Environmental Plant Physiology
Facilities and Tools

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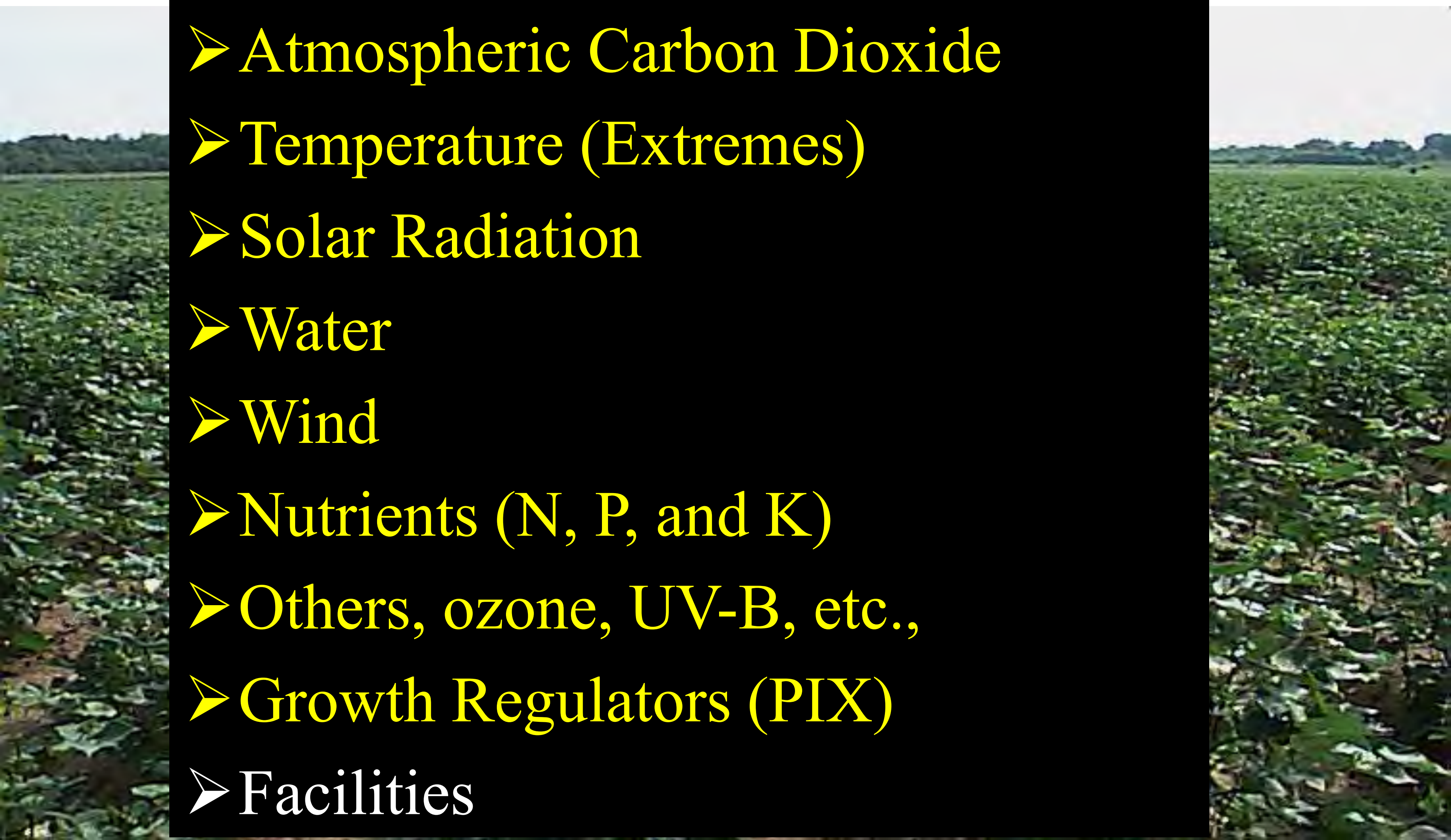
Environmental and Cultural Factors Limiting Potential Yields



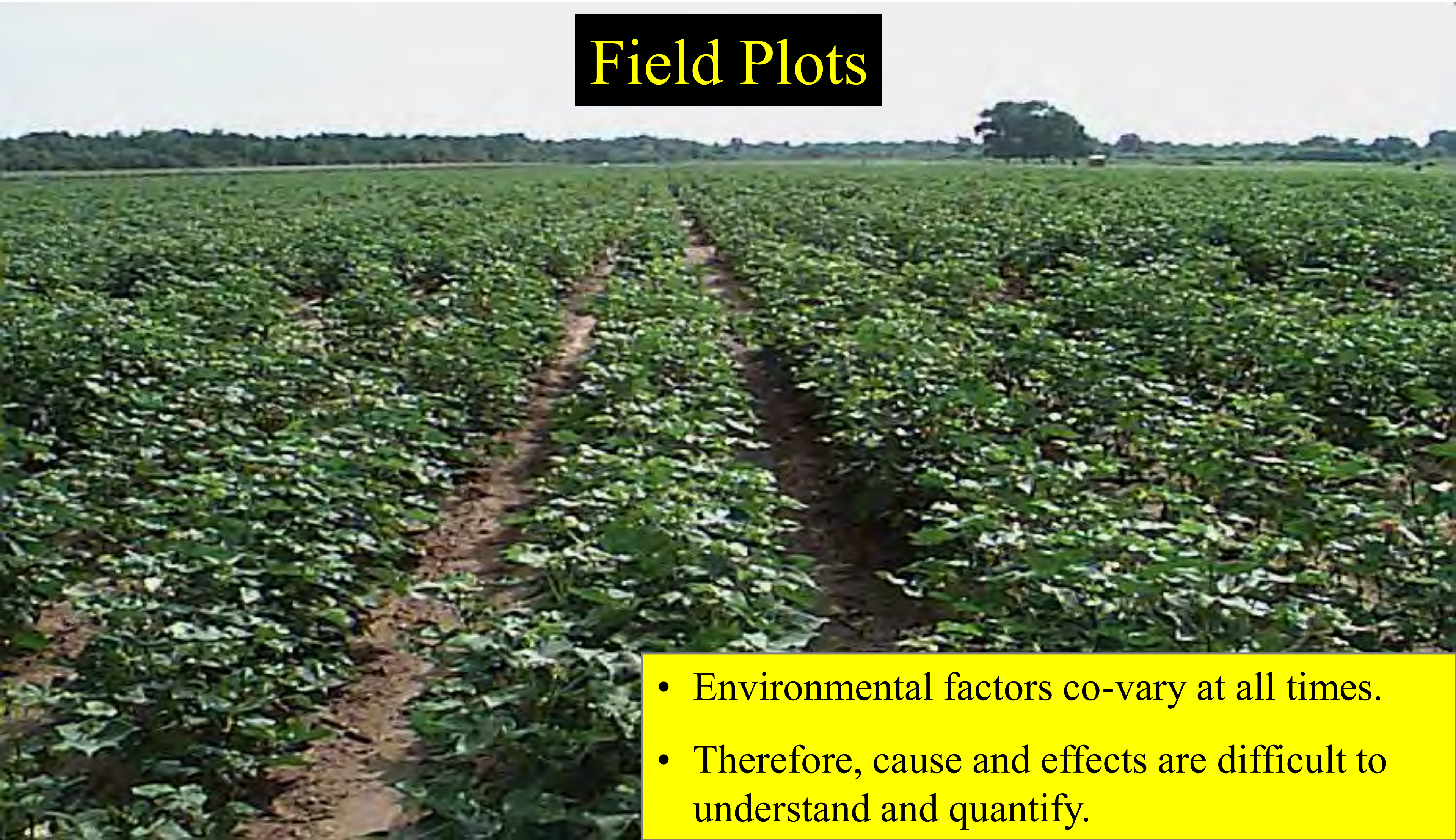
- Atmospheric Carbon Dioxide
- Temperature (Extremes)
- Solar Radiation
- Water
- Wind
- Nutrients (N, P, and K)
- Others, ozone, UV-B, etc.,
- Growth Regulators (PIX)
- Facilities

Environmental Plant physiology and Facilities and Tools

- ✓ Facilities:
  - ➢ Field plots
  - ➢ Free-air carbon dioxide enrichment (FACE) facilities and Temperature-Free-air carbon dioxide enrichment (T-FACE), and Open-top chambers
  - ➢ Indoor plant growth chambers and Greenhouses
  - ➢ Sunlit plant growth chambers
- ✓ Tools:
  - ➢ Crop simulation models

Crop Responses to Environment - Tools

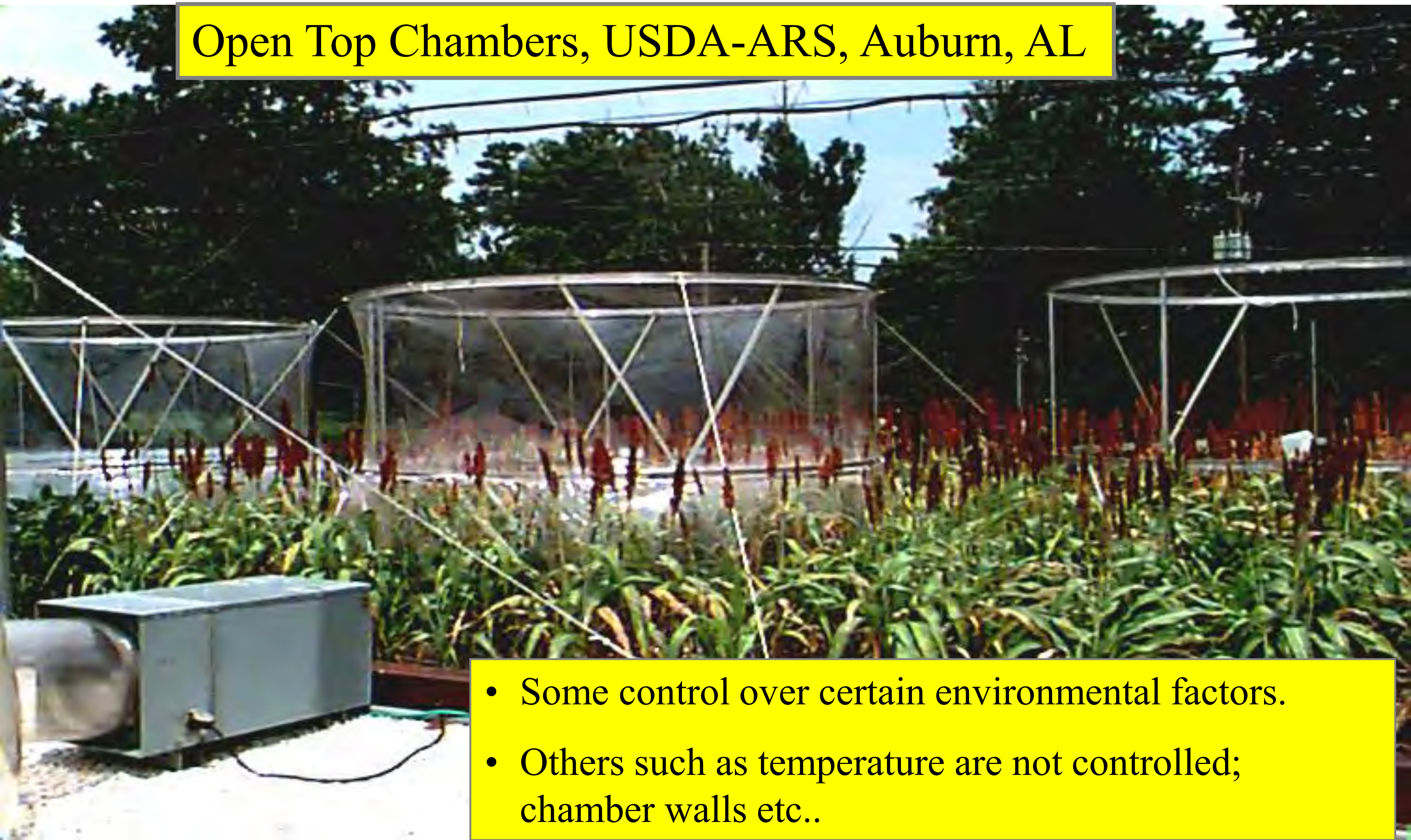
Field Plots



- Environmental factors co-vary at all times.
- Therefore, cause and effects are difficult to understand and quantify.

Crop Responses to Environment - Tools

Open Top Chambers, USDA-ARS, Auburn, AL



- Some control over certain environmental factors.
- Others such as temperature are not controlled; chamber walls etc..

Crop Responses to Environment - Tools

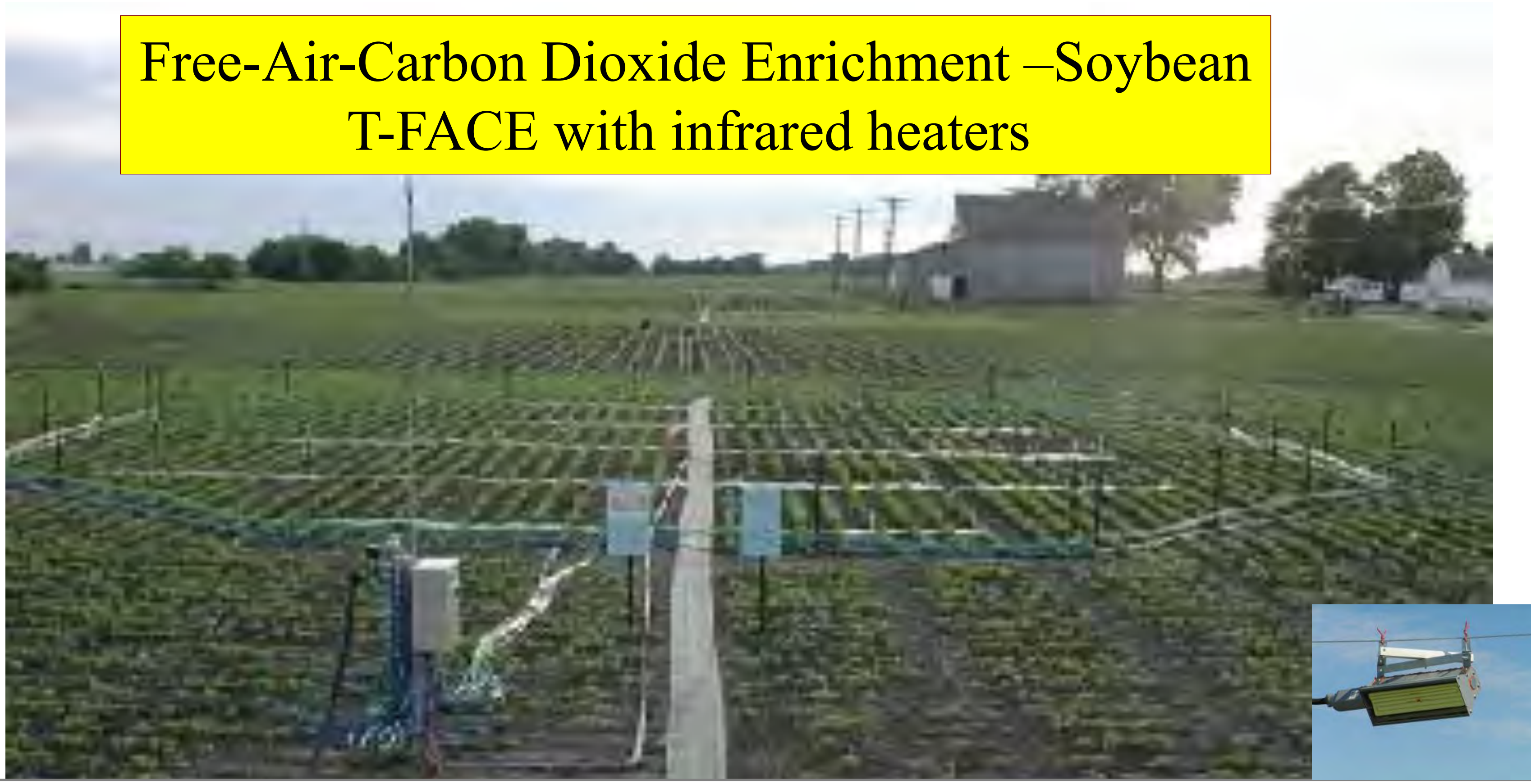
Open Top Chambers, USDA-ARS, Beltsville, MD

- Some control over certain environmental factors.
- Others such as temperature are not controlled; chamber walls etc..

Crop Responses to Environment - Tools

Crop Responses to Environment - Tools

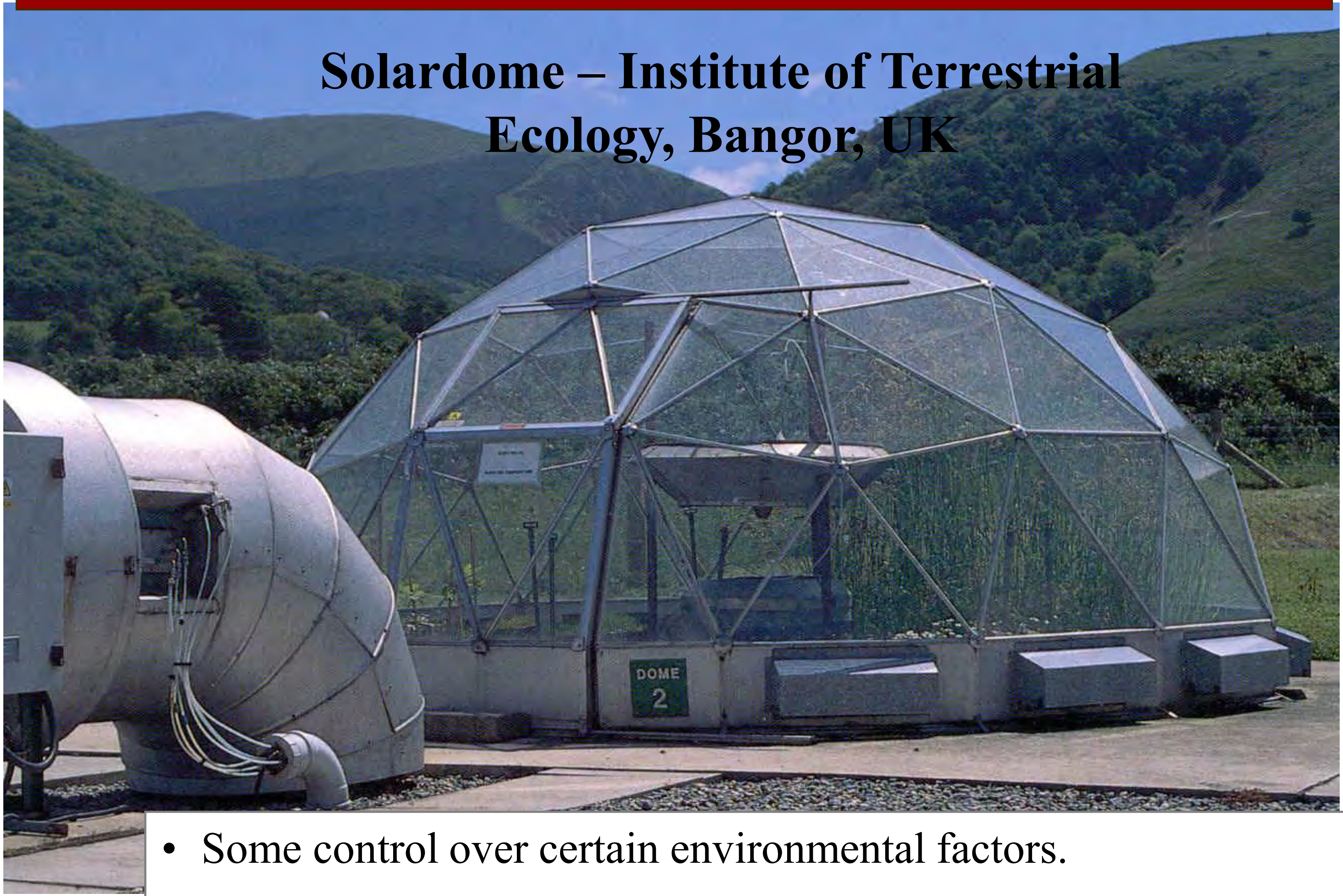
Free-Air-Carbon Dioxide Enrichment –Soybean
T-FACE with infrared heaters



- Large study area allows for multiple disciplines.
- Some control over certain environmental factors such as CO_2 and ozone.
- Others such as temperature earlier are not controlled, but recently added infrared heating.

Crop Responses to Environment - Tools

Solardome – Institute of Terrestrial Ecology, Bangor, UK



- Some control over certain environmental factors.
- Others such as: temperature controlled to certain degree to the ambient levels; chambers walls etc.

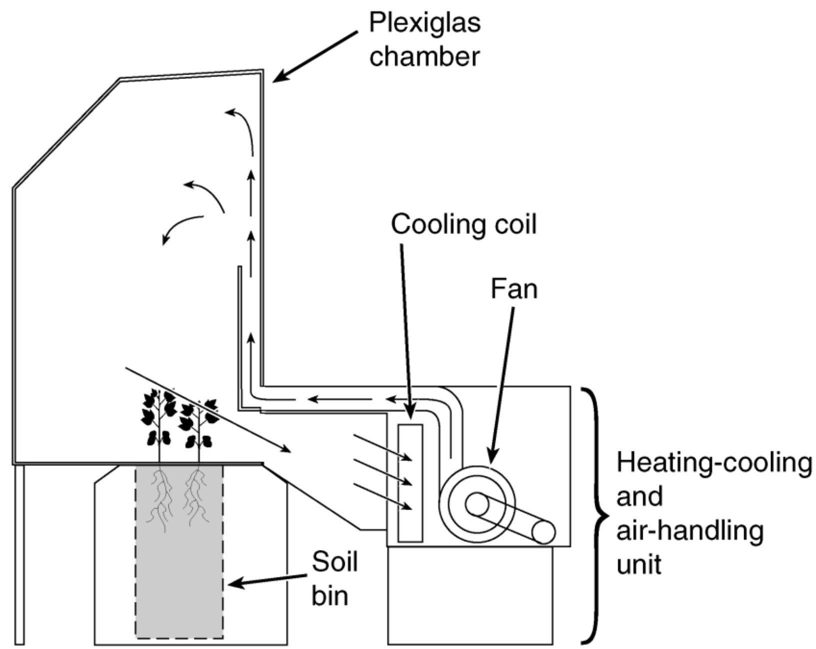
Crop Responses to Environment - Tools

Indoor plant growth chambers and greenhouses

- Some control over certain environmental factors.
- Suitable for certain studies; however, low light levels, poor control over temperatures, inadequate pot sizes and fertility and irrigation management.

SPAR - Soil-Plant-Atmosphere-Research

Plant Process Quantification and Modeling



A 50 ton cooling & coolant circulating system

Two 5.5 kW heating, air circulation & moisture condensing system

Mini-rhizotron system for non-destructive root growth and development

SPAR - Soil-Plant-Atmosphere-Research

What Can We Control?

- ✓ Temperatures: 10 to 45 ^{o}C or 50 to 113 ^{o}F
- ✓ CO_2 concentration: Subambient to 1000 ppm
- ✓ Ultraviolet-B radiation: 0 to three times of ambient UV-B (up to 16 kJ)
- ✓ Water regimes: Can be manipulated based on measured ET nicely
- ✓ Fertilization: One or several nutrients can be easily manipulated either alone or in combination
- ✓ Solar radiation: sunlit (>95% passes through the Plexiglas and reaches plant canopy), no artificial light

SPAR - Soil-Plant-Atmosphere-Research

What Can We Measure?

✓ Abiotic conditions:

- Air, canopy and dew-point temperatures
- Solar and ultraviolet-B radiation
- Chamber and outside CO_2 concentrations
- Soil water and temperature by depth
- Relative humidity

✓ Processes:

- Canopy photosynthesis, respiration, and evapotranspiration
- Leaf-level physiological, biochemical and molecular processes

SPAR - Soil-Plant-Atmosphere-Research

What can we measure?

- ✓ Growth and developmental processes:

  I. Phenological rates:

  - Similar events: Leaf and internode addition rates, duration rates, etc.

  - Dissimilar events: seed to emergence, emergence to square, square to flower and flower to open boll.

  II. Growth rates:

  - Leaf, internode (stem), root, and fruiting structures (square, boll, lint, seed/grain etc.).

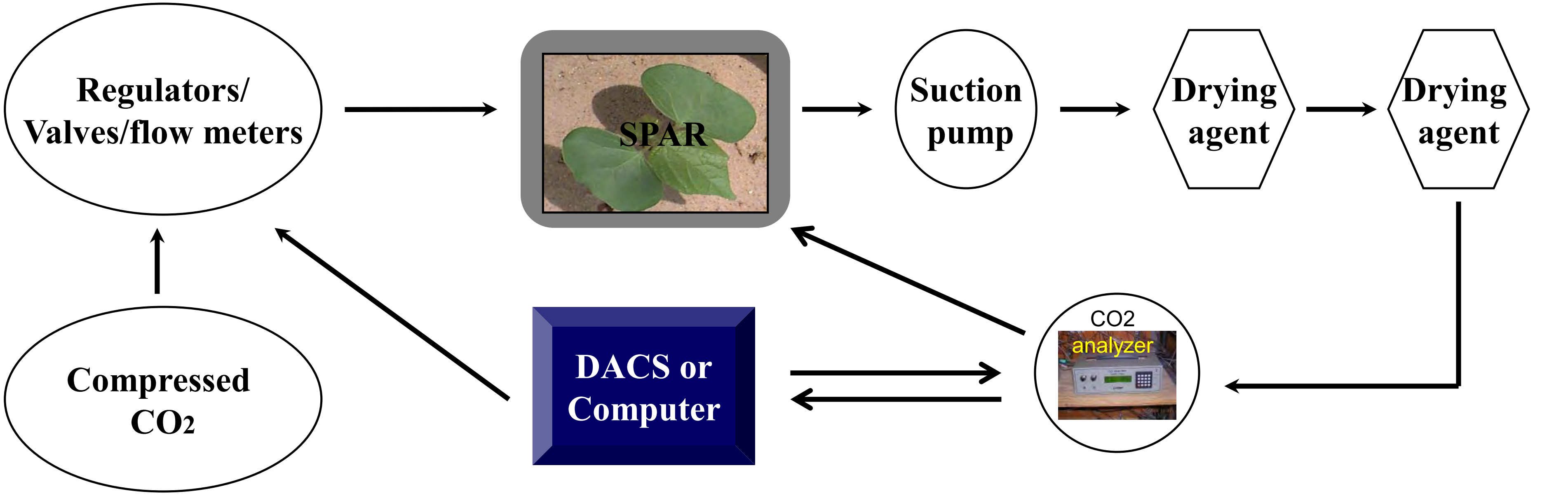
SPAR - Measuring Carbon Fluxes

Measuring Photosynthesis: Mass-balance approach

During sunlit hours, by maintaining steady or constant CO_2 concentration inside the SPAR chamber, we can calculate:

Net photosynthesis = Amount of CO_2 injected – leak rate

Gross Photosynthesis = Net photosynthesis + Respiration

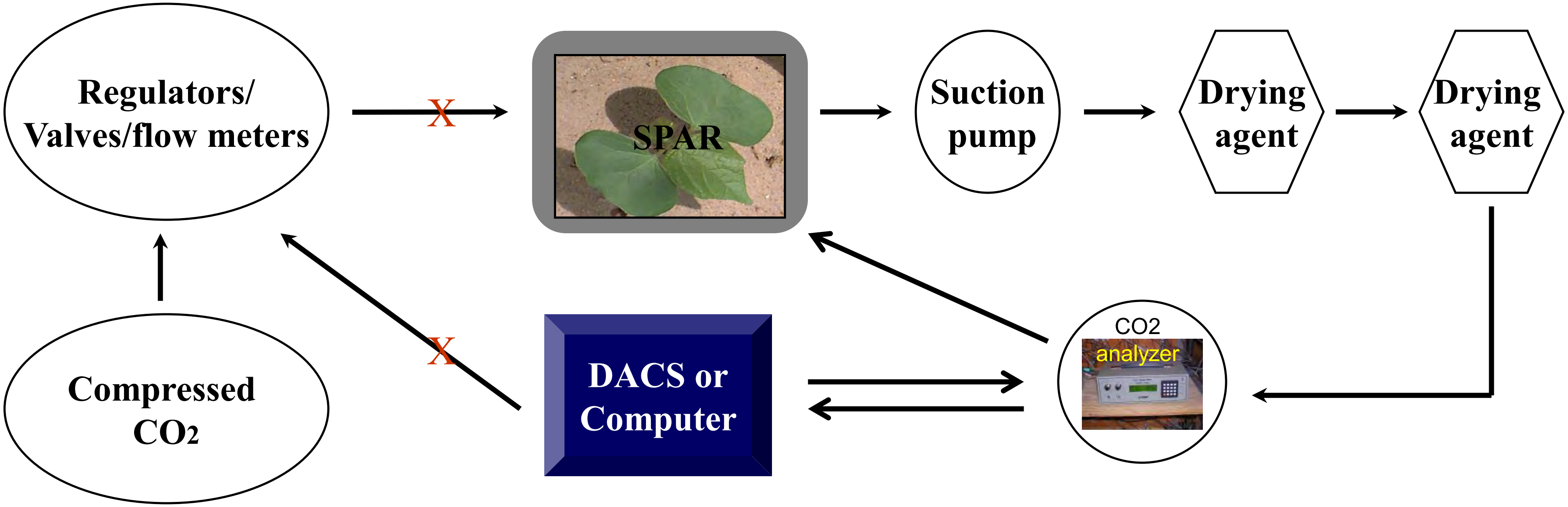


SPAR - Measuring Carbon Fluxes

Measuring Respiration:

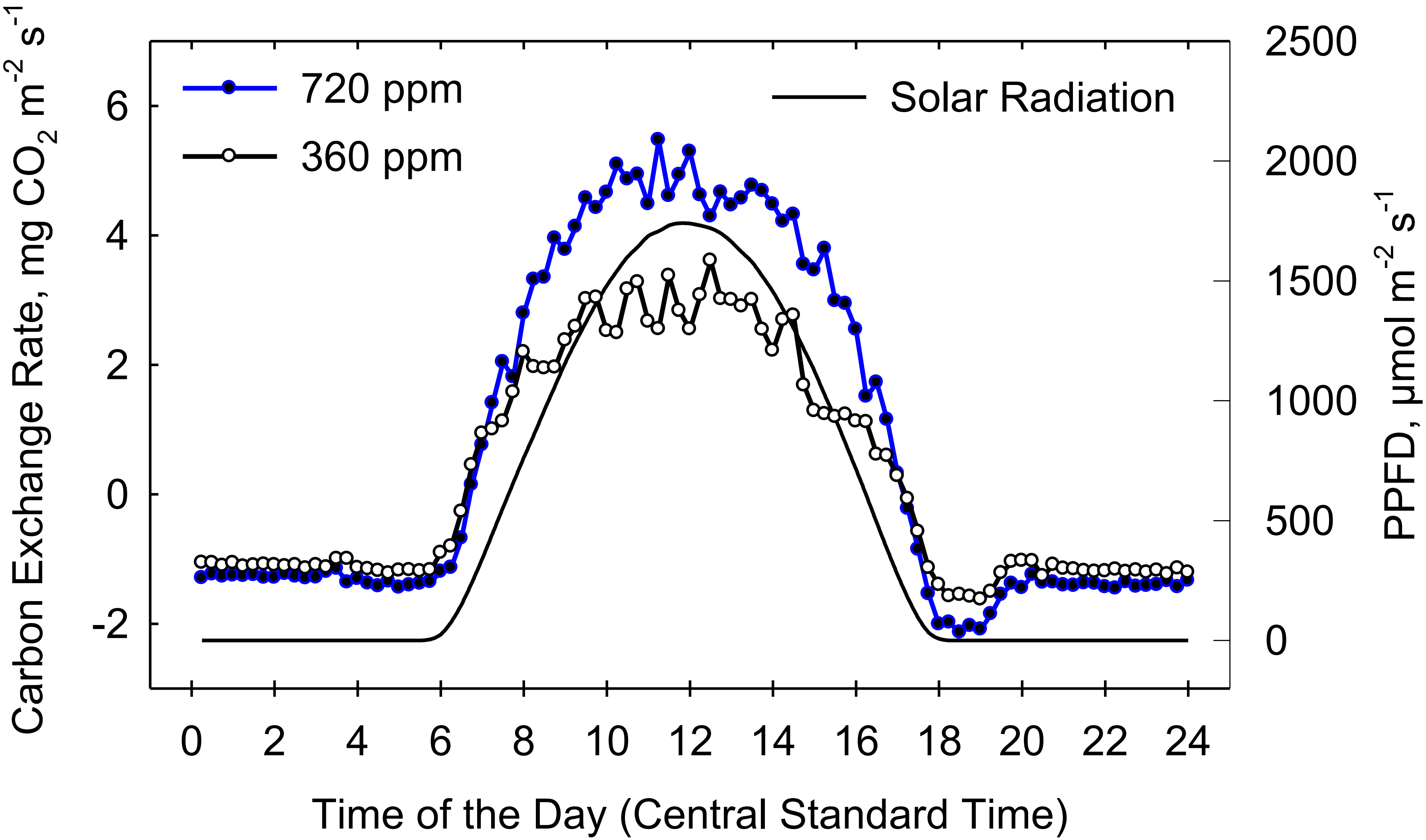
During nighttime, by measuring the rise or build up CO_2 concentration inside the SPAR chamber, we can calculate,

Respiration rate = [(CO_2 Conc., at Time 2 - CO_2 Conc., at Time 1) + leak rate]



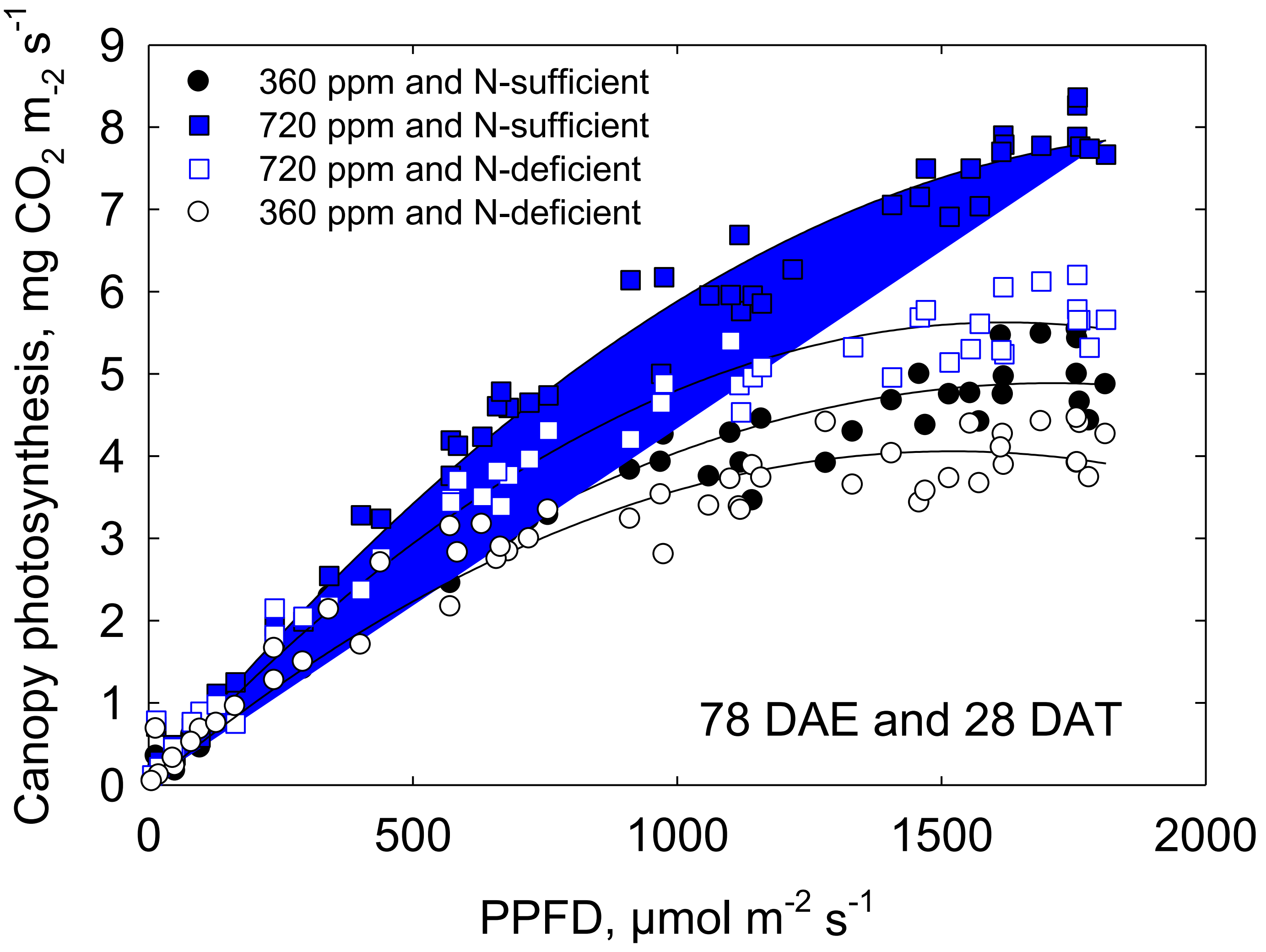
SPAR – Process Quantification and Modeling

Canopy Photosynthesis and Diurnal Trends



SPAR – Process Quantification and Modeling

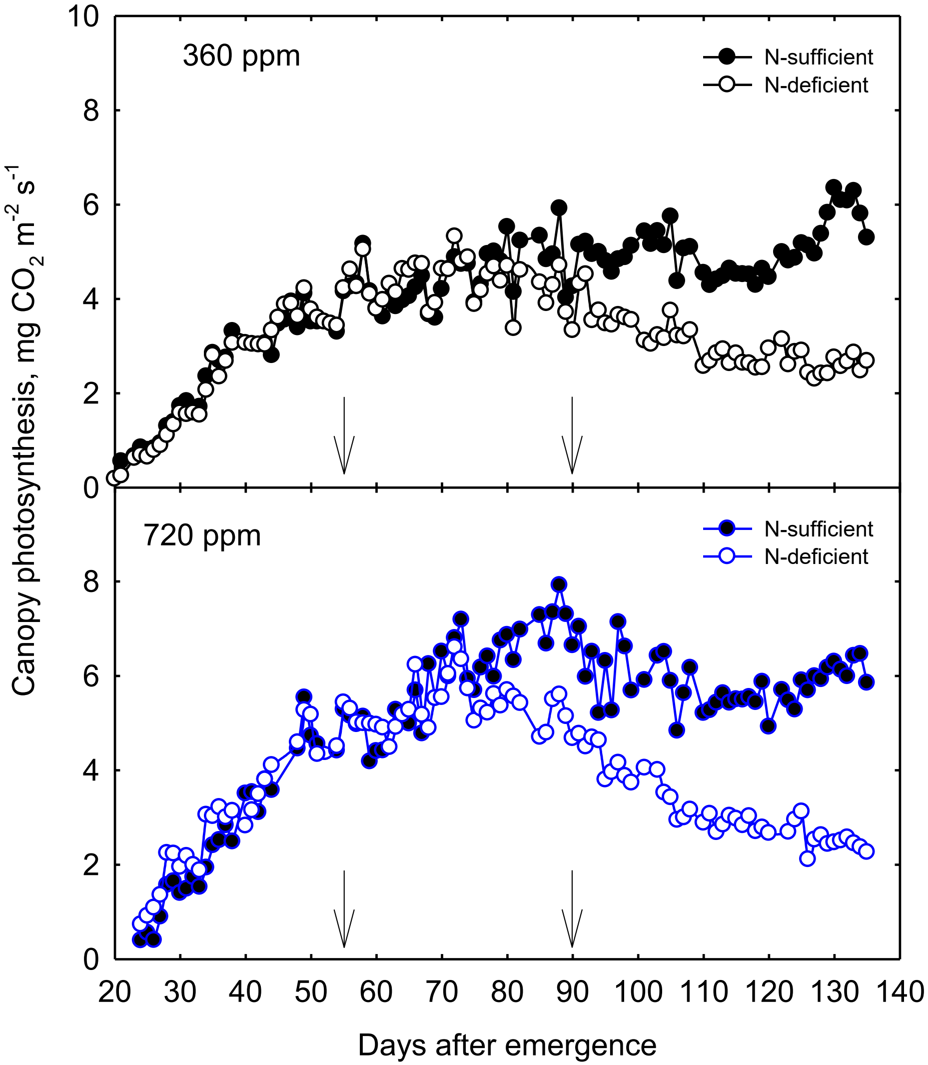
Canopy Photosynthesis and Light Response Curves



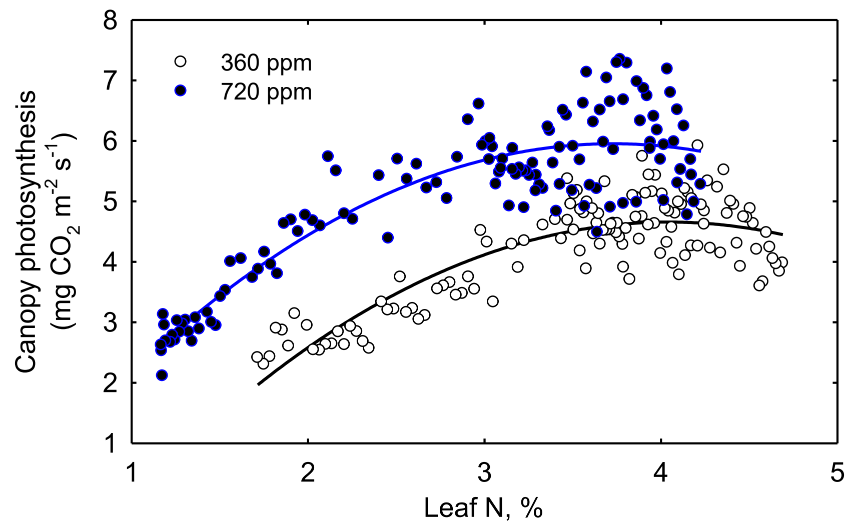
SPAR – Process Quantification and Modeling

Cotton Canopy Photosynthesis – N and CO_2

Temporal Trends in Photosynthesis Processes



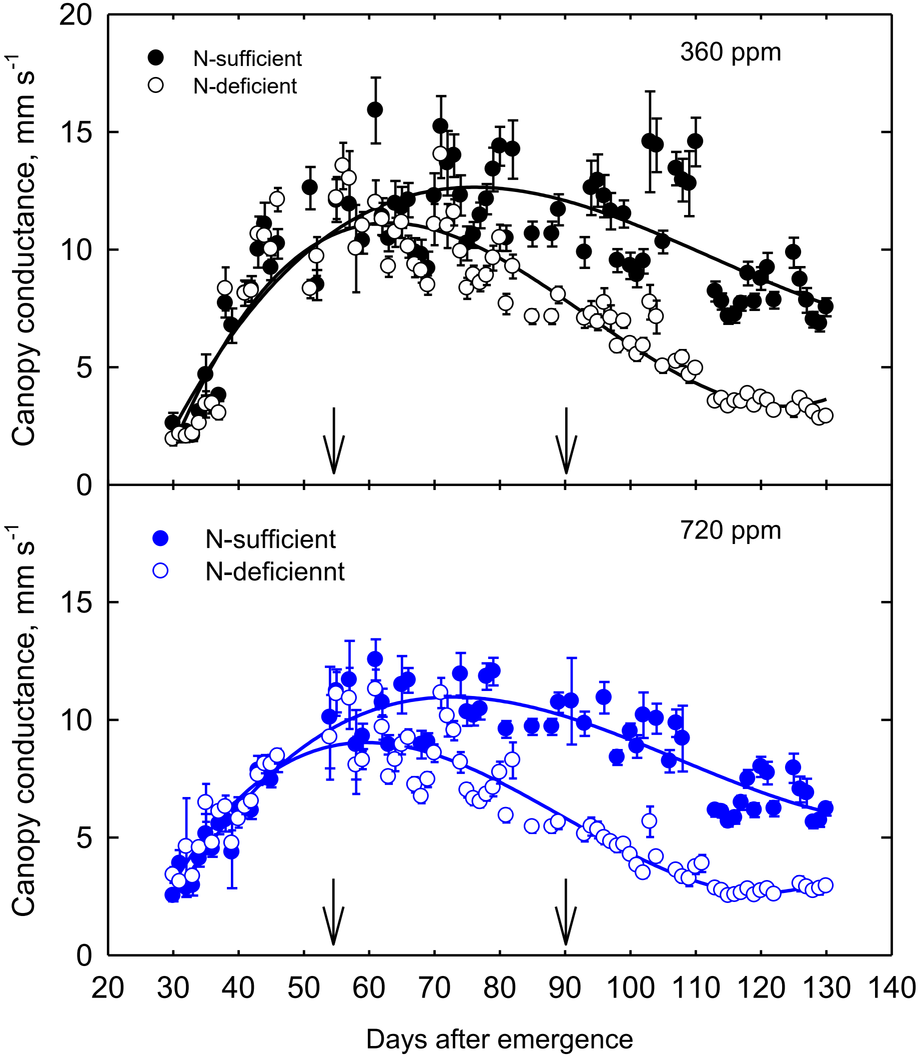
Nitrogen and Photosynthesis



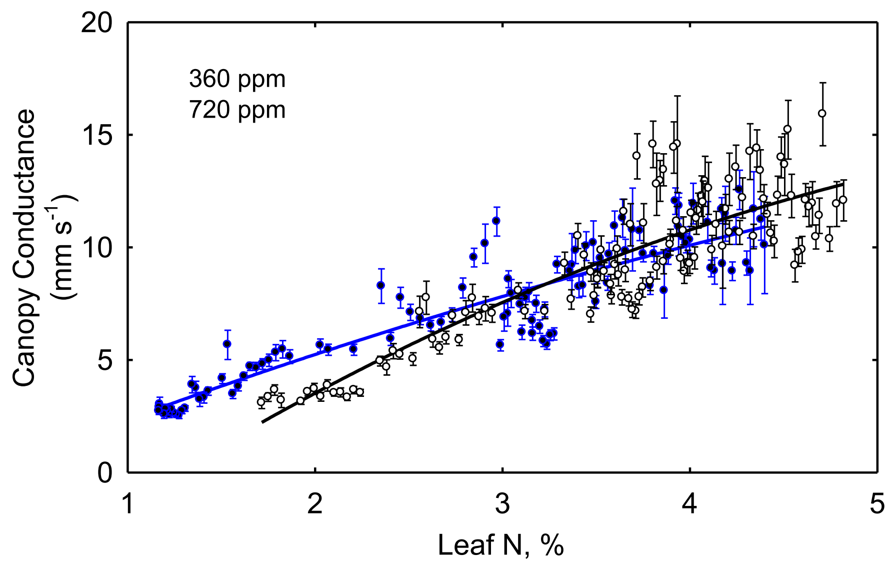
SPAR – Process Quantification and Modeling

Cotton Conductance – N and CO_2

Temporal Trends in Canopy Conductance

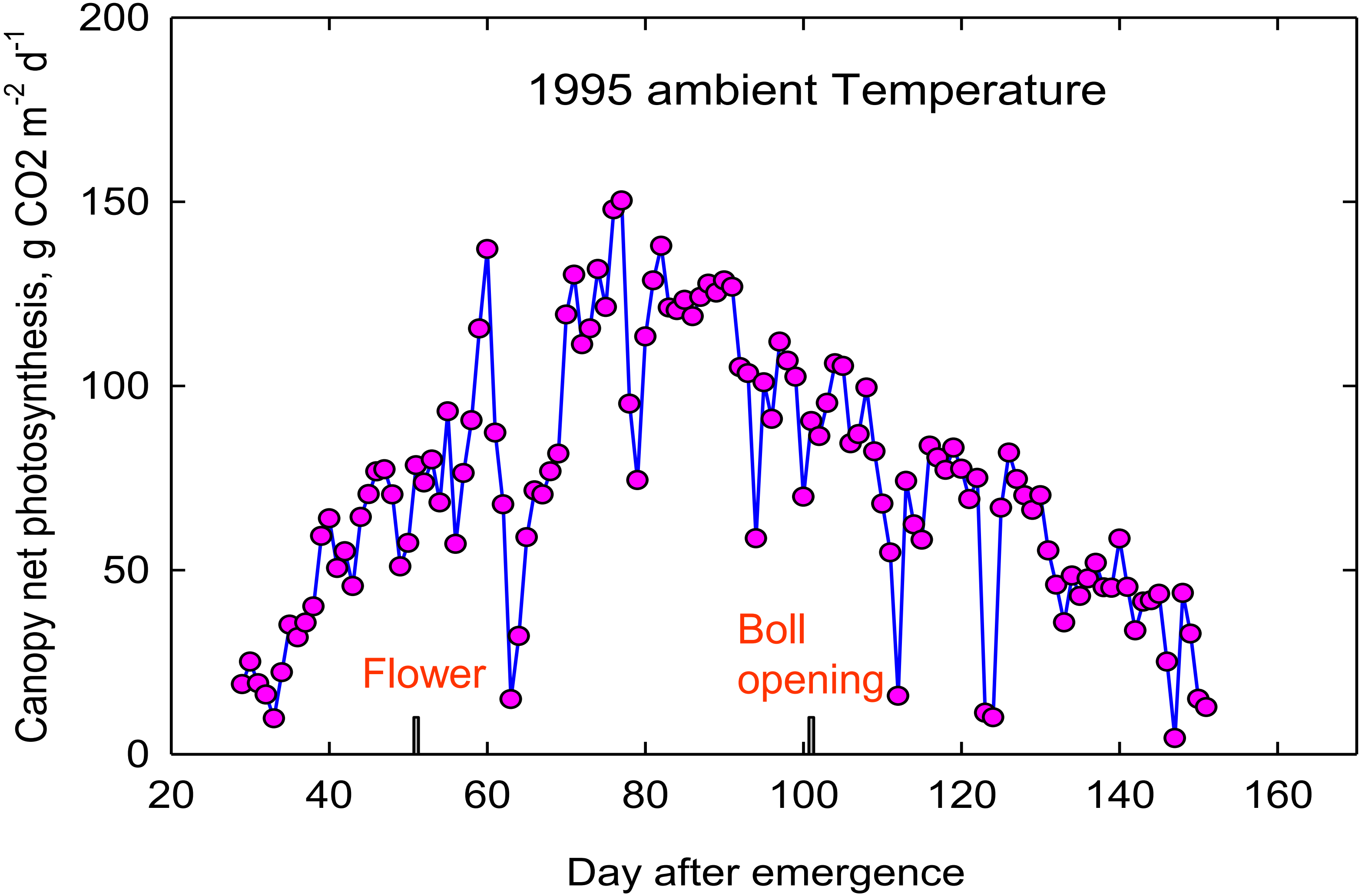


Nitrogen and Canopy Conductance Relationship



SPAR – Process Quantification and Modeling

Integration of Canopy Net Photosynthesis



SPAR – Process Quantification and Modeling

Leaf-level Gas Exchange and Reflectance Measurements

- We can monitor leaf-level gas exchange:
  - ✓ Photosynthesis, stomatal conductance, transpiration, fluorescence, etc.
- We can monitor leaf-level reflectance measurements:
  - ✓ Leaf reflectance properties, pigments etc.
- We can also monitor leaf temperatures and leaf water potentials:
  - ✓ Leaf temperatures by infrared thermometers.
  - ✓ Leaf water potential by Pressure bomb.

SPAR – Process Quantification and Modeling

Measuring Evapotranspiration (ET)

1. Measuring Evapotranspiration (ET):

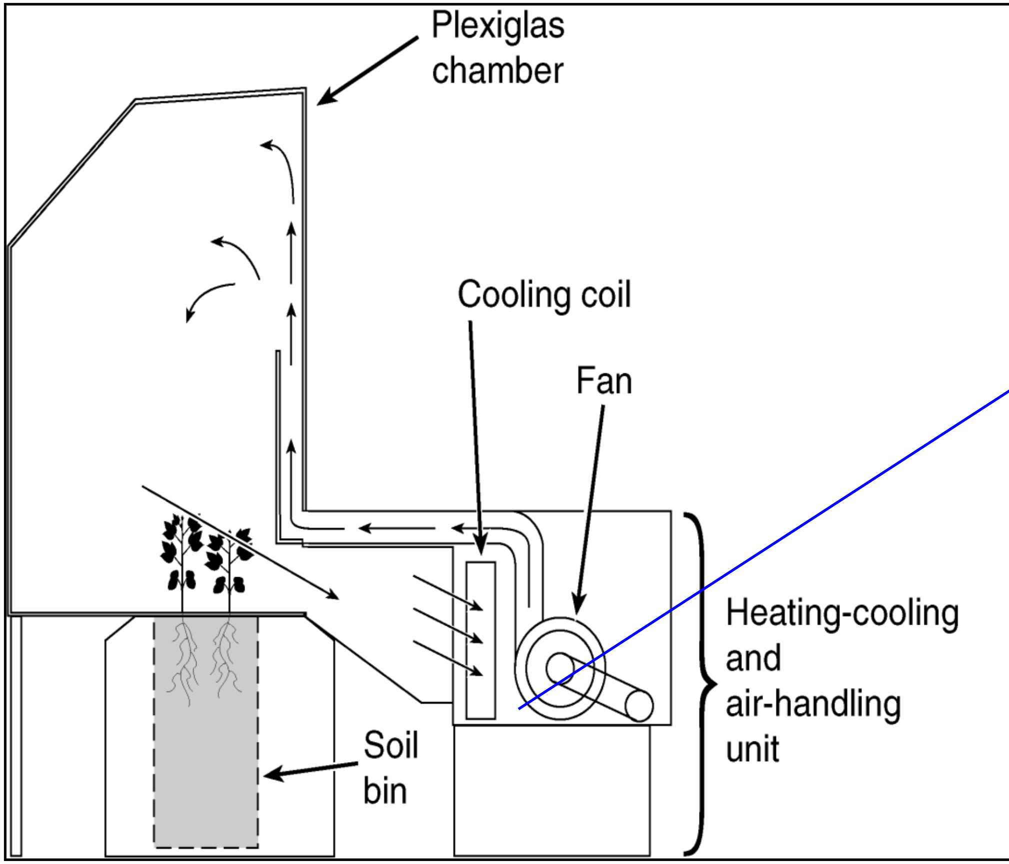
During day and nighttime periods, by collecting the condensate (moisture in the air) while passing through the cooling coils, ET is measured using a set of values, controllers and pressure transducers every 15 minutes.

2. Measuring transpiration:

By sealing the soil surface and around the plant stems, one can accurately measure transpiration.

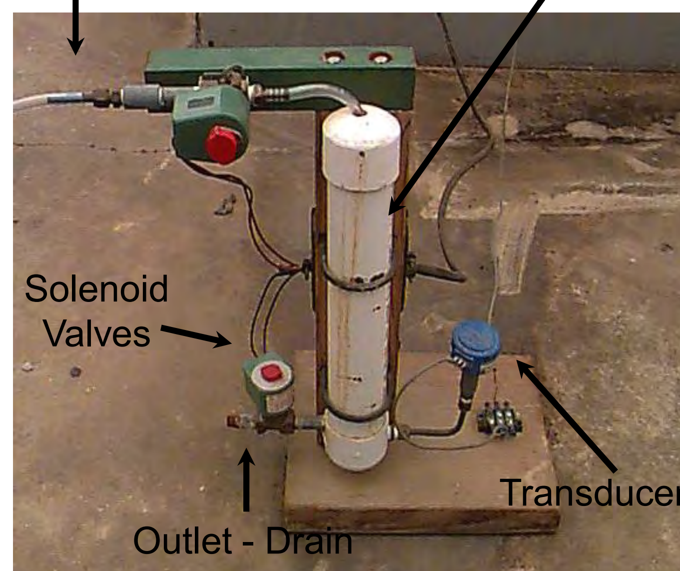
SPAR – Process Quantification and Modeling

Measuring Evapotranspiration



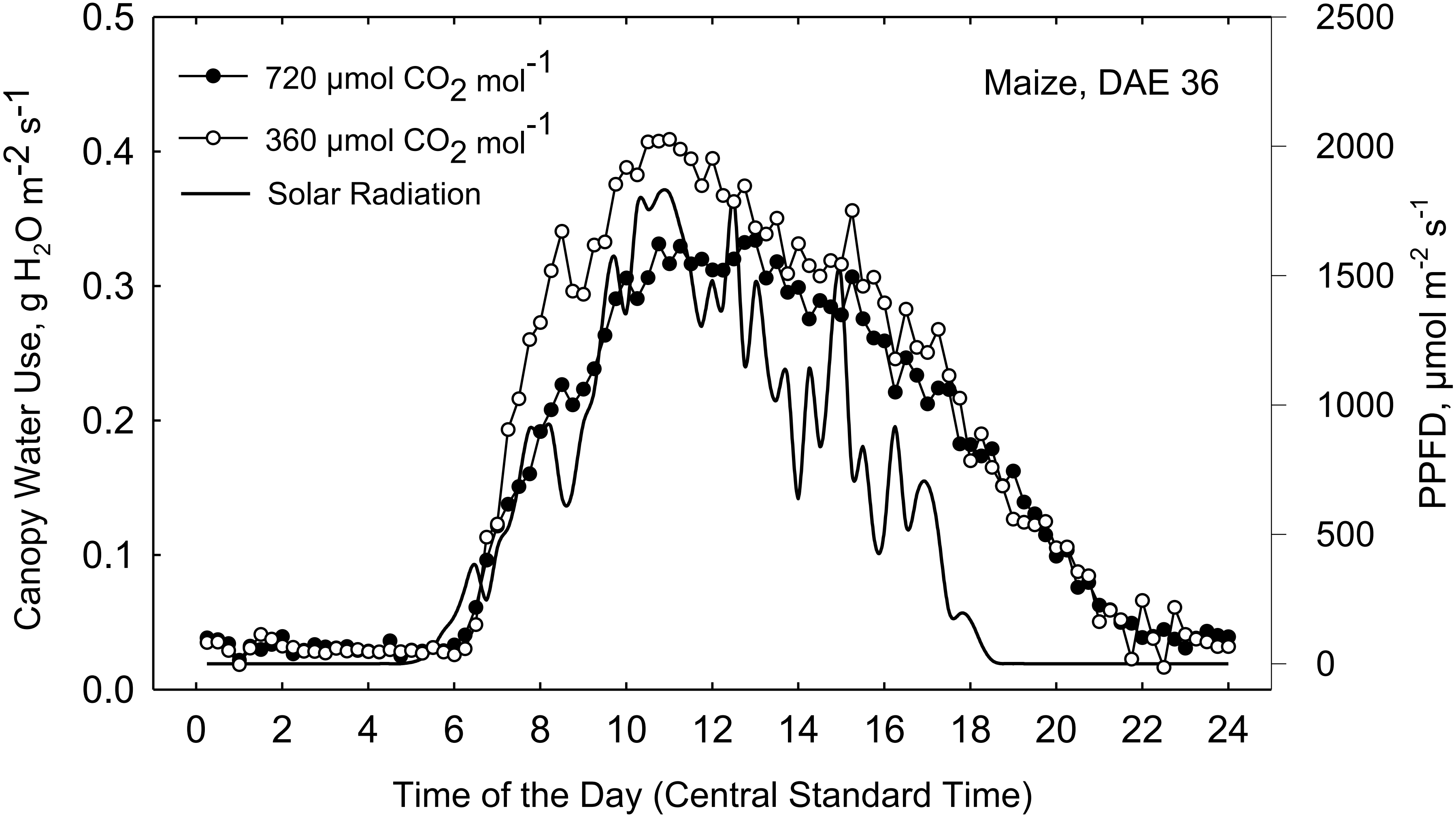
Inlet – From Condenser Coils in the unit

Condensate ET Reservoir



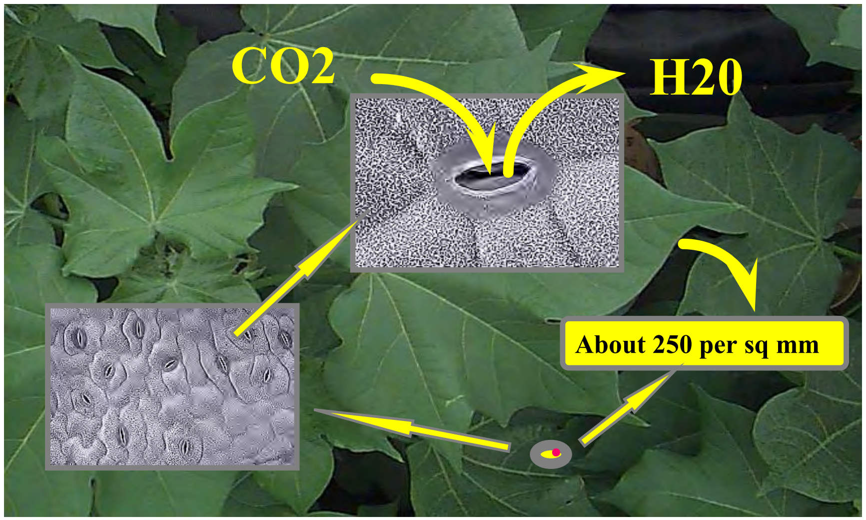
SPAR – Process Quantification and Modeling

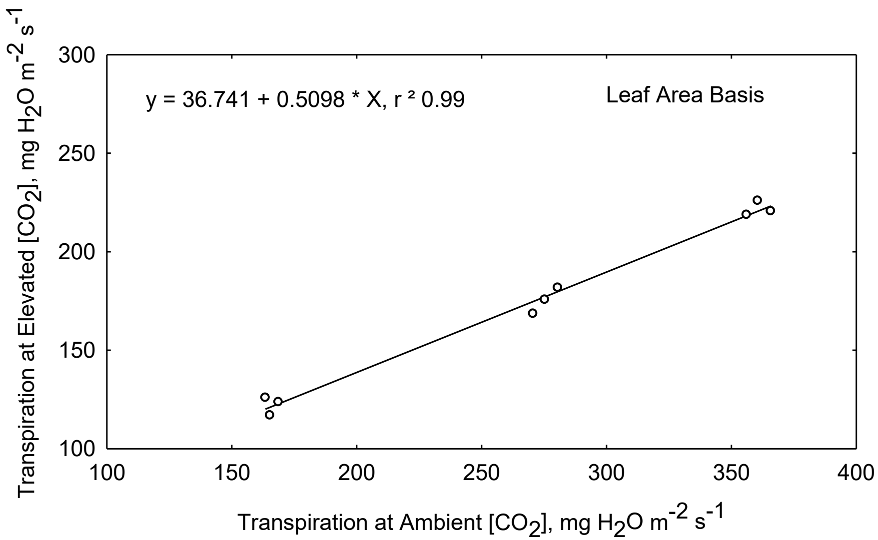
Maize - Canopy Evopotranspiration – Diurnal Trends

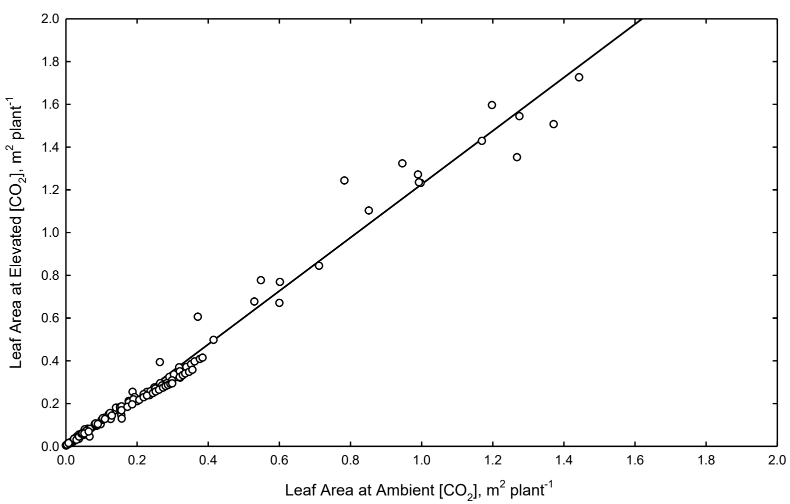


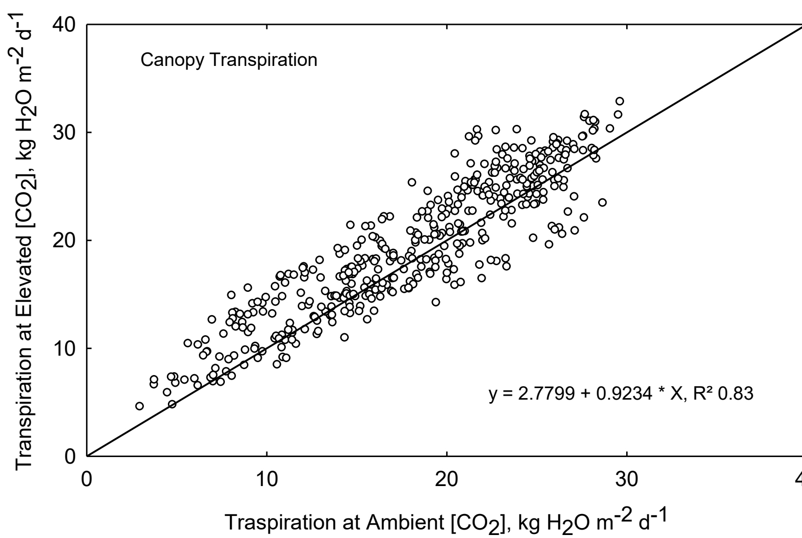
SPAR - Process Quantification and Modeling

Cotton - Leaf and Canopy Transpiration and Leaf Area





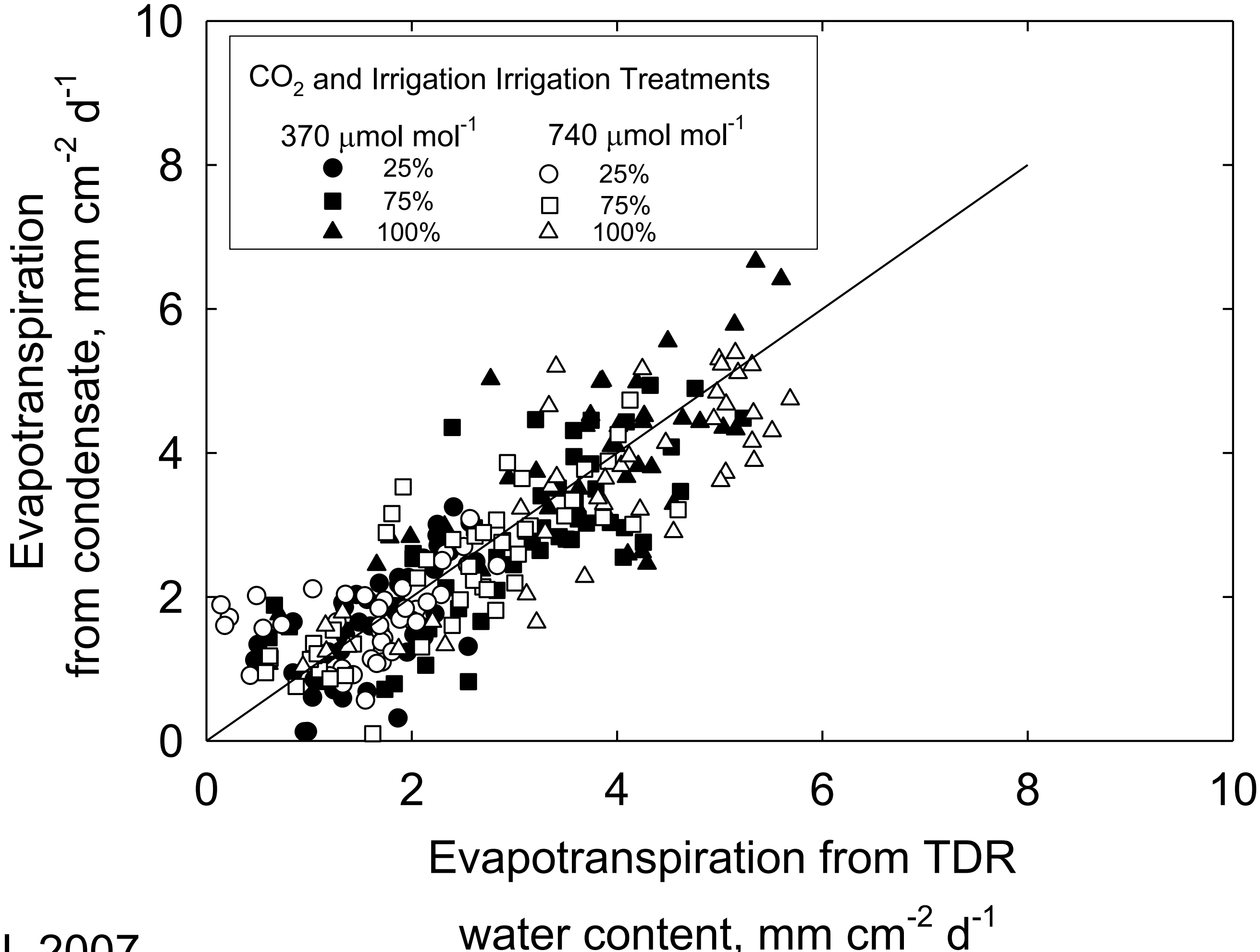




SPAR – Process Quantification and Modeling

Evapotranpsiration and Two Methods

Condensate and TDR - Potato

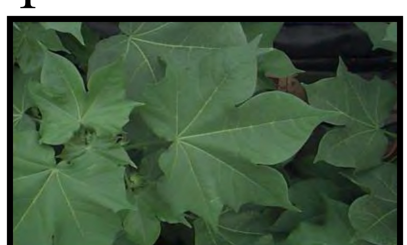


Dennis et al. 2007

SPAR – Process Quantification and Modeling

Cotton – Determining Potential Developmental Rates

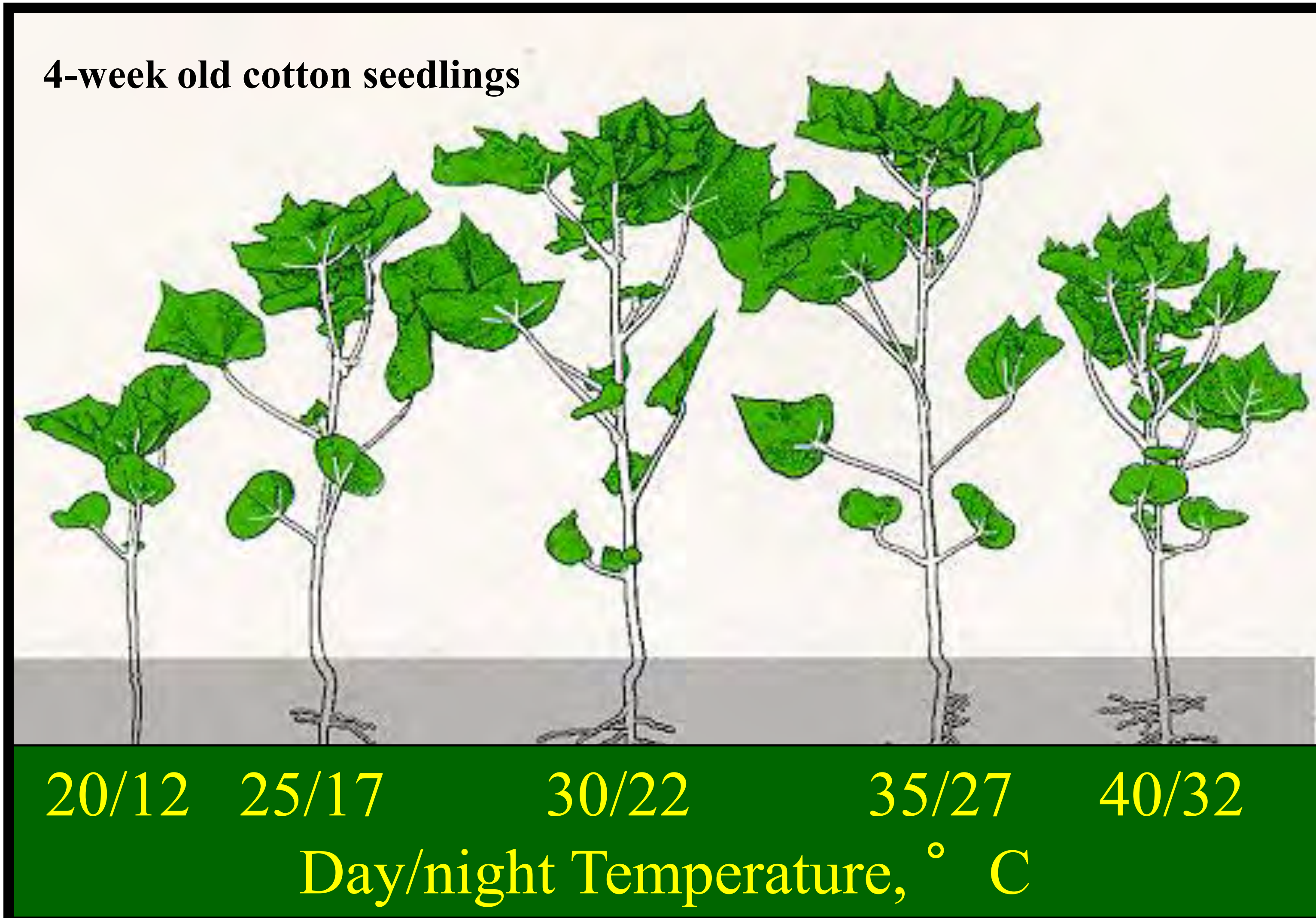
Leaf addition rates on the mainstem and branches and leaf expansion duration



SPAR – Process Quantification and Modeling

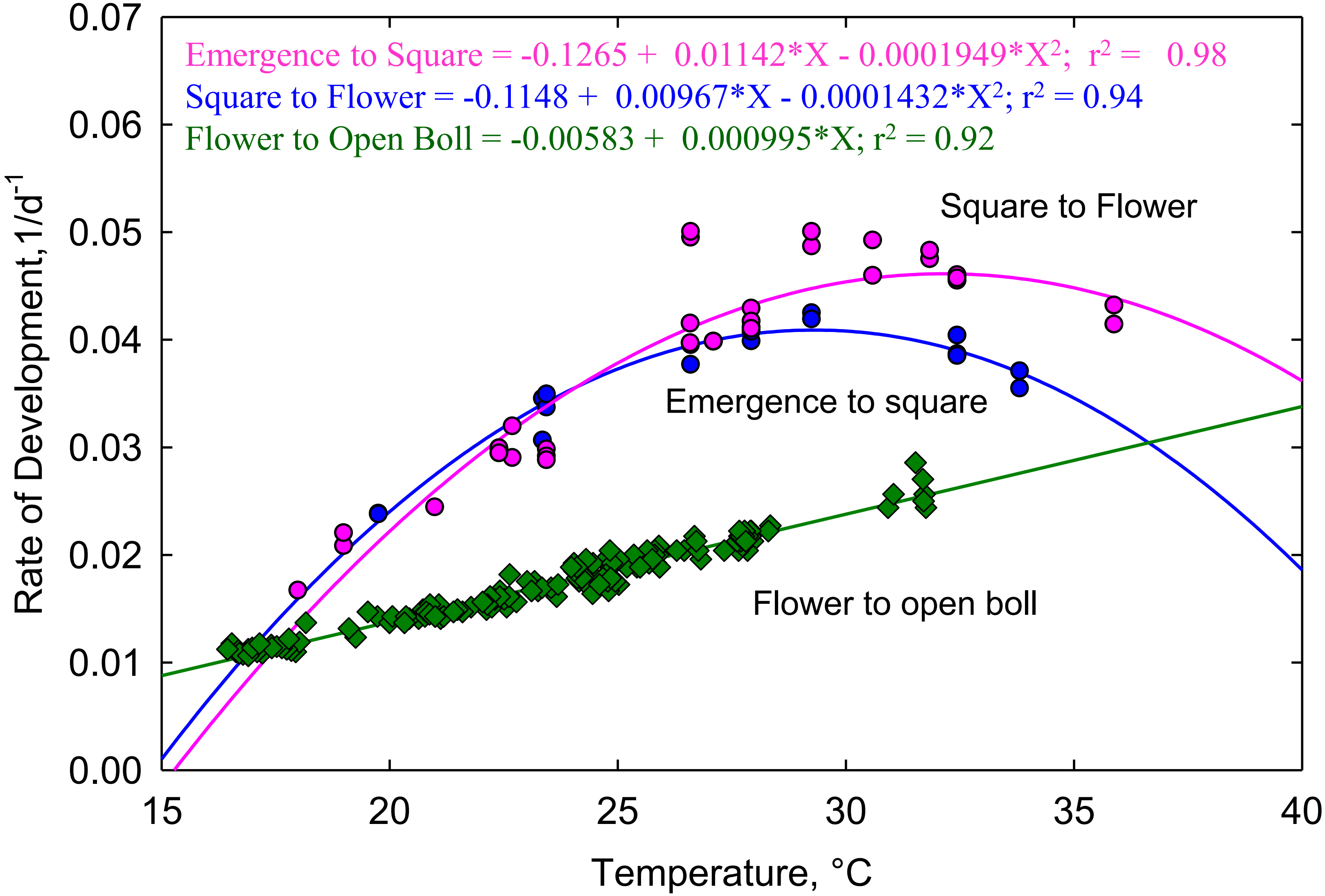
Cotton – Growth and Developmental Rates

Pictorial Representation



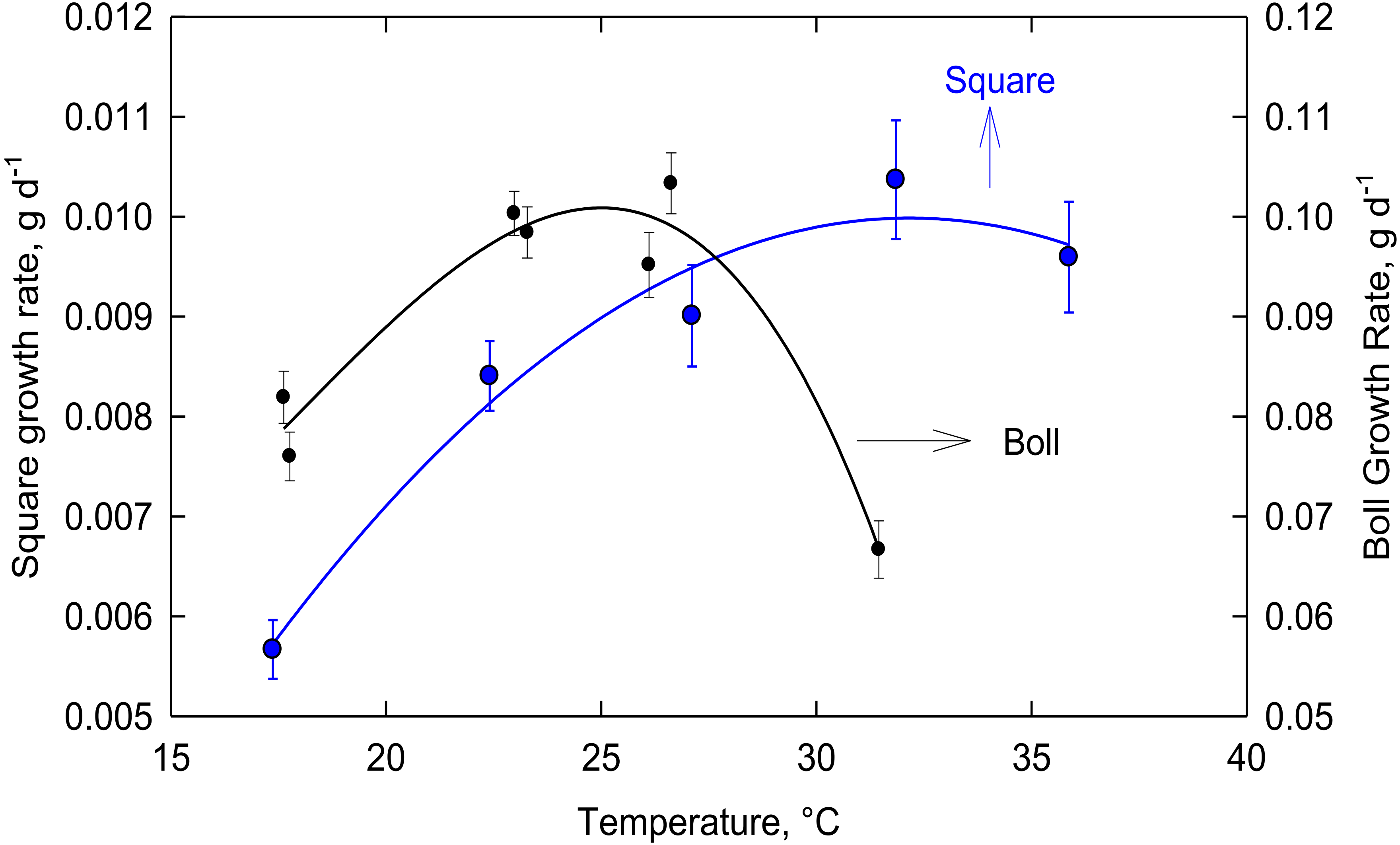
SPAR – Process Quantification and Modeling

Cotton – Developmental Rates



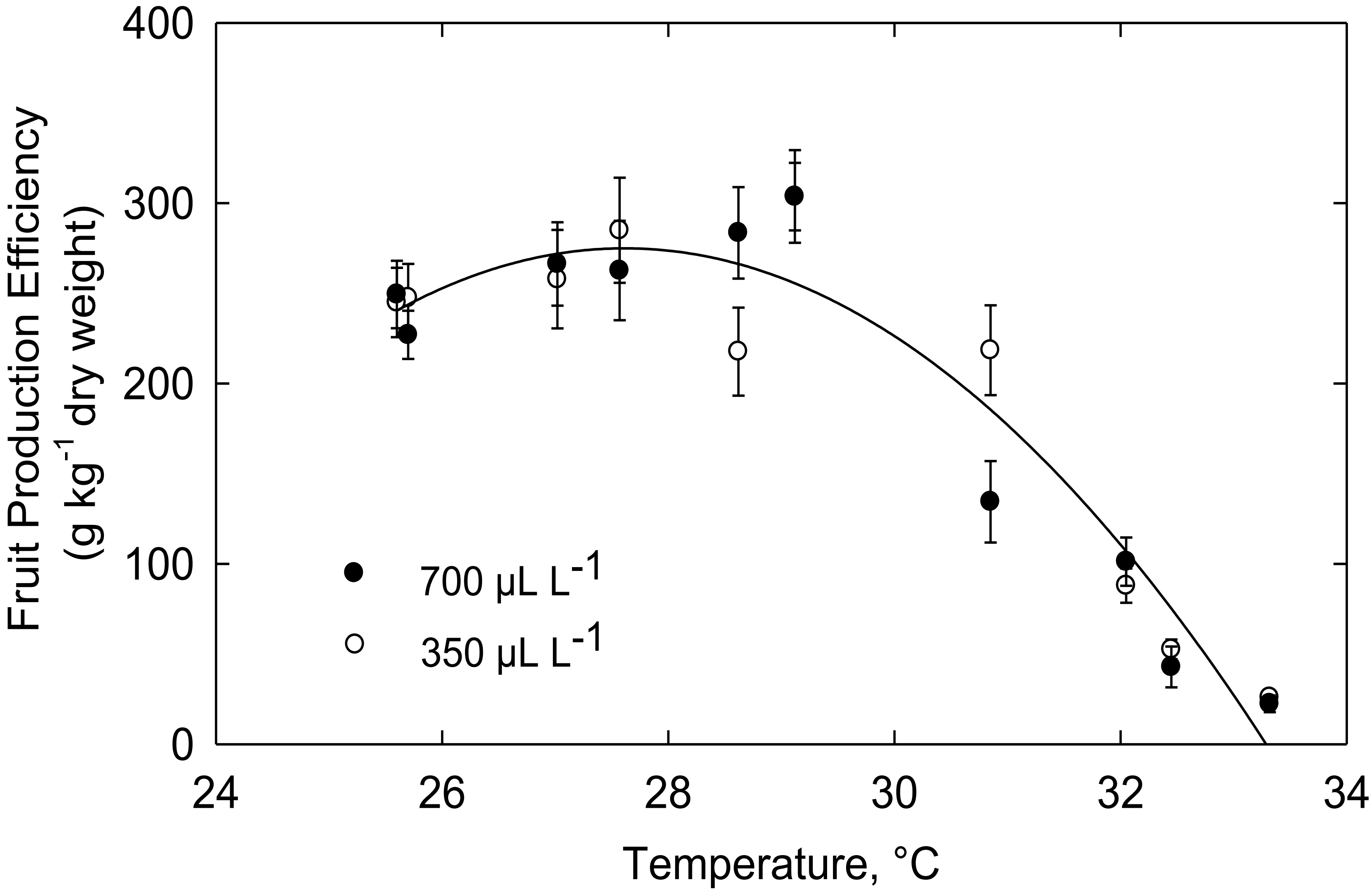
SPAR - Plant Responses and Modeling

Cotton – Square and Boll Growth Rates



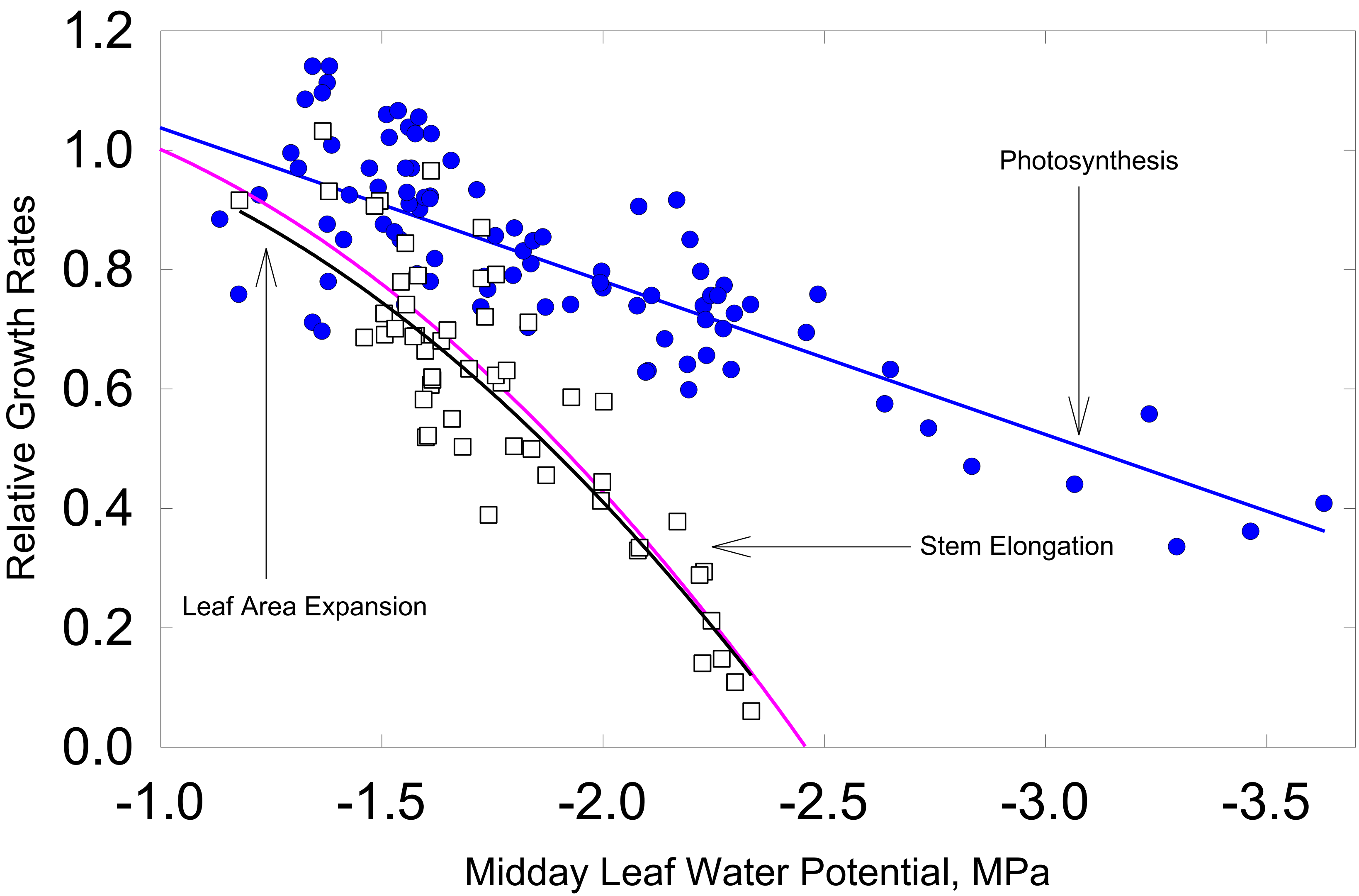
SPAR - Plant Responses and Modeling

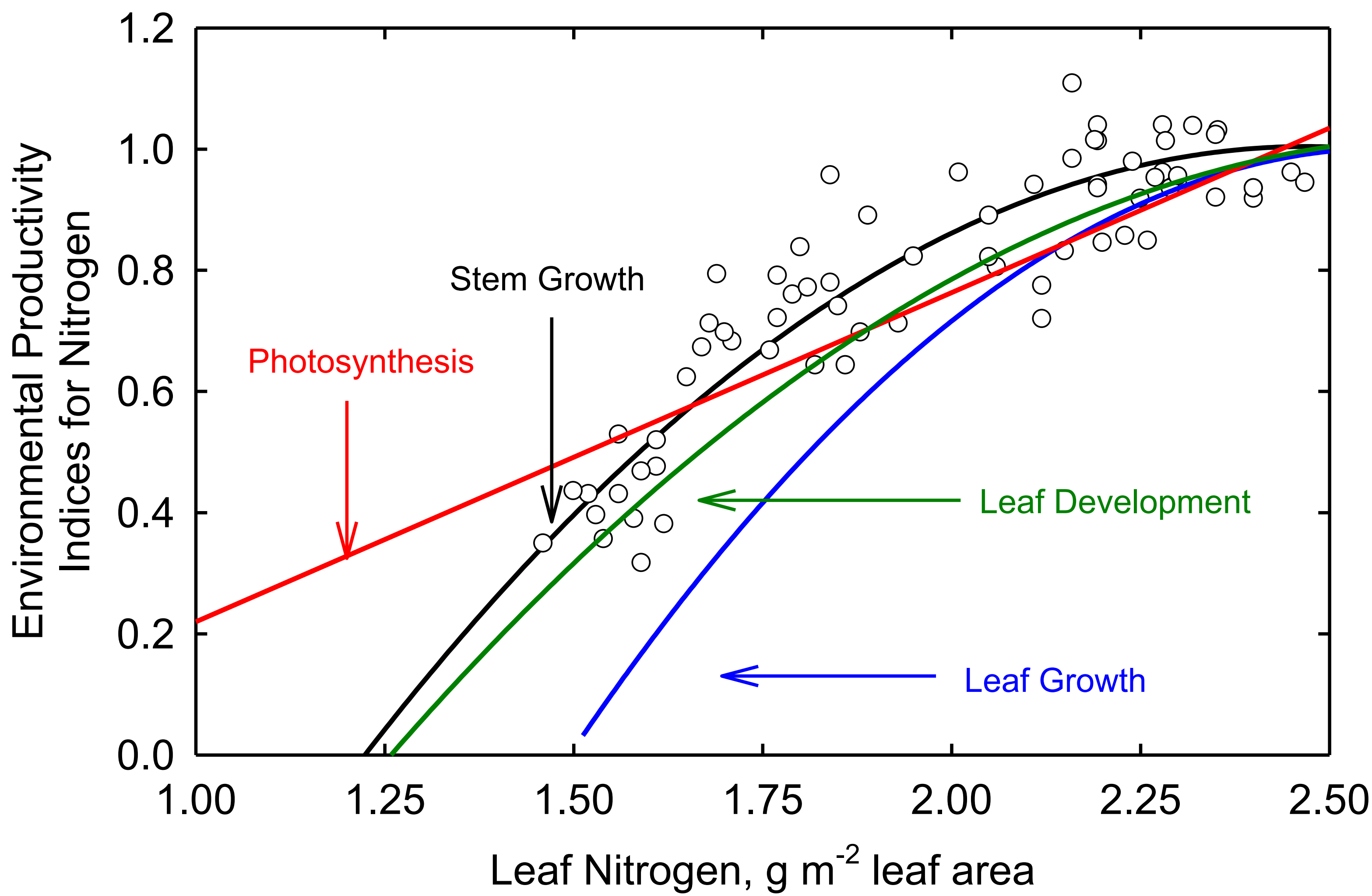
Cotton – Fruit Production Efficiency



SPAR – Plant Responses and Modeling

Cotton Growth Rate Responses to Water Stress

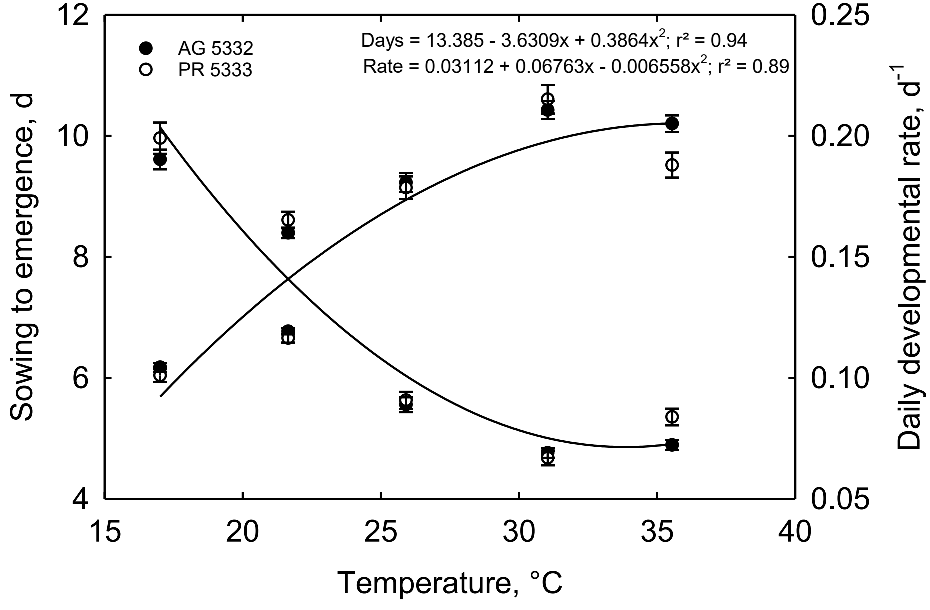



Environmental Productivity
Indices for Nitrogen
Leaf Nitrogen, g m^-2 leaf area
Stem Growth
Photosynthesis
Leaf Development
Leaf Growth
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.00
1.25
1.50
1.75
2.00
2.25
2.50

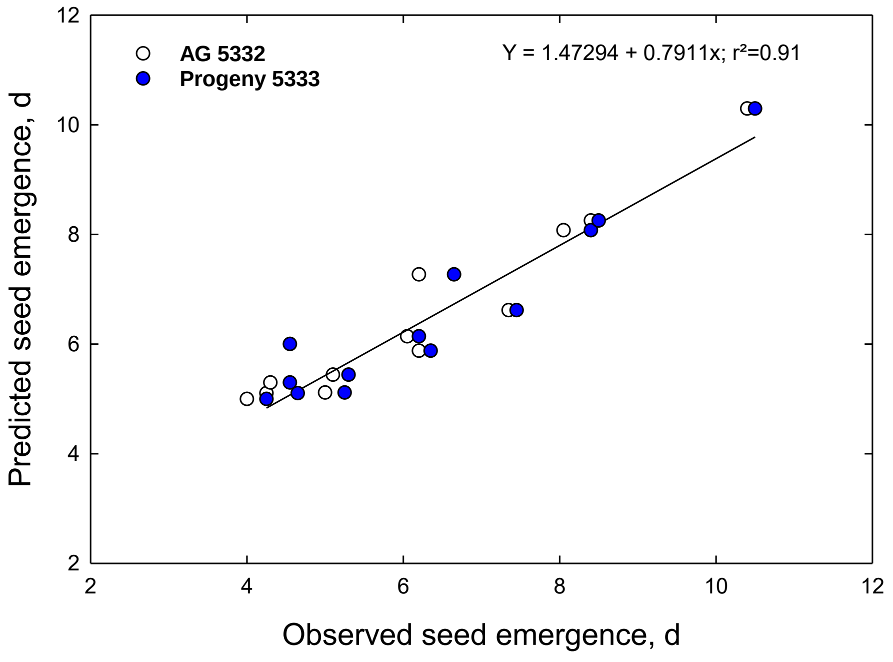
SPAR – Plant Responses and Modeling

An Example – Soybean Seed Germination

Model Development



Model Validation



Temperature - Soybean Growth Development
Model Application

	Stoneville, MS		Tunica, MS	
Planting date	Avg. Air Temp. ° F	Days to emergence	Avg. Air Temp. ° F	Days to emergence
March 20	55.0	13.0	53.5	14.0
March 30	58.0	12.0	56.0	12.5
April 10	62.0	10.5	60.0	11.0
April 20	65.5	9.0	63.5	10.0
April 30	67.0	9.0	65.0	9.5
May 10	70.0	8.0	68.5	8.5
May 20	73.0	7.0	71.5	7.5

Dr. Larry Heatherly
at:
http://mssoy.org/blog/temperature-and-soybean-emergence/

SPAR – Plant Responses and Modeling

What about Replication?

Environment variables

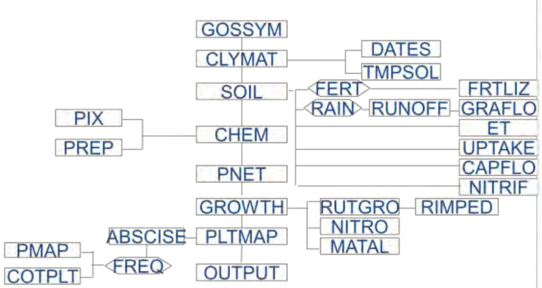
Variable	Mean and SD of 12 SPAR Units
Tmax, ° C	23.0 ± 0.2
Tmin, ° C	18.2 ± 0.7
CO_2 - day, ppm	700 ± 90
CO_2 - night CO_2	548 ± 52
Humidity - day, %	58 ± 5
Humidity - night, %	60 ± 4

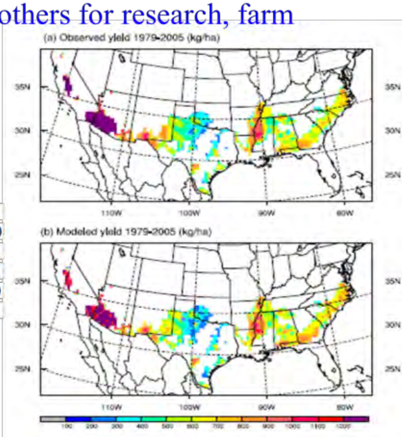
Plant variables

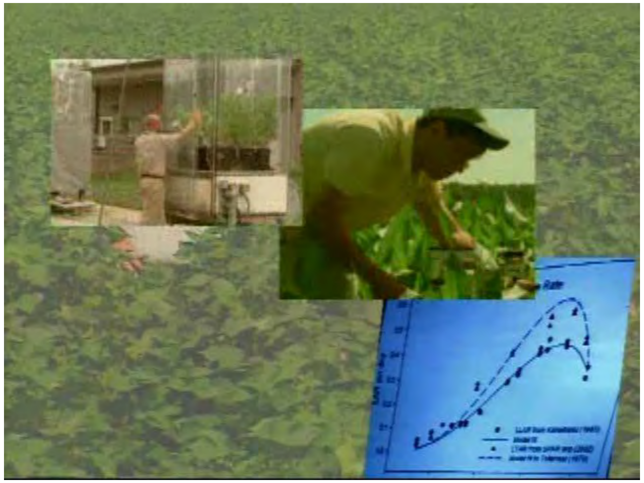
Variable	Mean of 12 SPAR ± Variance	Range of variance within the SPAR
Height, cm	54.9 ± 1.7	2.2 – 18.0
Leaf area, cm^2	141 ± 784	1716 -5120
Total weight, g $plant^{-1}$	16.9 ± 2.1	22.2 – 84.2
Yield, g $plant^{-1}$	12.2 ± 0.99	13.4 – 46.5

Environmental Plant Physiology Research

- Over 200 functions, generated from SPAR facility, have been used to develop/upgrade the cotton simulation model, GOSSYM and several other variants.
- The model has been used by USDA and others for research, farm management, and policy arenas.





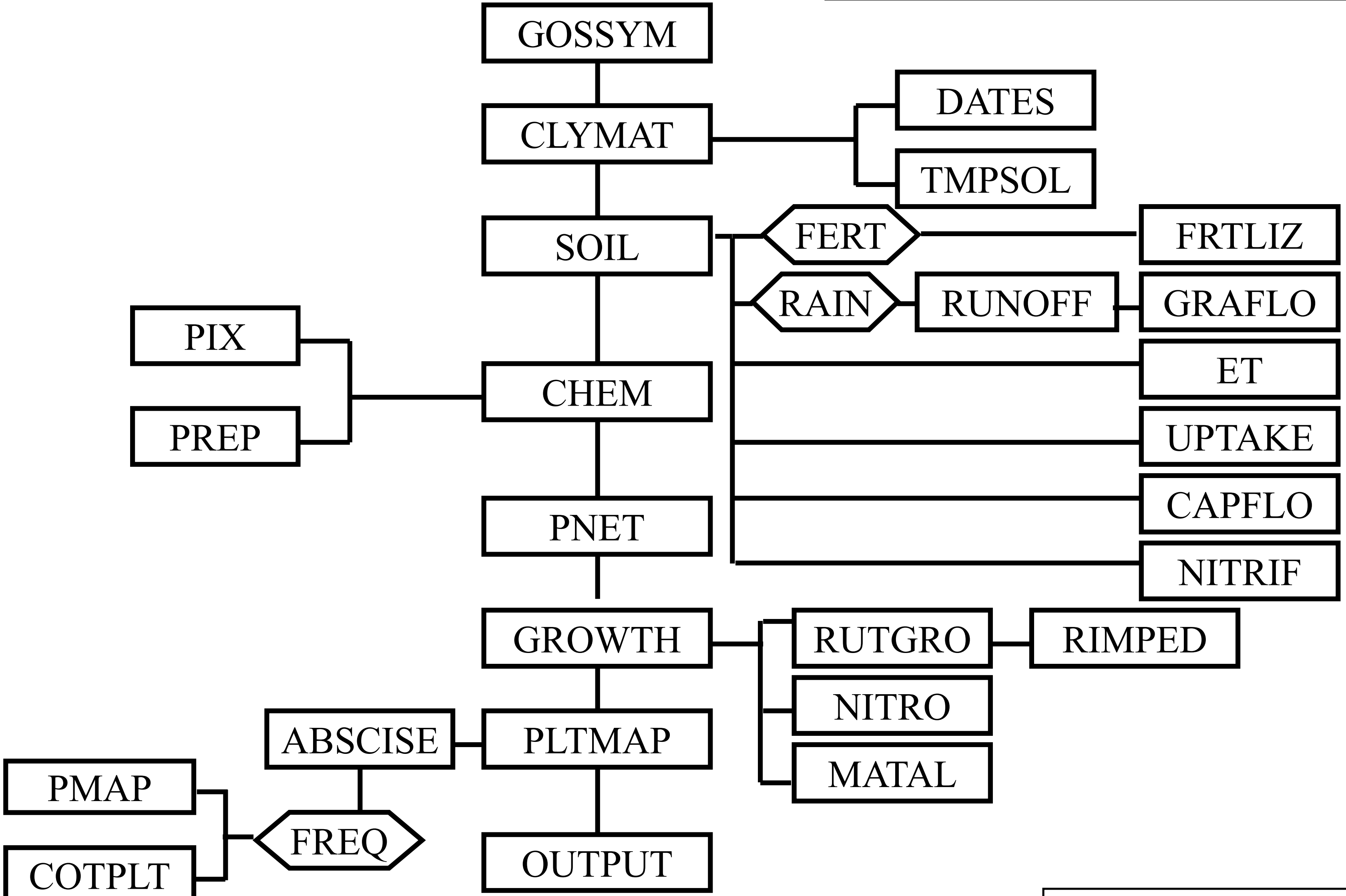


SPAR – Plant Process Quantification and Modeling

- ✓ Sunlit, but other abiotic factors can be controllable nicely.
- ✓ Not too expensive if the objectives are to quantify processes and to develop modeling tools.
- ✓ Very well suited for multiple environmental effects on plants either alone or in combination.
- ✓ Particularly very well suited to address omics (genomics, metabomolics, proteomics) questions related environmental controls and responses in crop and plant science area.
- ✓ Space is limited.

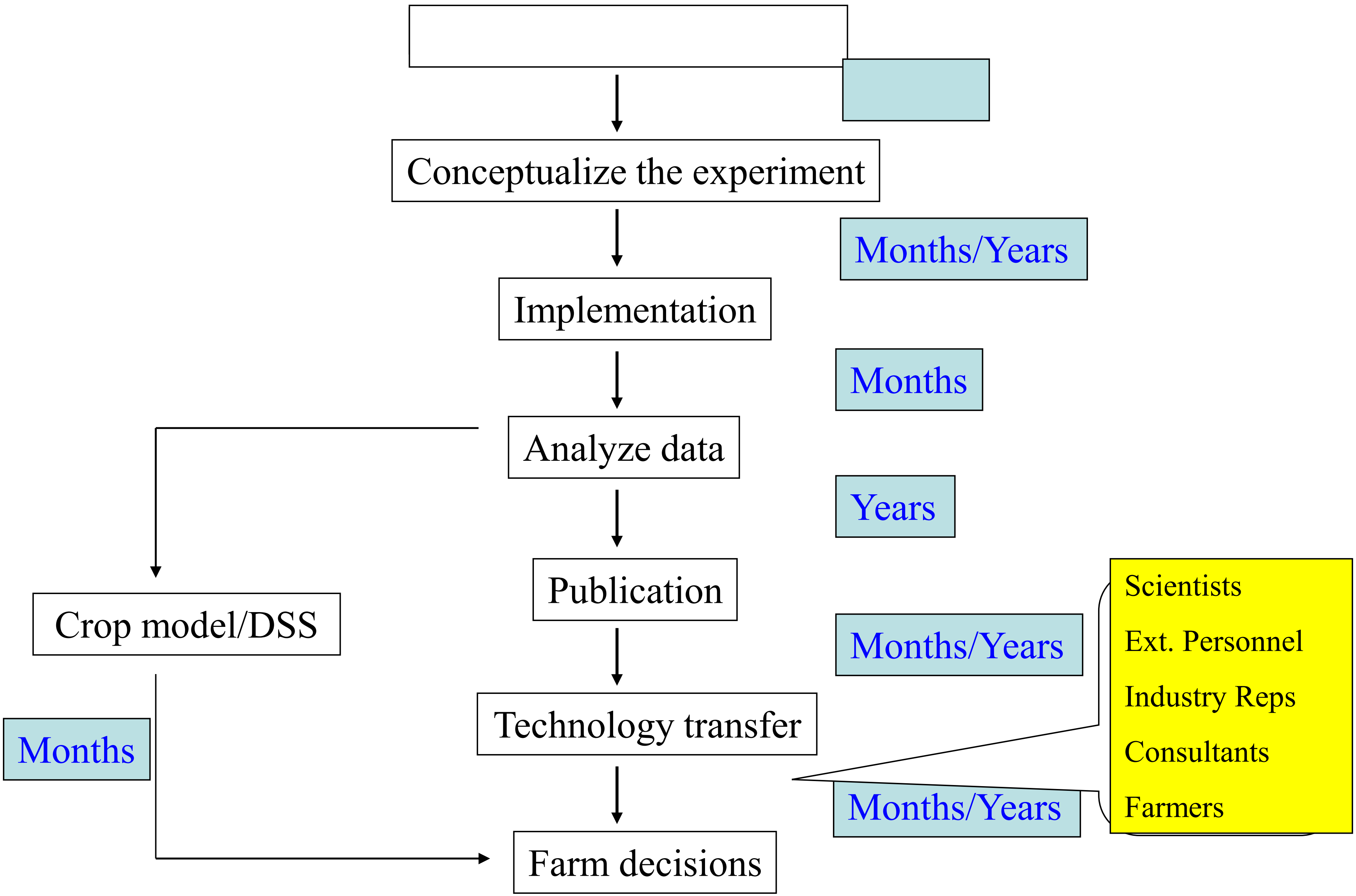
System Simulation Tools

The Cotton simulation model, GOSSYM

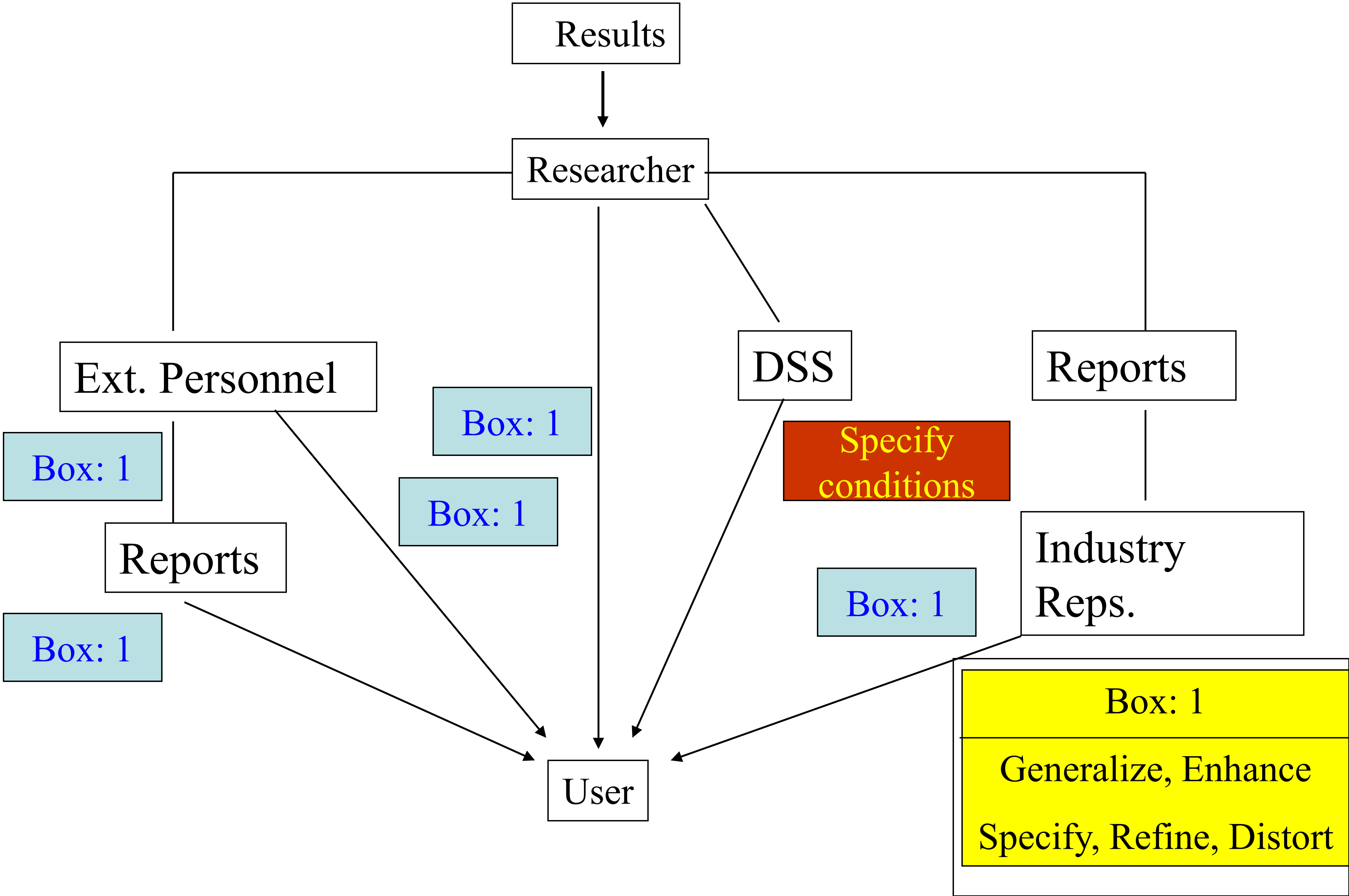


Program flow

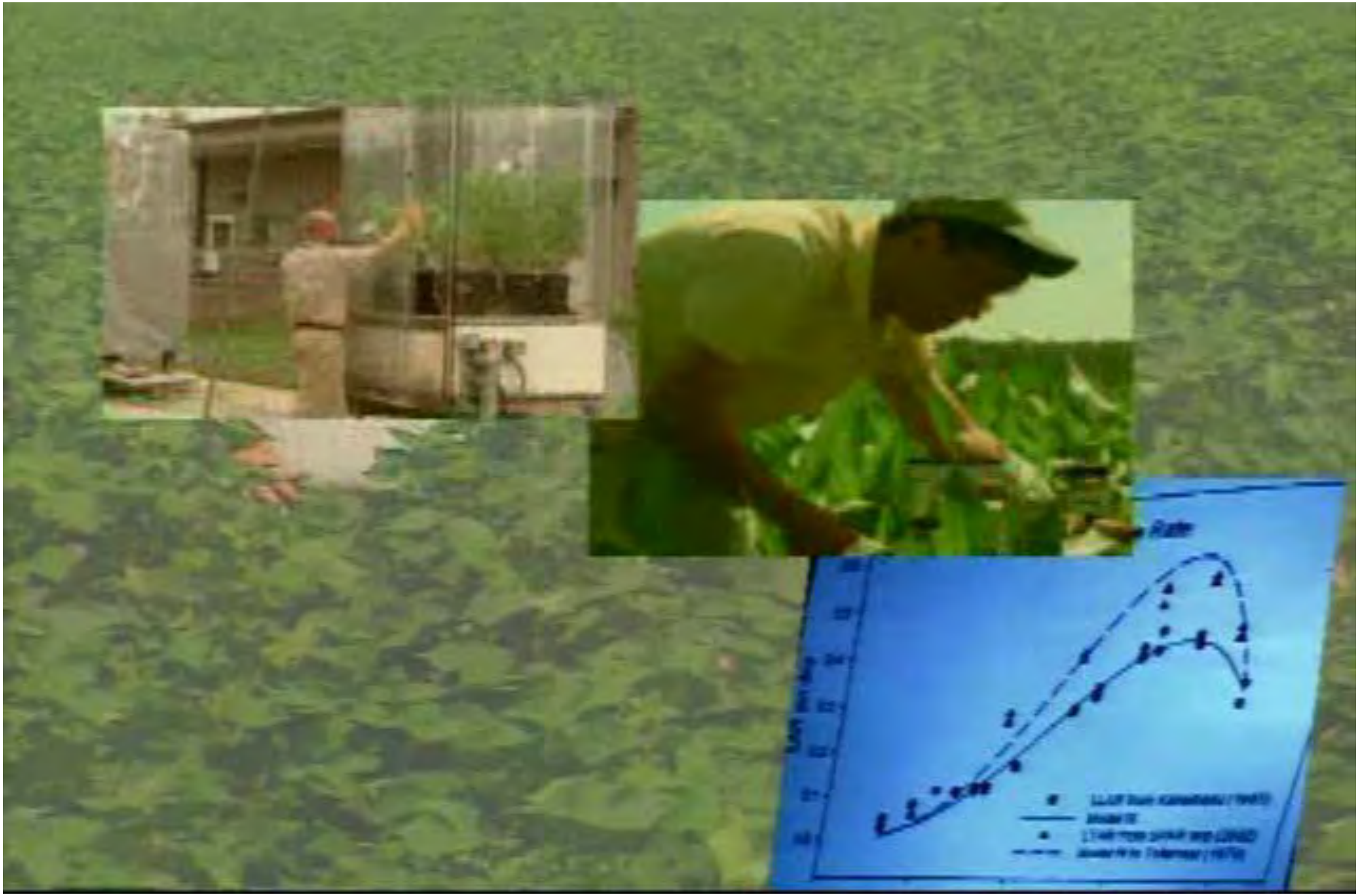
Timeline for Information Flow



Timeline for Information Flow



SPAR and Crop Model Applications



Summary - SPAR Capabilities

- With cotton as an example crop, we have shown how the SPAR system can be used to generate data needed for understanding the various facets of growth and developmental processes and how this understanding can be used for building process-level models and in learning how to manage the cotton crop.
- Operating a SPAR facility to acquire such data will often be more economical than the use of field plot experiments because it allows the scientist to avoid many of the covarying and confounding factors that occur in field experiments. Thus, the basic processes can be related more directly to the environmental variables being studied.

Summary - SPAR Capabilities

- As we progress in developing systems for understanding plant responses to environment, whether in support of global climatic change research, the application of plants in the remediation of environmental conditions, or the increased application of precision agriculture technologies, the need for diagnostics and management decision aids will become more urgent.
- Mechanistic plant models and automated, user-friendly expert systems can facilitate selection of the optimum solutions to problems with many variables.

Summary - SPAR Capabilities

- Essentially all of the engineering and computing technologies needed to allow the use of variable and site-specific technologies, such as precision agriculture, are now available.
- However, our understanding of the plant ecophysiological responses to the environment as it relates to specific growth and developmental events requires further development.
- 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 plant growth and development at the landscape or even the plot scale, modeling some meaningful portions of the system provides clarity.

Summary - SPAR Capabilities

- For a model to correctly predict plant responses to physical conditions, the concepts and the response functions must be appropriately assembled. Critical environment-genotype relations should be incorporated into the model.
- These relationships include, but should not be limited to, the phenological responses of specific genotypes to temperature and their responses to environmental stresses.
- We would, for example, expect to find quantifiable differences among genotypes in fruit-shed sensitivity to above-optimum temperature and to deficiencies of water and/or nutrients.
- One might also find differences in fruit-shed sensitivity to carbon deficiency caused by imbalance between photosynthesis, fruiting rate, and vegetative growth.

Summary - SPAR Capabilities

- These environment-genotype interactions can be measured and incorporated into a meaningful model.
- When a model is based on appropriate concepts and processes, it has predictive capability in new environments and can be used either alone or with other emerging newer technologies to disseminate useful plant growth and development information.

Summary - SPAR Capabilities

- In the past, the SPAR facility has been used extensively for research on only a few species, with a primary purpose of providing functional parameterizations used in crop simulation models, which, in turn, are a component of expert crop-management decision-support systems.

- There are a variety of approaches and facilities to investigate plant responses to the environment. Among these, the SPAR facilities are optimized for the measurement of plant and canopy-level physiological responses to precisely controlled, but naturally lit, environmental conditions. The data that have been and will be obtained are unique and particularly instructive for applied and basic plant biologists.

Facilities

Suggested Reading Material

- Reddy, K. R., J. J. Read, J. T. Baker, J. M. McKinion, L. Tarpley, H. F. Hodges and V. R. Reddy. 2001. Soil-Plant-Atmosphere-Research (SPAR) facility - a tool for plant research and modeling. **Biotronics** 30: 27-50.

- Reddy, K. R. V. G. Kakani, J. M. McKinion and D. N. Baker. 2002. Applications of a cotton simulation model, GOSSYM, for crop management, economic and policy decisions. In: L. R. Ahuja, Liwang Ma and T. A. Howell (Eds.) **Agricultural System Models in Field Research and Technology Transfer**, CRC Press, LLC, Boca Raton, FL, USA. Pp 33-73.