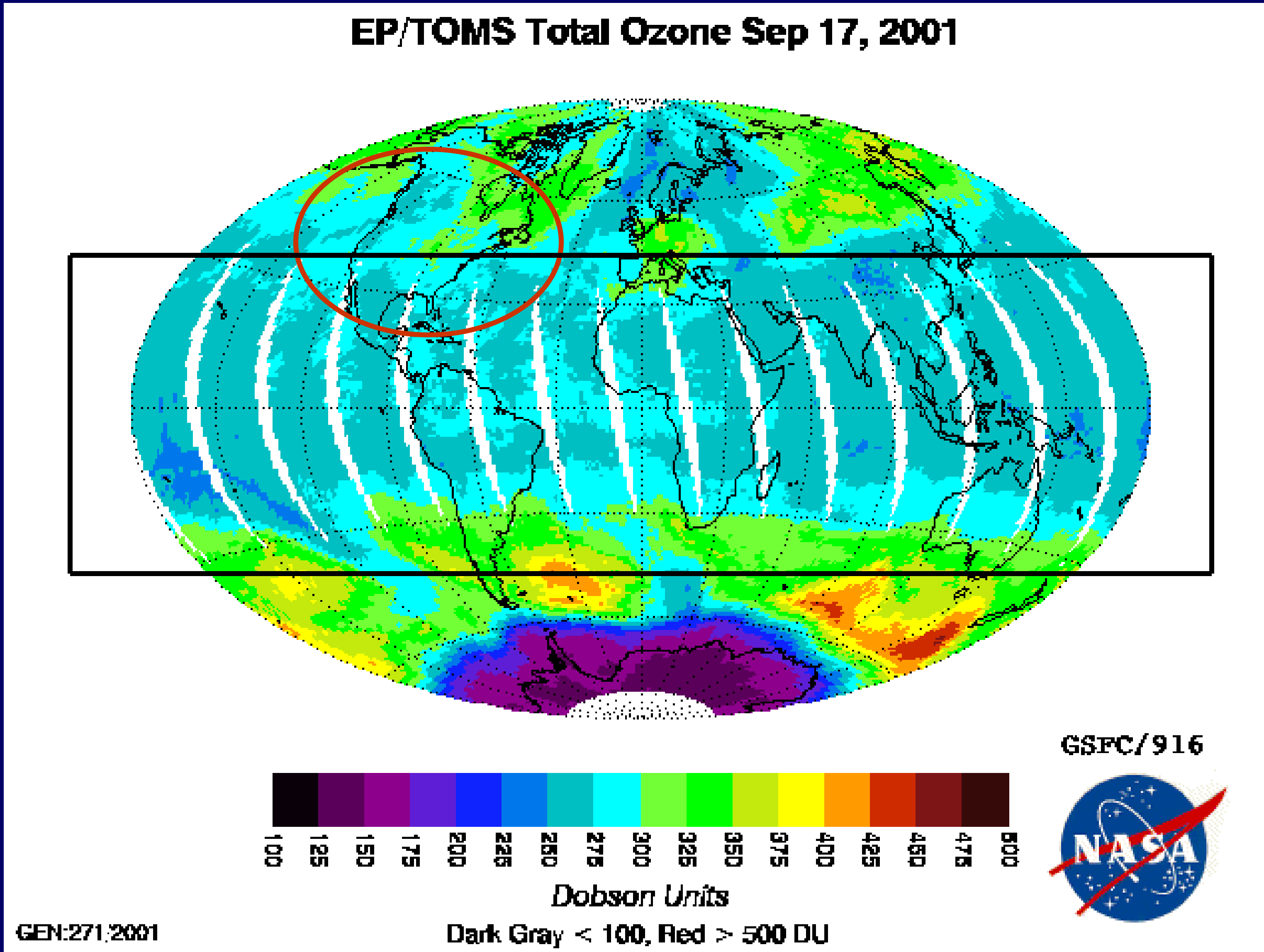
Why are we concerned with UV now?



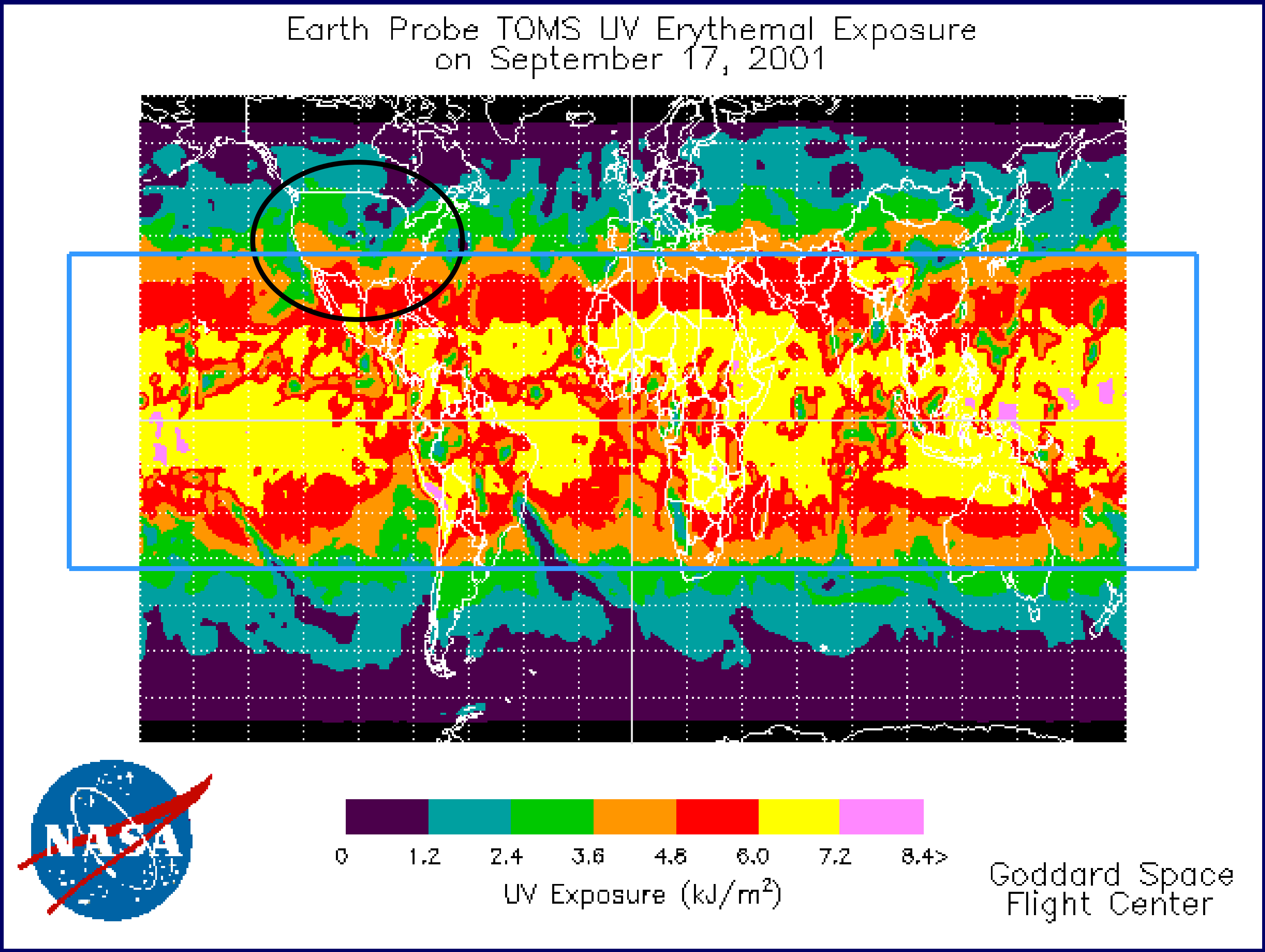
USDA – UV Radiation Monitoring Program



Satellite Based Ozone levels - 2001

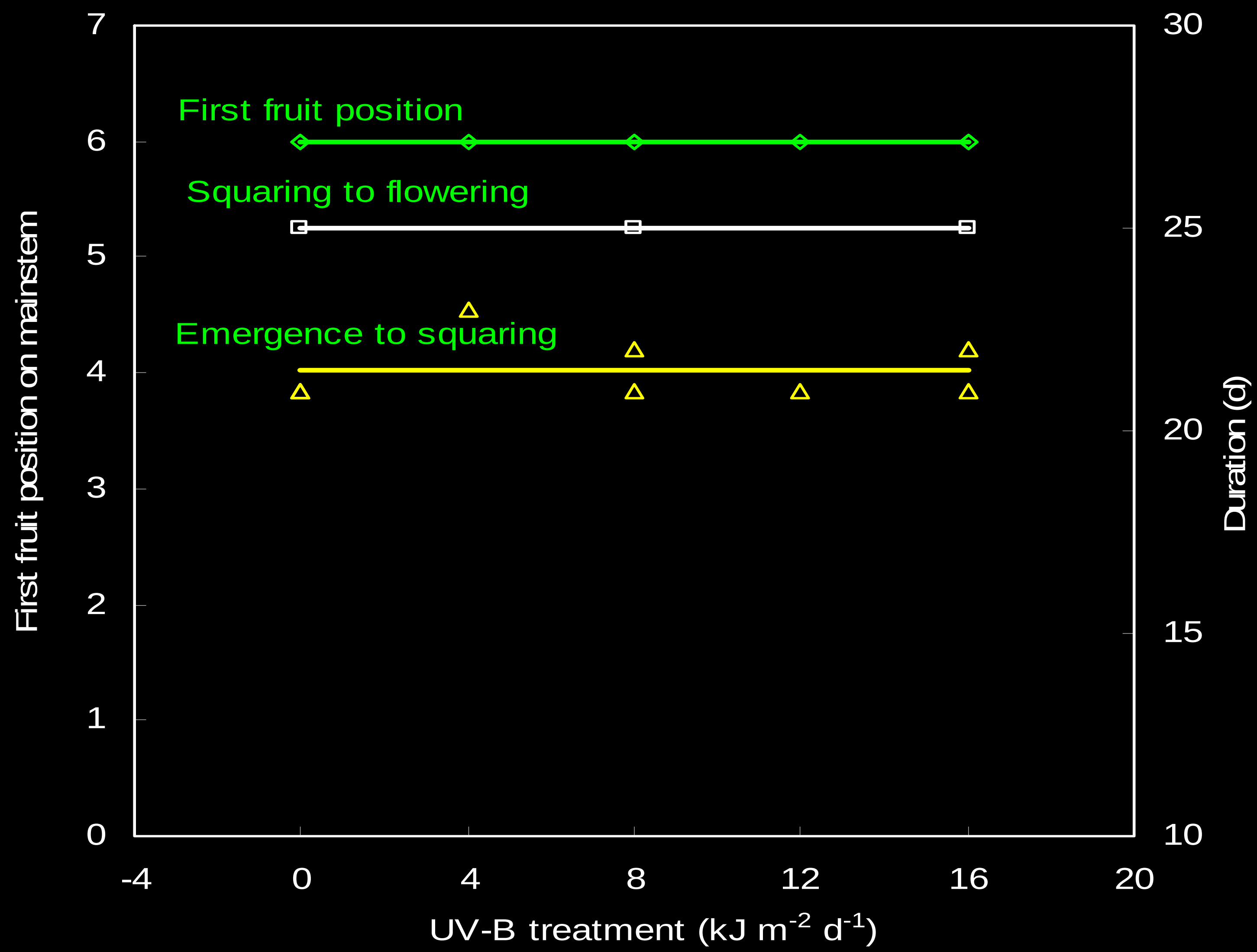


Satellite Based UV Radiation levels - 2001



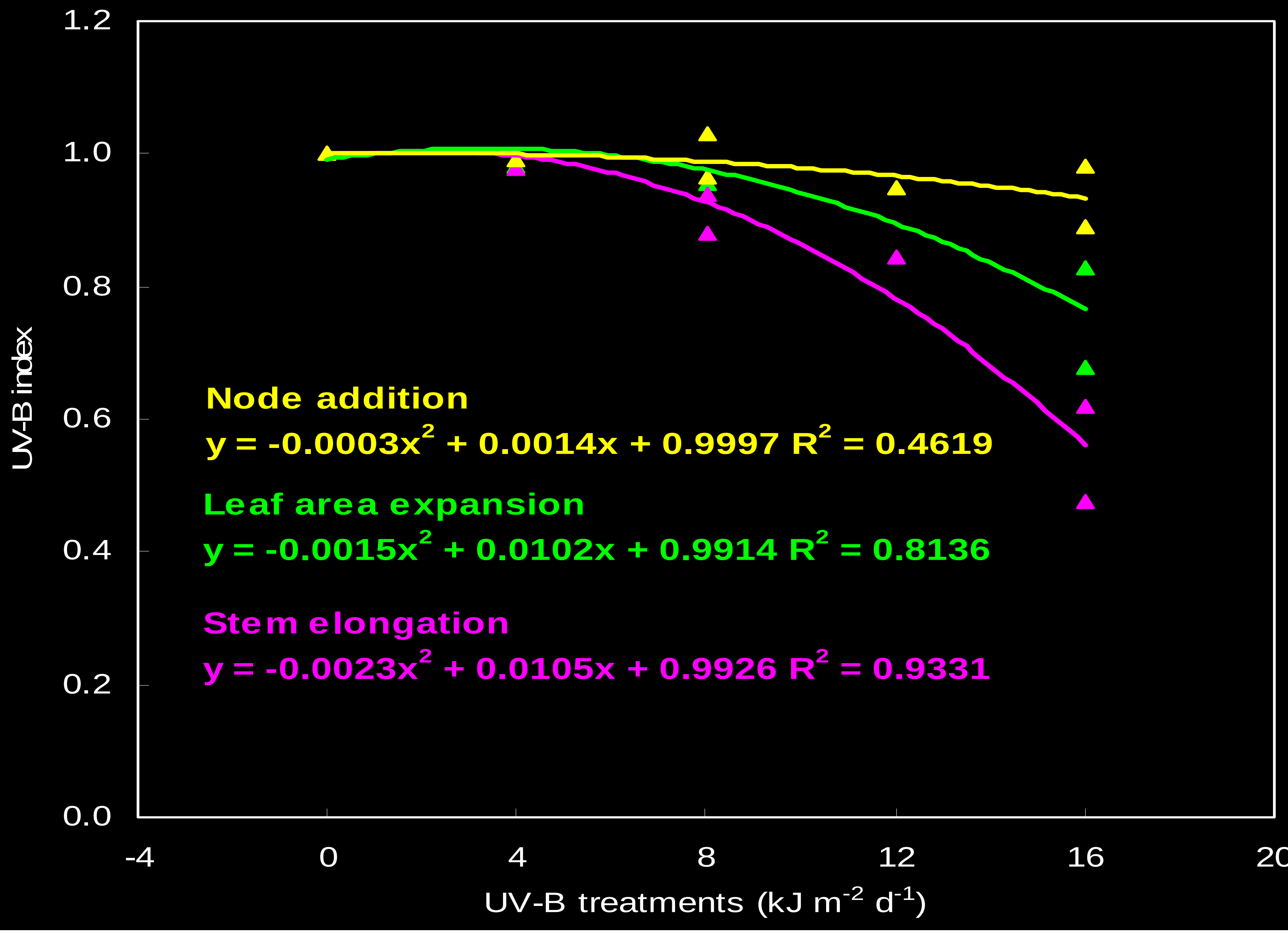
UV-B Radiation – Growth

EPI Factors for various growth Processes



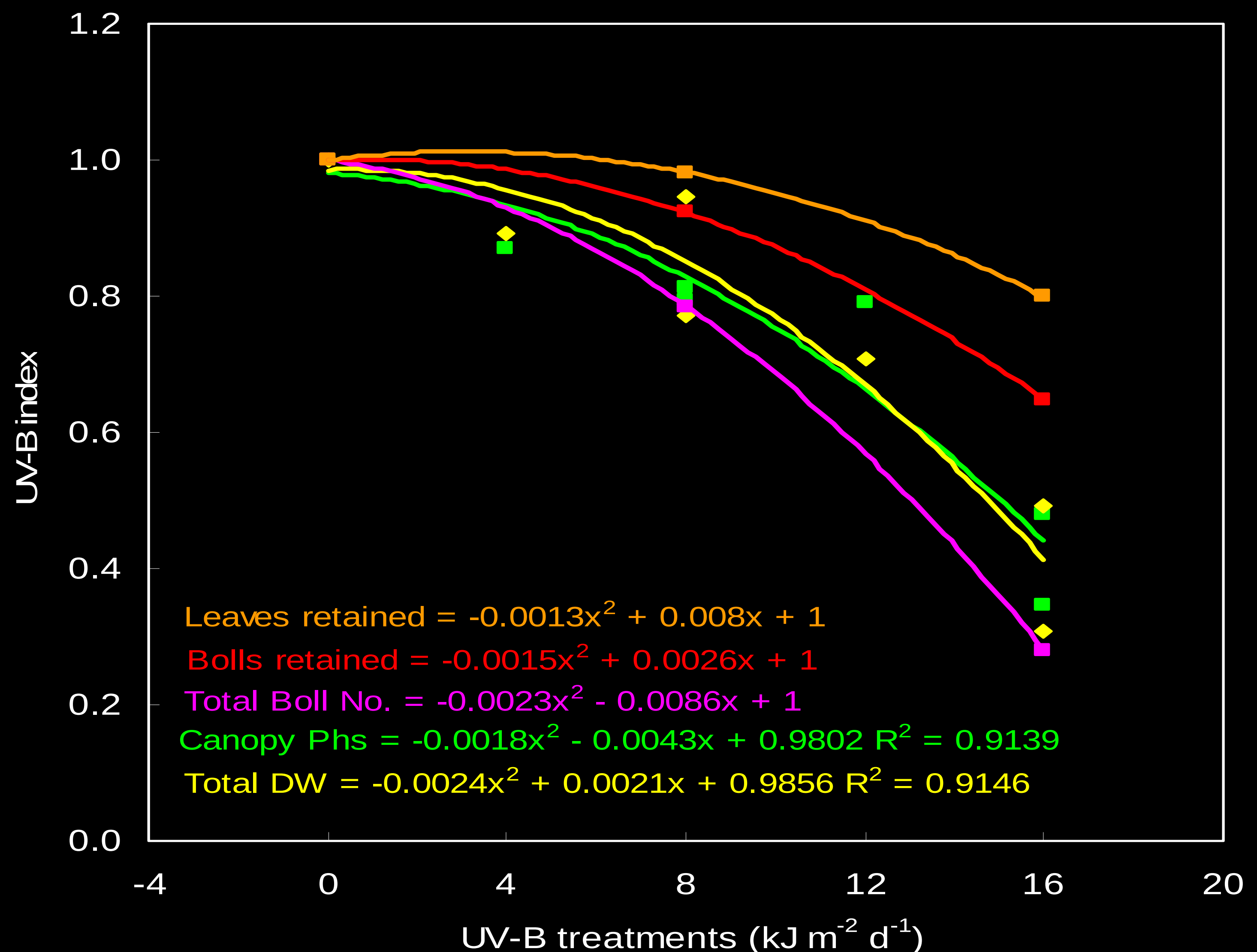
UV-B Radiation – Phenology

EPI Factors for various Developmental Processes

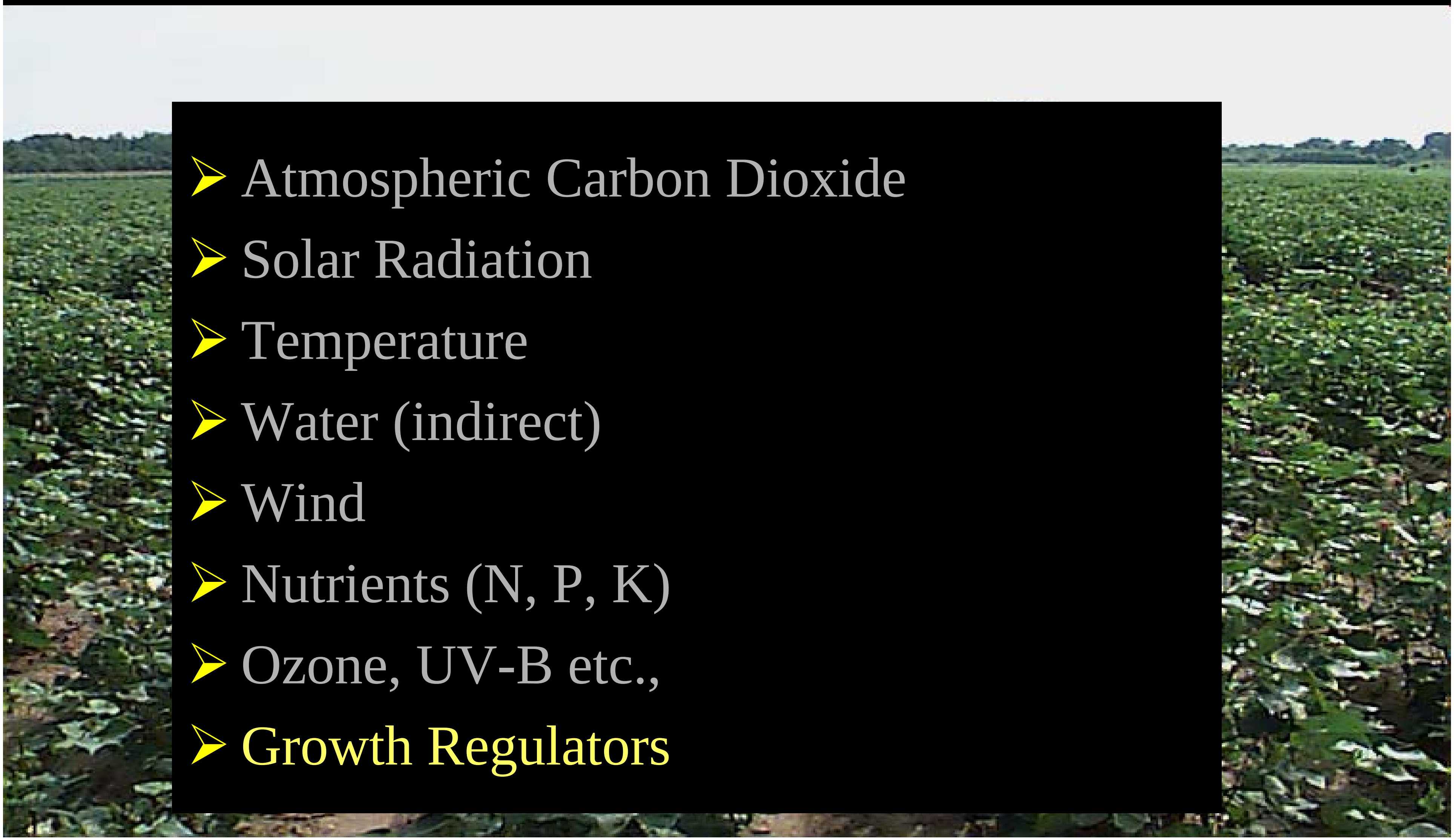


UV-B Radiation – Cotton Growth

EPI Factors for various growth Processes



Environmental limiting crop growth, development and yield



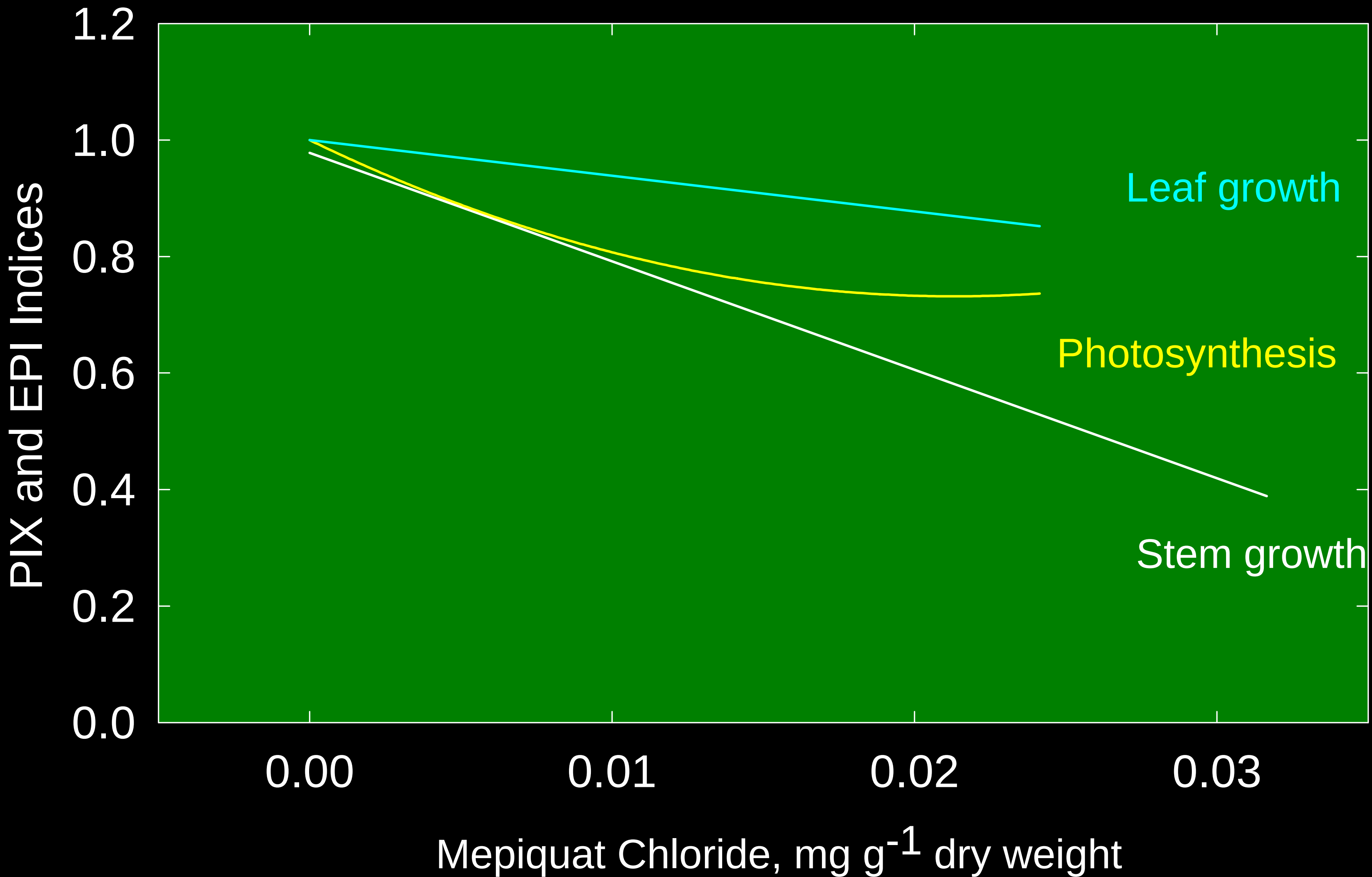
- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Environment Factors

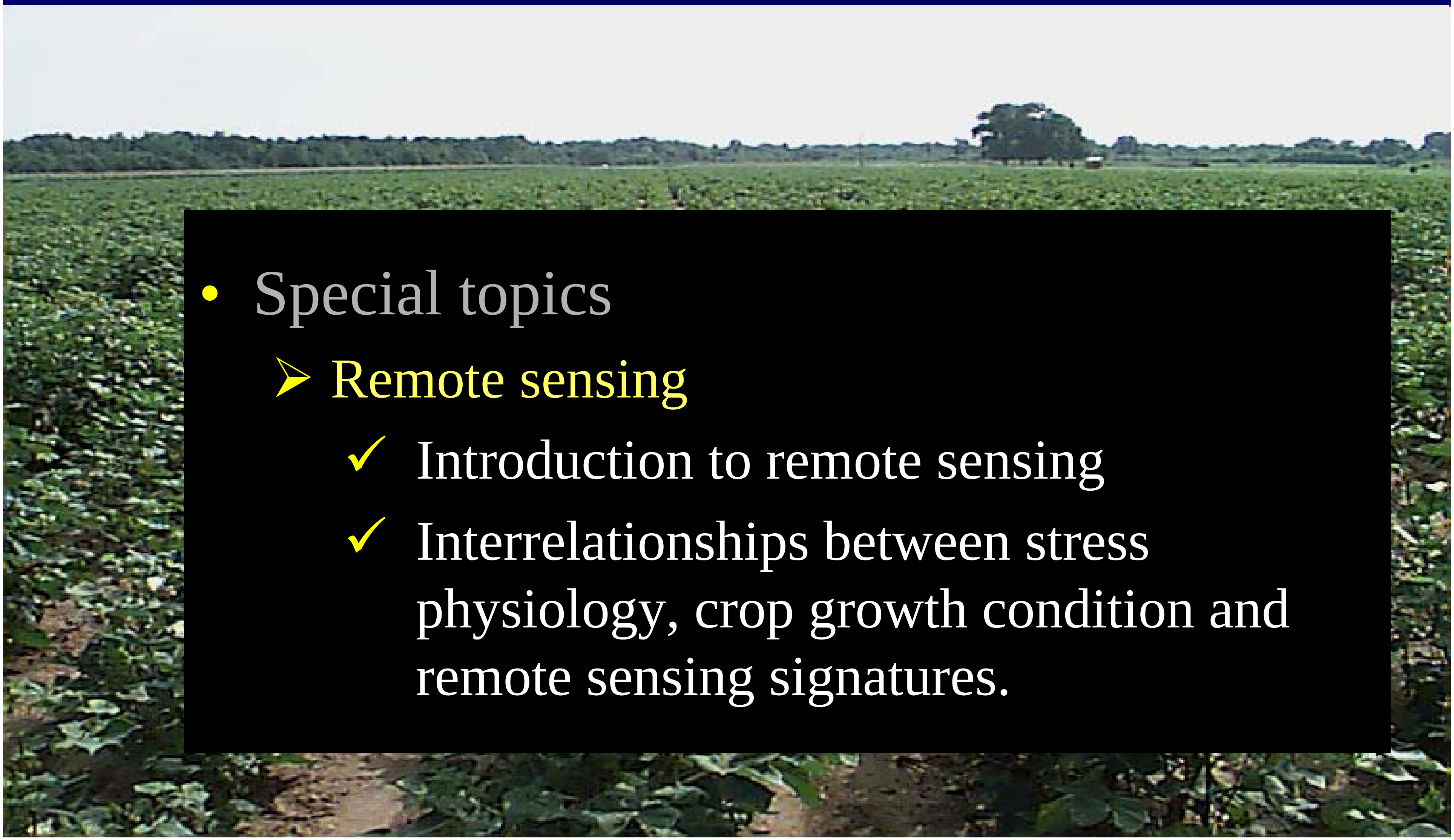
Growth Regulators - Mepiquat Chloride (PIX):

- Moderately Affects:
  -- *Leaf, stem and branch growth and LAI*
- Slightly Affects:
  -- *Photosynthesis*

Mepiquat Chloride (PIX) - Growth
EPI Factors

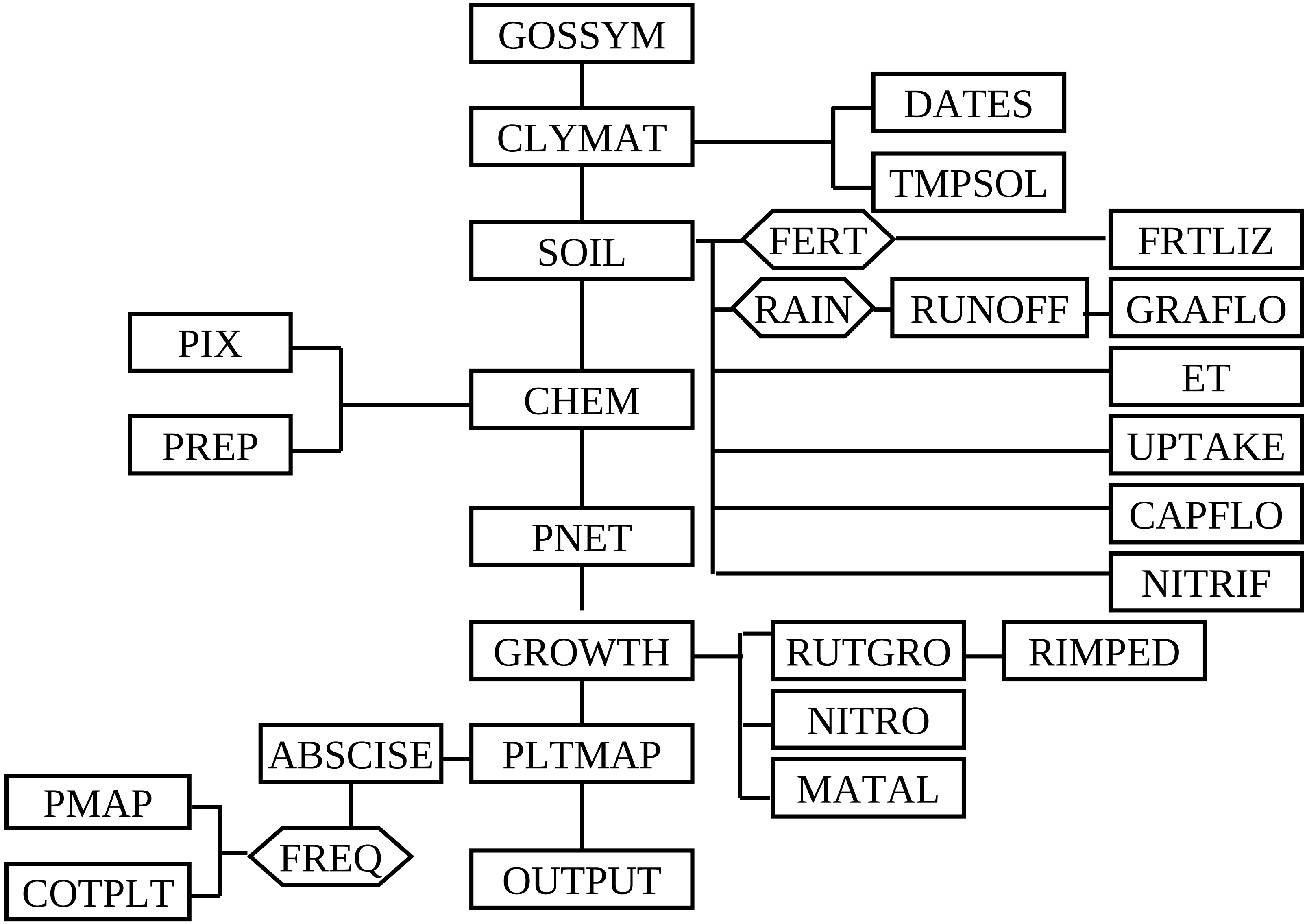


Environmental Plant Physiology and Remote Sensing

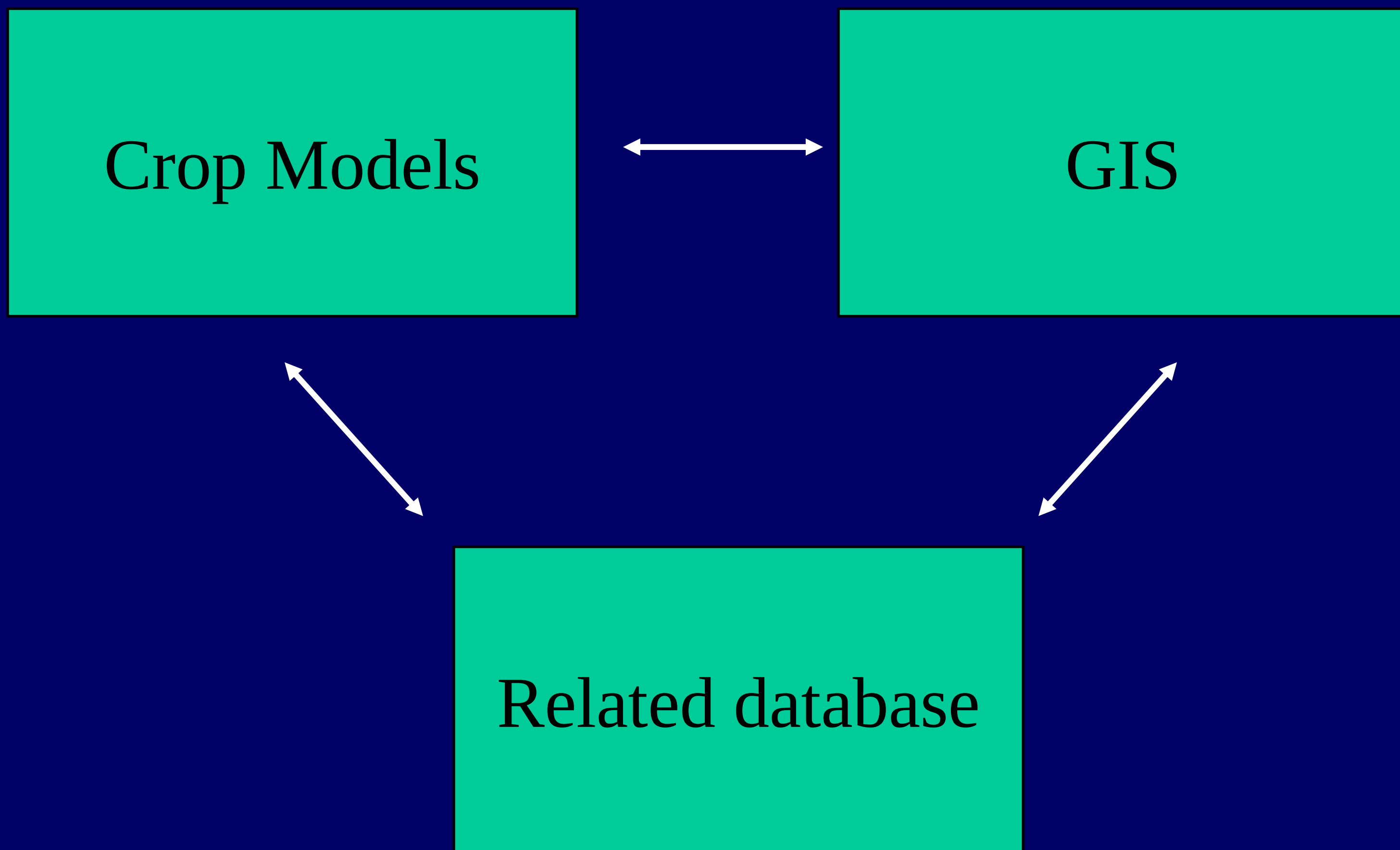


- Special topics
  - Remote sensing
    - ✓ Introduction to remote sensing
    - ✓ Interrelationships between stress physiology, crop growth condition and remote sensing signatures.

Flow Diagram of GOSSYM Cotton Crop Simulation Model



Technology Fusion and Delivery System



Environmental Plant Physiology and Crop Modeling

- Modeling forces the organization of known information and concepts.
- Although we may not know enough to develop a comprehensive model that includes all aspects of the farm or crop production system, modeling some meaningful portions of the system provides clarity.
- For a model to correctly predict plant responses to physical conditions, the concepts and the response functions must be appropriately assembled.

Environmental Plant Physiology, Crop Modeling, and Technology Integration for Decision Support System

- Critical environment-genotype relations should be incorporated into the model.
- When a crop model is based on appropriate concepts and processes it will have the predictive capability in new environments, and can be used either alone or with other emerging newer technologies to disseminate useful production information.
- Also, crop models should be integrated with other related technologies for technology integration and delivery.

Environmental Plant Physiology
Summary and Conclusions

- To study the effects of environmental factors on growth, development and other processes, we need:
  - ✓ Controlled environmental facilities with realistic environmental conditions including solar radiation.
  - ✓ Breakdown whole systems into sub-systems and study the influence of environmental factors on those subsystems.
  - ✓ Develop some concepts such as EPI to quantify the effects of multiple environmental factors on subsystems.
  - ✓ Integrate sub-systems into coherent whole plant/field/ecosystem system-level models/tools.

Environmental Plant Physiology
Summary and Conclusions

- Validated/integrated system simulation models will be useful:
  - ✓ To test hypothesis.
  - ✓ To understand multiple environmental effects or interactions.
  - ✓ For resources management at the filed-level.
  - ✓ For resource management to assist policy decisions.
  - ✓ As an educational tool to understand the effects of environment/management effects on crop functioning.
  - ✓ For impact assessment of climate change on cop production systems across regions and nations.

“You cannot build peace on empty stomachs.”

John Boyd Orr
Nobel Peace Laureate
First FAO Director General

“You can’t eat the potential yield, but need to raise the actual by combating the stresses”

Norman E. Borlaug
Nobel Peace Laureate