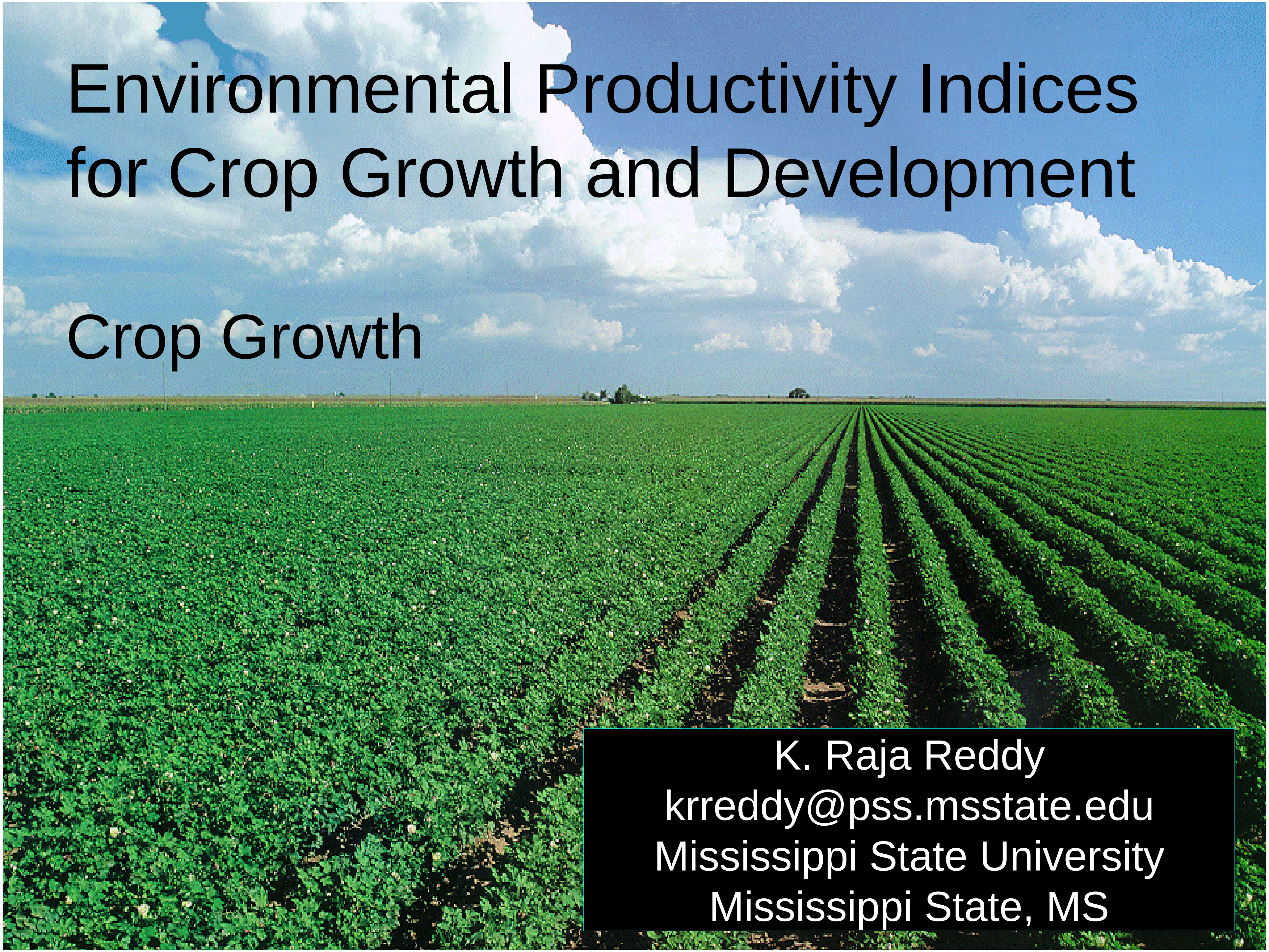

Environmental Productivity Indices for Crop Growth and Development

Crop Growth

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Crop Growth and Development and Environment

Goals and Learning Objectives:

- To understand the effects of multiple environmental factors on crop growth and development.
  - Crop growth and development and environment and applying Environmental Productivity Index (EPI) concept using cotton as an example crop.
  - Crop growth and development and environment: Species variability, and applicability of EPI concept across species.

Crop growth and Development and Environment

You will learn:

- ✓ Effects of environmental factors on crop growth-phenology and growth of various individual organs and plant as a whole.
- ✓ How to develop build whole plant or canopy from organ-based functional algorithms.
- ✓ How to calculate potential growth and developmental rates under optimum conditions.
- ✓ How to develop environmental productivity indices for various environmental factors to decrement the potential crop growth and developmental rates under multiple environmental conditions.

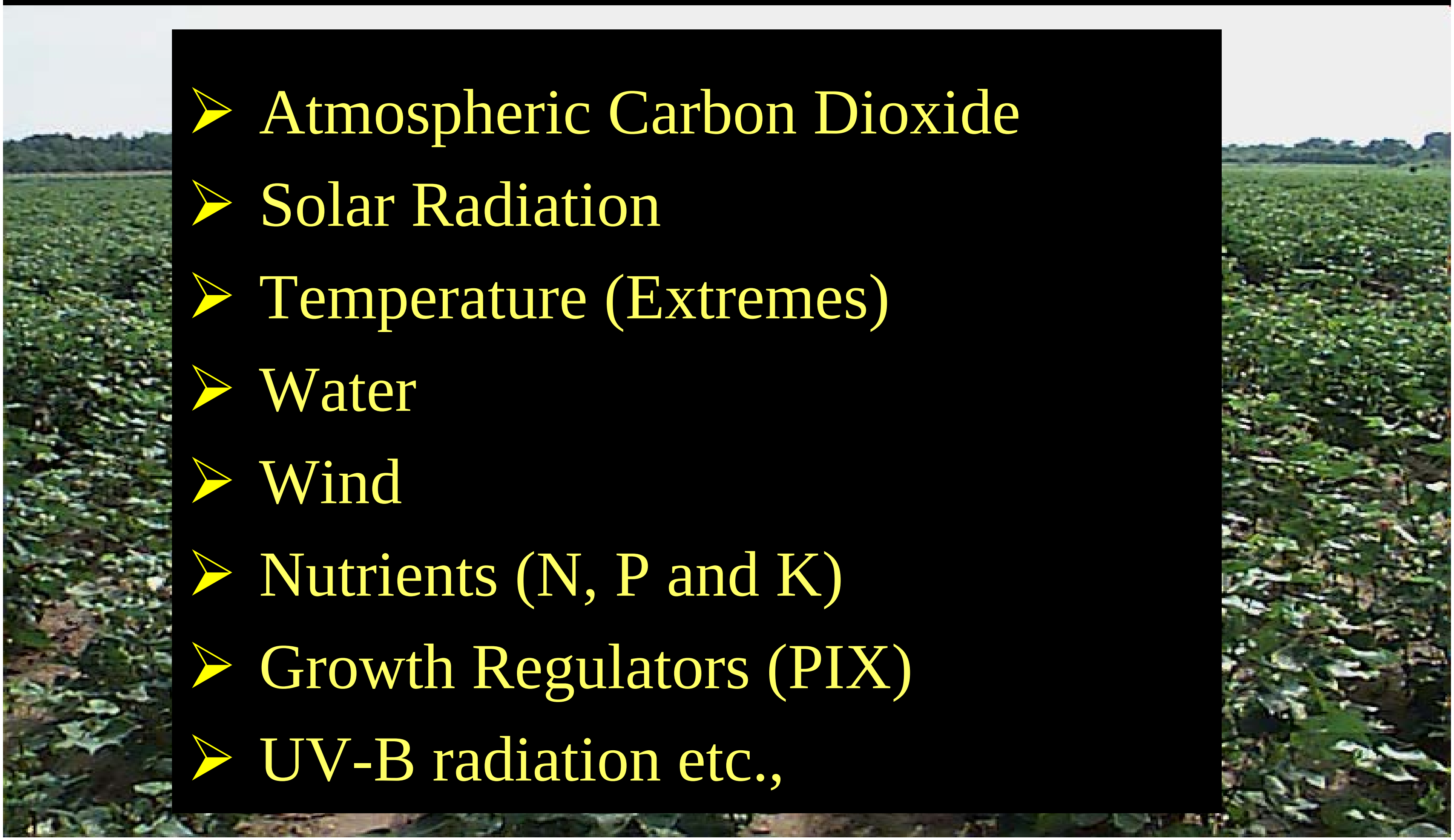
Terminology and Definitions

- Growth:
  - Growth is an increase in length, area, or weight of plants as a whole or of individual organs.
- Phenology:
  - Phenology is the study of periodic biological phenomena.
  - They refer to like events such as the time intervals between mainstem or branch leaves on a plant, unlike events such as the time intervals between plant emergence and formation of flower bud, flower or mature fruit, and /or a duration of process such as the time interval between unfolding or appearance of leaf or internode, and until those organs reach maximum size or length.
  - Therefore, phenology refers to the initiation, differentiation, and development of organs.

Crop Growth - Importance

- Crop growth:
  - Growth of various organs, in length or area or weight, or crop as whole, is very important in crop production.
    - ✓ Internodes elevate other organs, particularly leaves, for optimum PAR interception.
    - ✓ The size, weight and quality of individual organs, particularly the final product of a crop, are important.
    - ✓ Any factor (abiotic, biotic) or process (intra-plant) that affects growth of these organs will have profound influence on yield of economic importance.

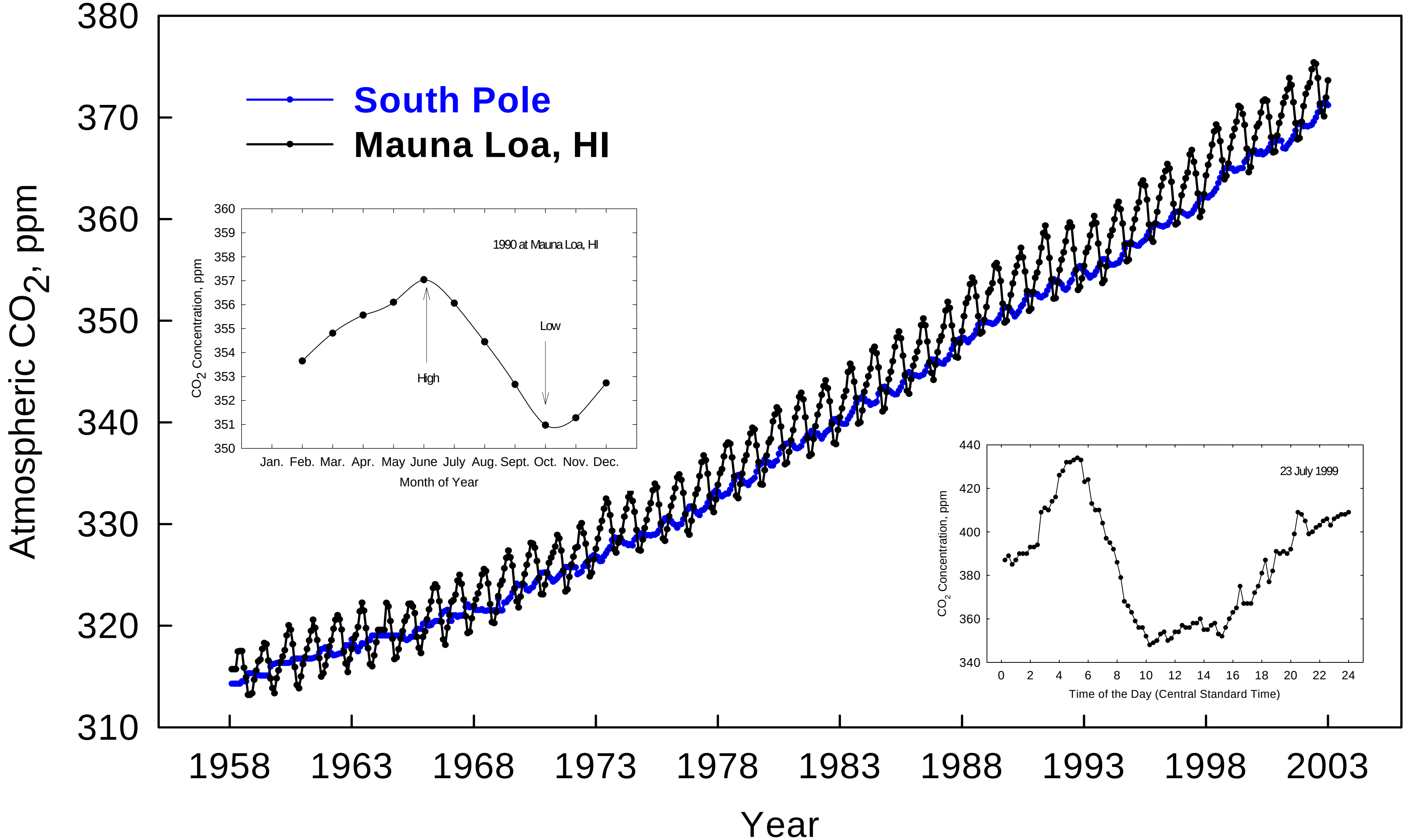
Environmental and Cultural Factors Influencing Crop Growth



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

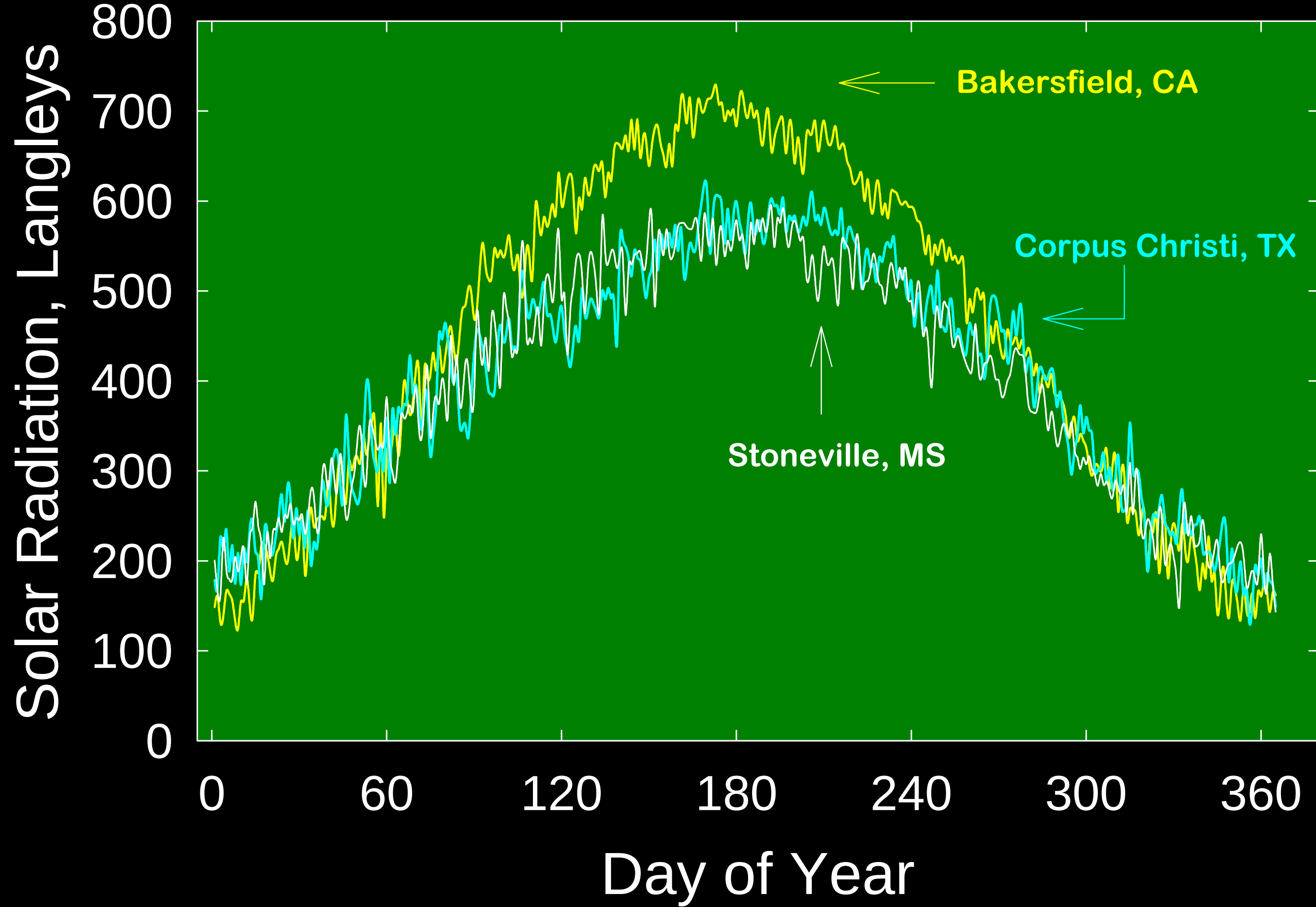
Global Atmospheric CO2 Concentrations

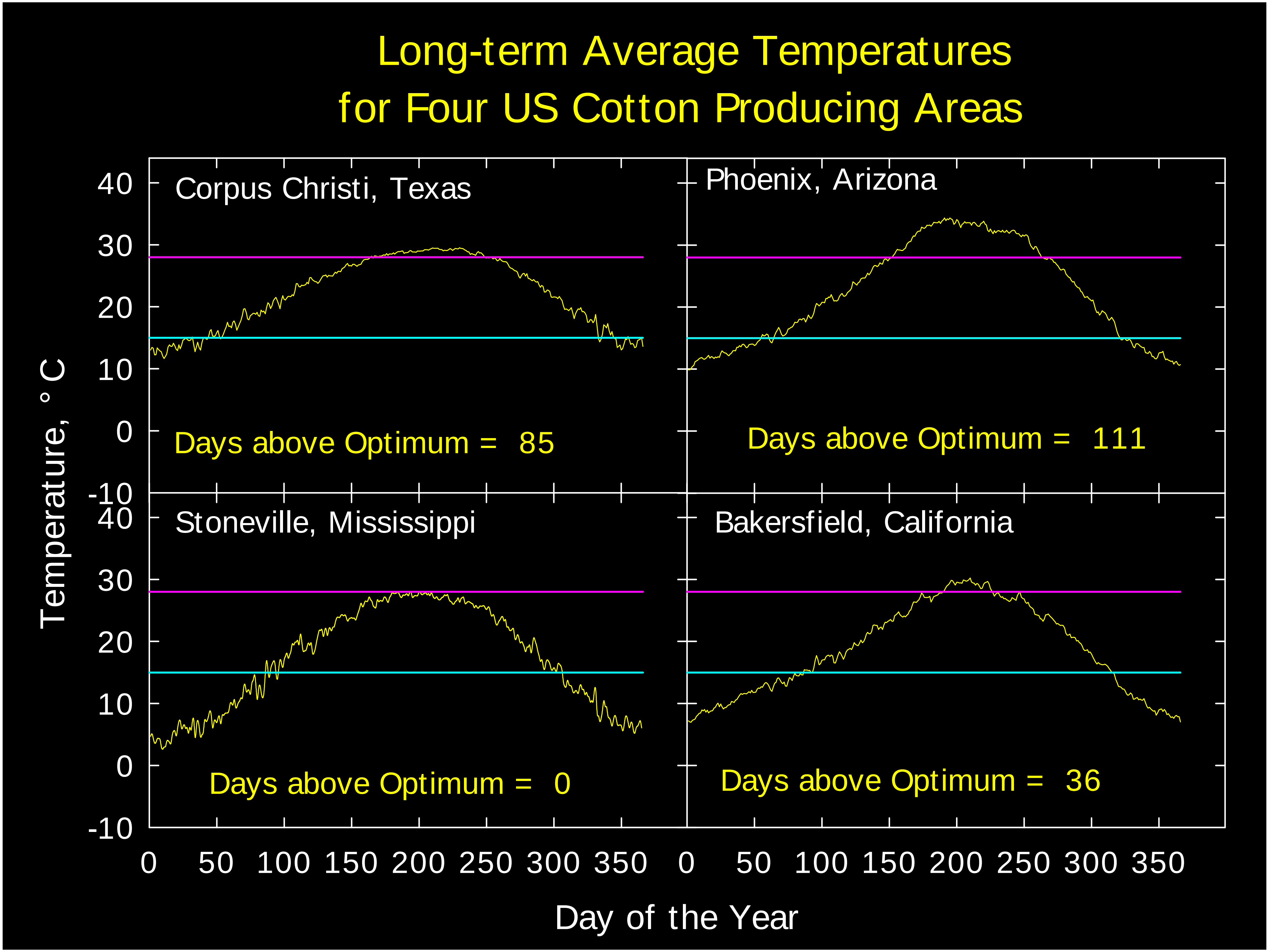
Mauna Loa, HI and South Pole



Radiation Conditions - Seasonal Trends

Bakersfield, CA, Corpus Christi, TX and Stoneville, MS

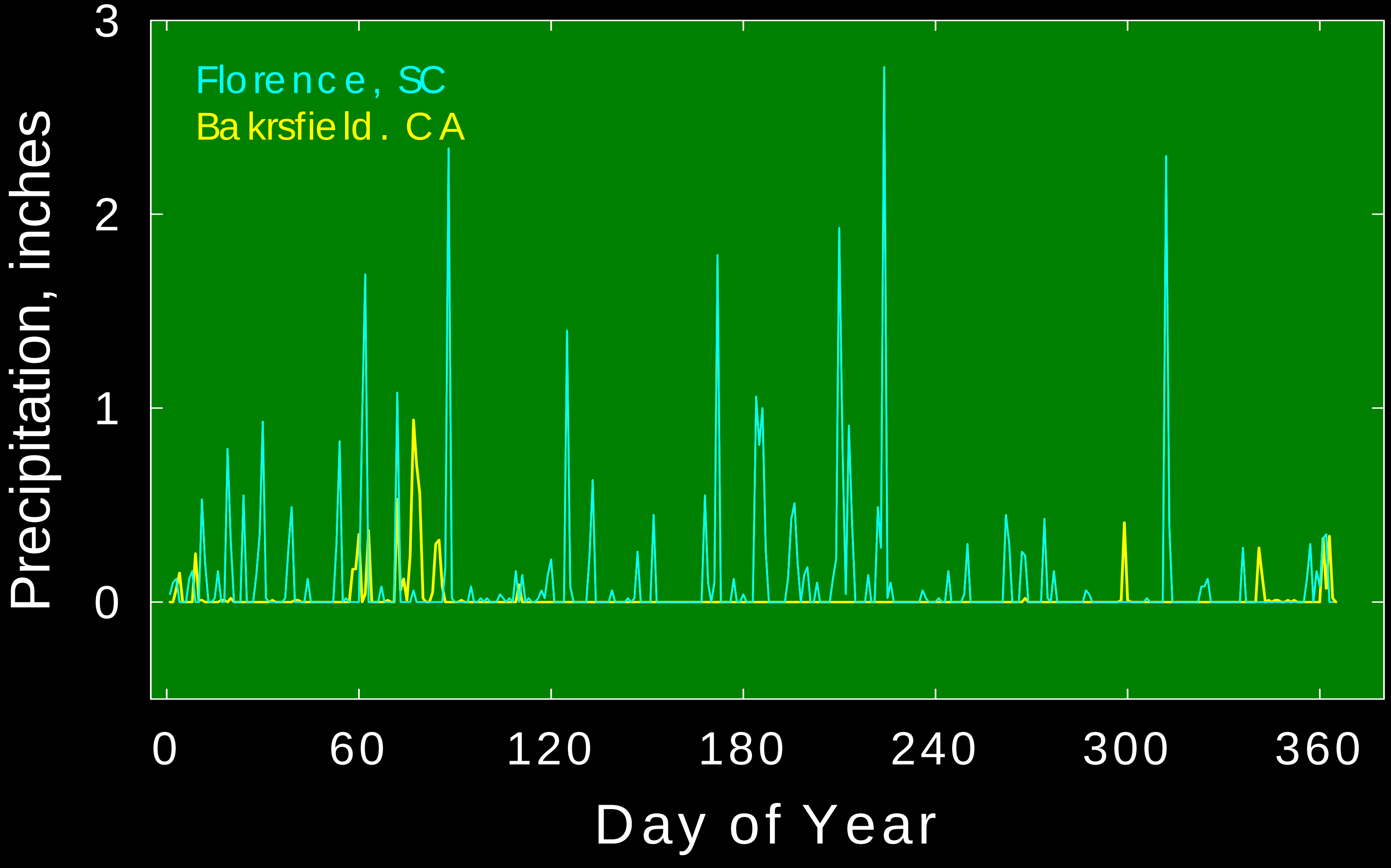




Long-term Average Temperatures
for Four US Cotton Producing Areas
Corpus Christi, Texas
Days above Optimum = 85
Phoenix, Arizona
Days above Optimum = 111
Stoneville, Mississippi
Days above Optimum = 0
Bakersfield, California
Days above Optimum = 36
Temperature, ° C
Day of the Year
40
30
20
10
0
-10
0
50
100
150
200
250
300
350

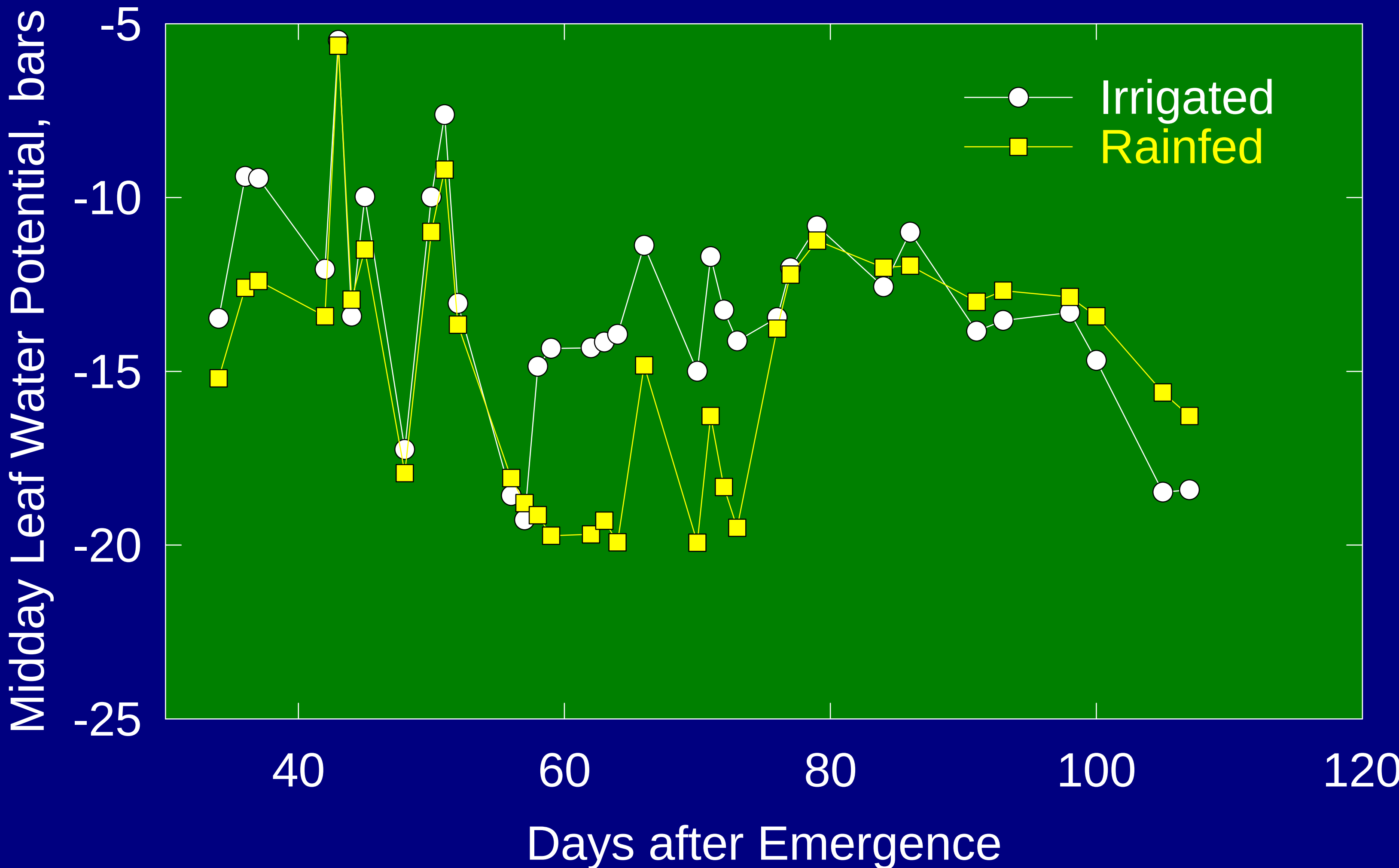
Precipitation - Seasonal Trends

Bakersfield, CA and Florence, SC - 1991

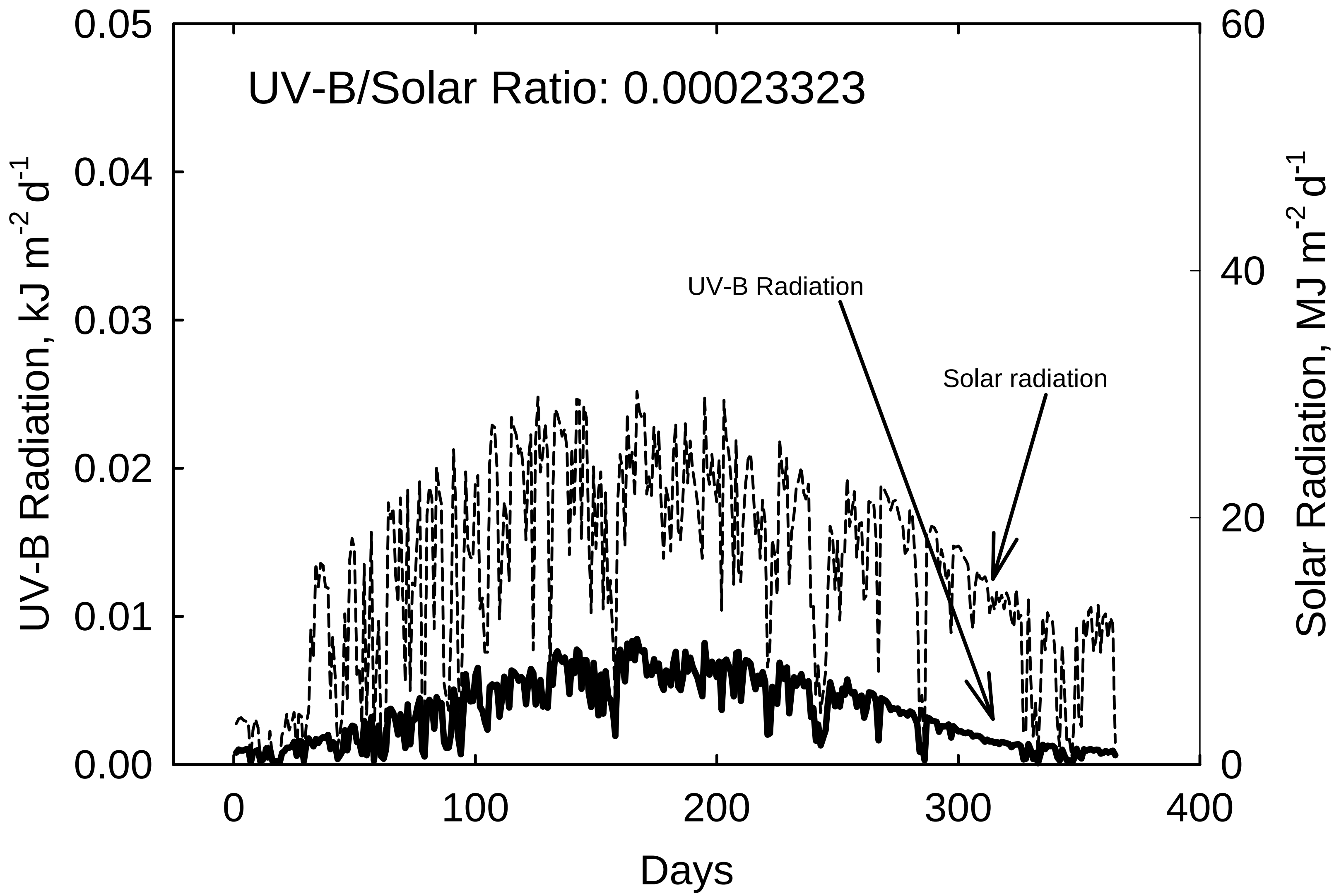


Seasonal Trends - Midday Leaf Water Potential

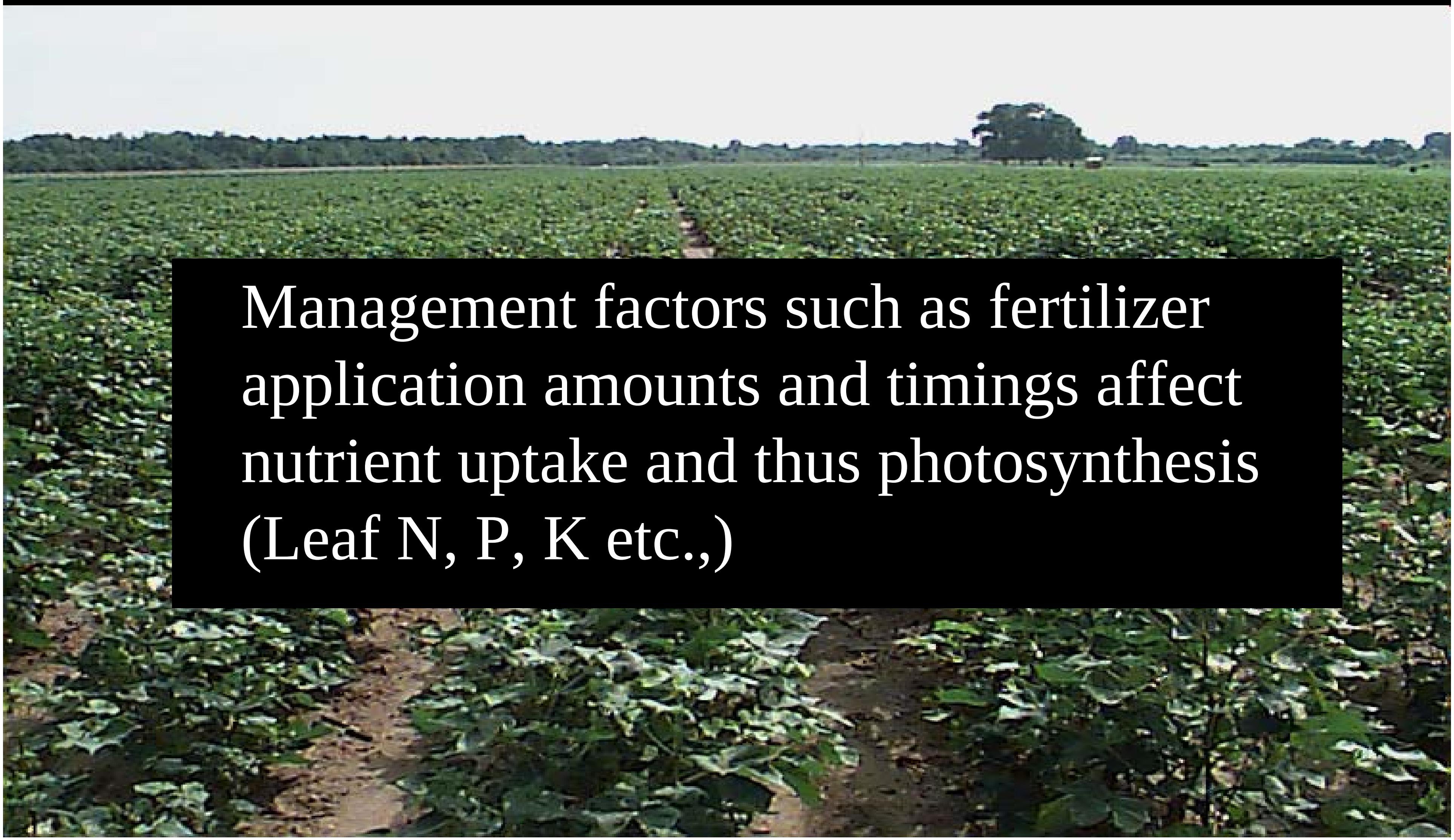
Irrigated and rainfed cotton, MSU North Farm -1995



Seasonal Trends Solar and UV-B Radiation

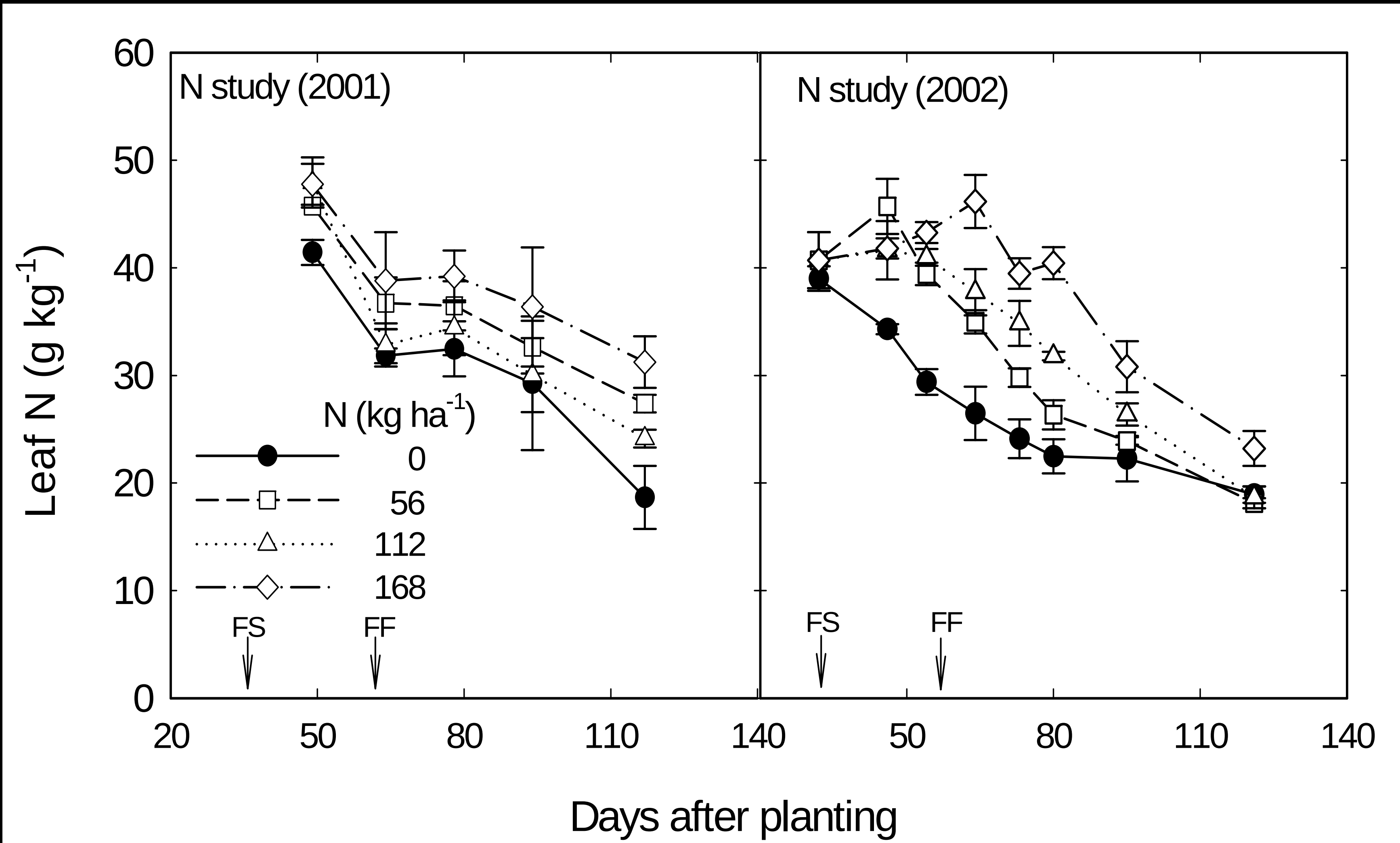


Photosynthesis - Management Factors

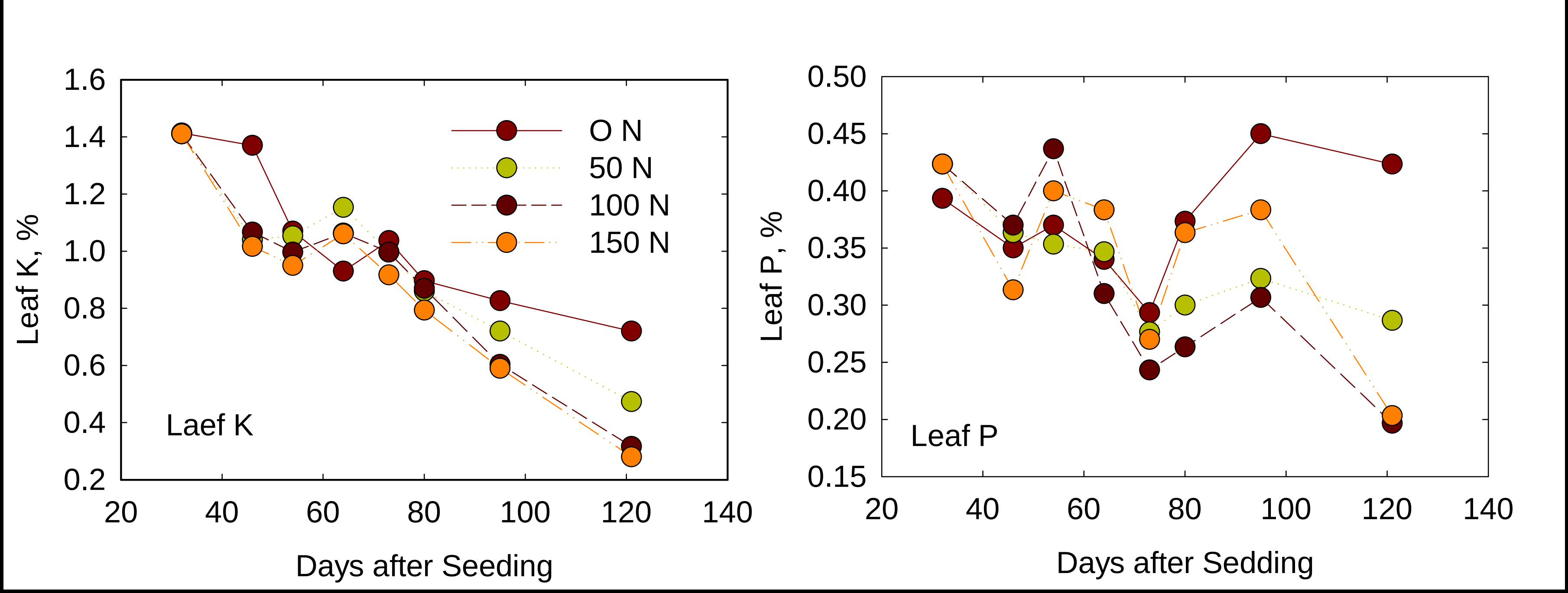


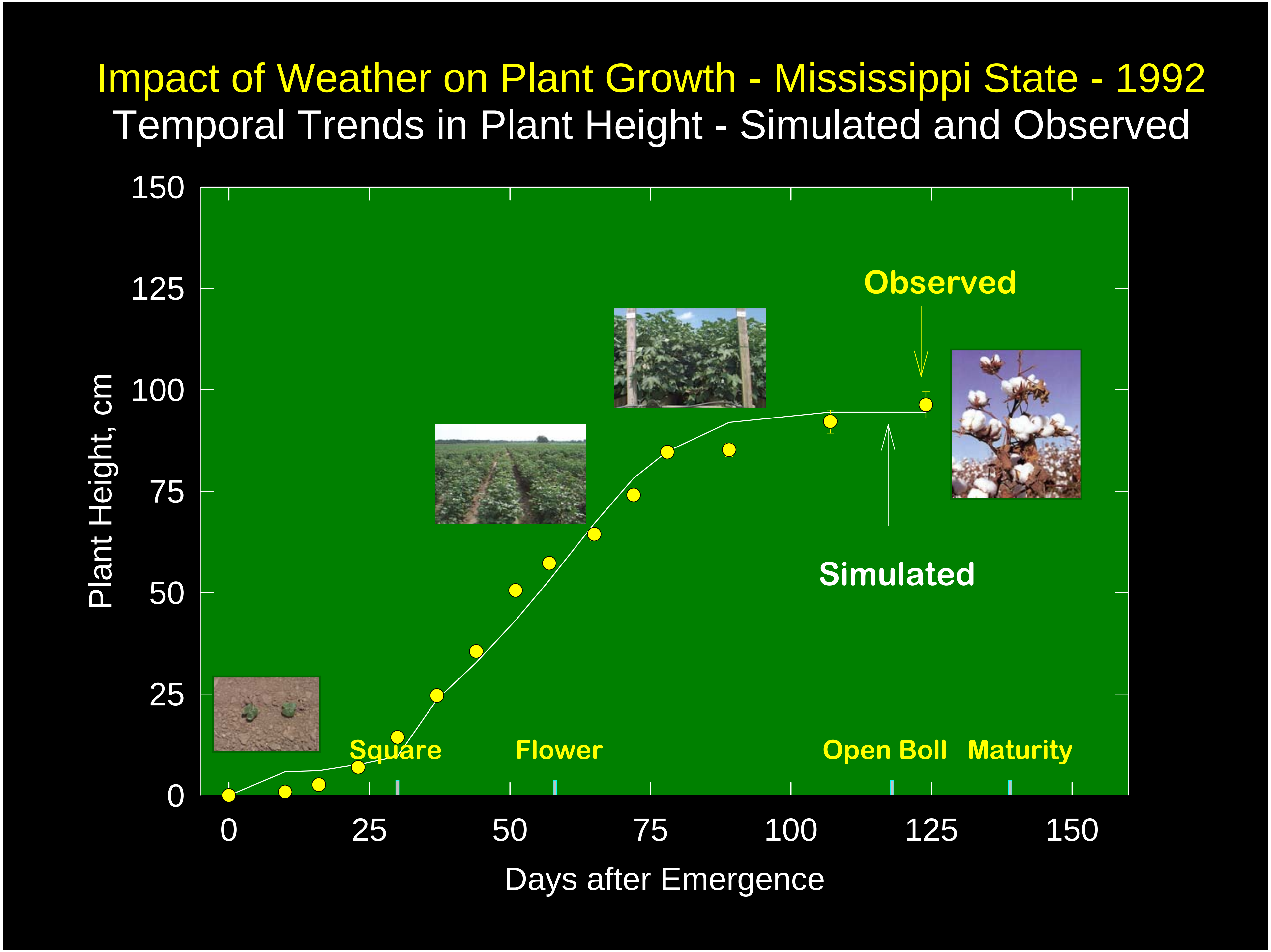
Management factors such as fertilizer application amounts and timings affect nutrient uptake and thus photosynthesis (Leaf N, P, K etc.,)

Cultural and Environmental Factors
Seasonal Trends – Leaf Nitrogen Concentration



Cultural and Environmental Factors Seasonal Trends – Leaf Potassium and Phosphorus Concentration





Impact of Weather on Plant Growth - Mississippi State - 1992
Temporal Trends in Plant Height - Simulated and Observed
Plant Height, cm
150
125
100
75
50
25
0
Observed
Simulated
Square
Flower
Open Boll
Maturity
0
25
50
75
100
125
150
Days after Emergence

Quantifying the Effects of Environmental Factors on Crop Growth

One way to quantify the effects of environmental factors on growth is to use environmental productivity Index (EPI) concept for growth like the way we used in calculating photosynthesis and phenology

EPI-growth = Temperature (potential) * Nutrient Index (C, N, P, K) * Water index * PPF Index * UV-B radiation Index * PGR Index etc.,

First, we have to define the potential growth for given species or cultivar. Potential growth is defined as the rate of growth (length, area or weight) that takes place at a range of temperatures under optimum environmental conditions (optimum water, nutrient, 0 UV-B etc.) and also during the period when intra-plant competition is also at minimum.

Quantifying the Effects of Environmental Factors Crop Growth

Then, we have to account for all the environmental factors that limit that potential.

Individual environmental factors affect the potential growth multiplicatively, not additively as in photosynthesis and phenology. For instance, if prolonged water stress causes plants to grow slower, growth of stems and leaves will reflect that condition even if the temperature and other factors are optimum.

The EPI index values for each of the environmental factors, range from 0 when a variable is totally limiting growth to 1 when it does not limit the growth process. The EPI for that given factor represents the fractional limitation due to that particular stress. Therefore, growth rates will be slower as the effect of that particular stress factor becomes more severe.

Quantifying the Effects of Environmental Factors Crop Growth

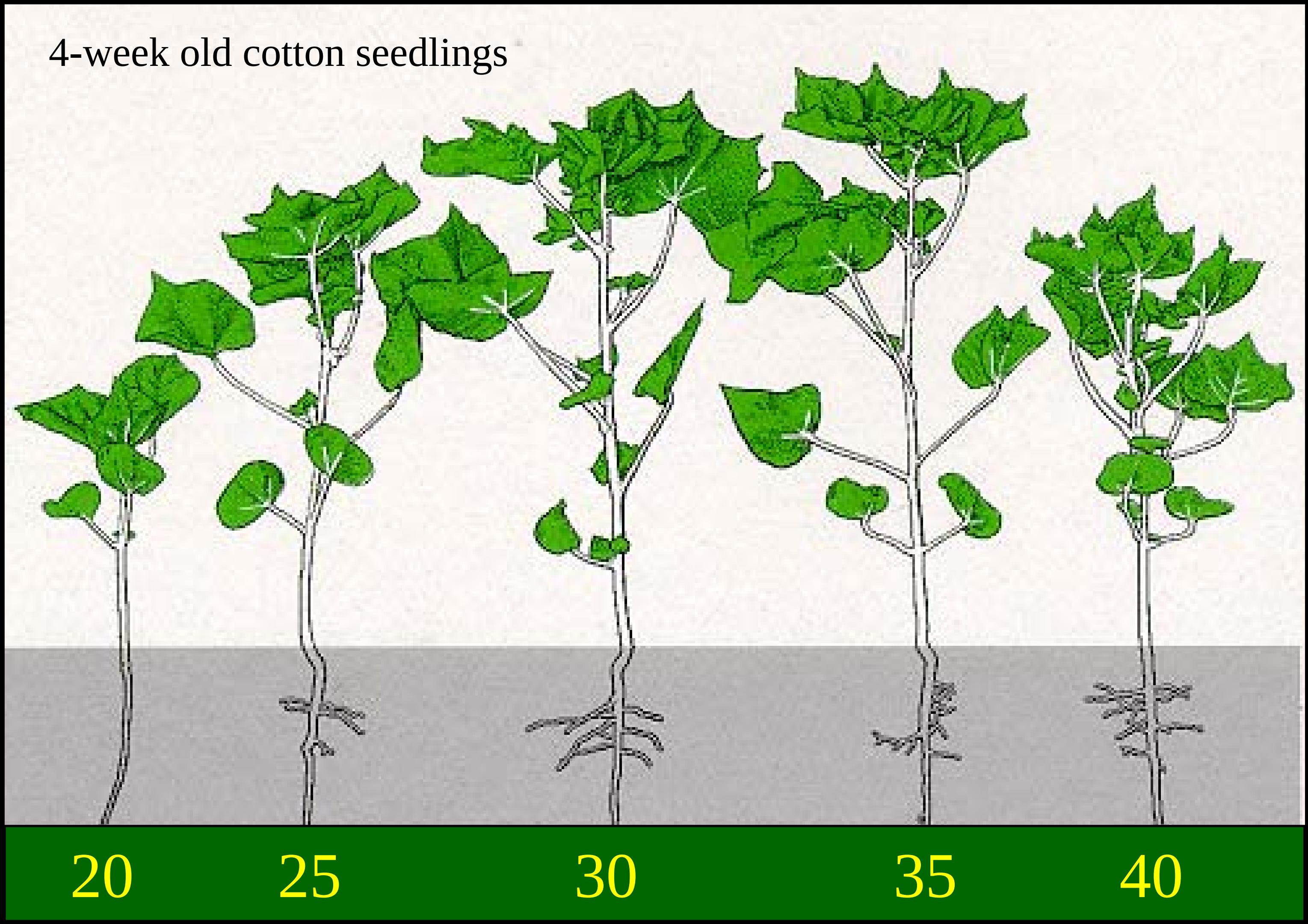
The EPI concept allows one to quantify the effect of environmental factors that limit crop growth in a multi-stress environments or in field conditions.

Cotton – Growth and Development

Growth – Potential

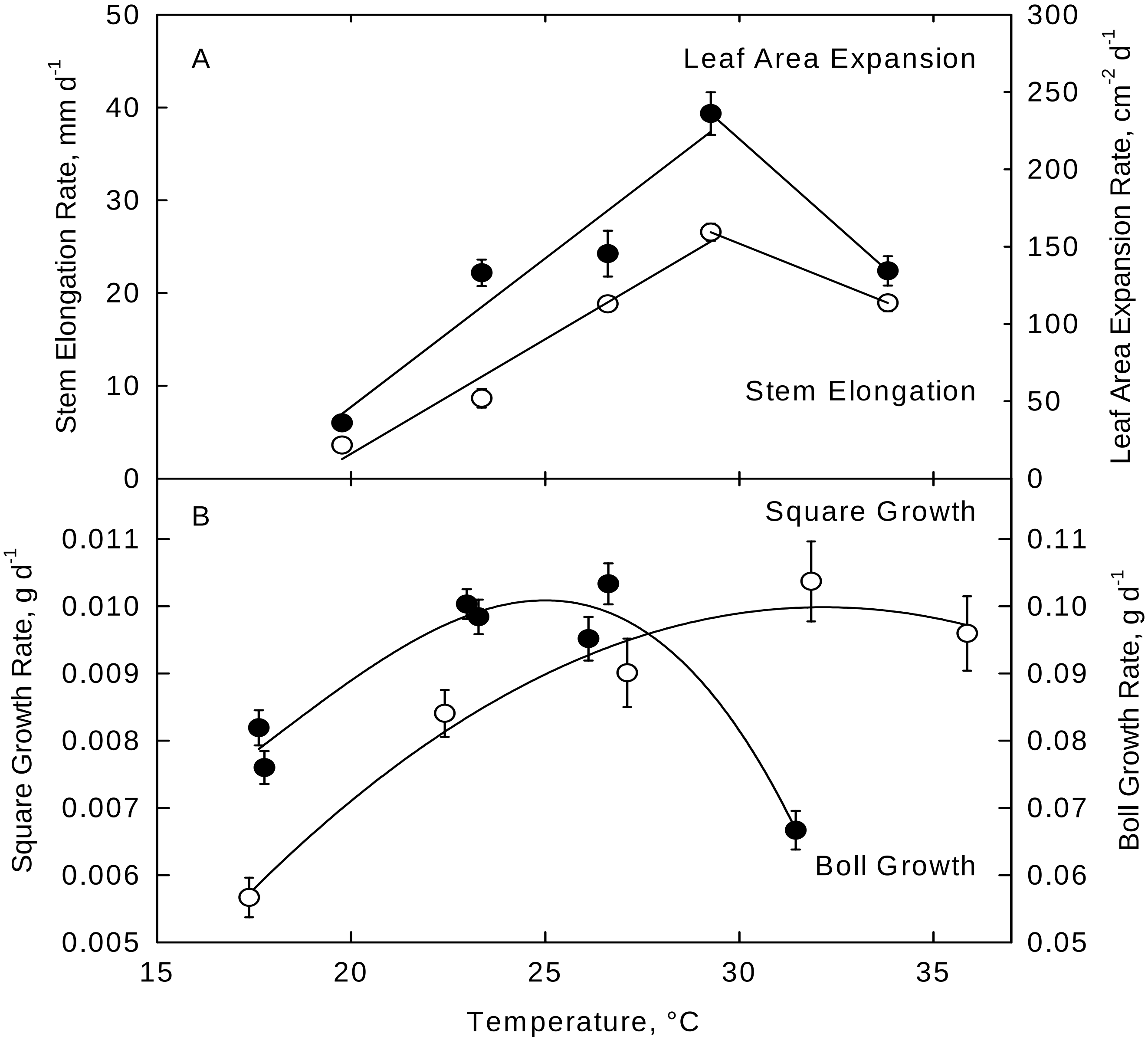
Crop Growth and Development - Environment

Response to Temperature



Crop Growth and Development - Environment

Response to Temperature

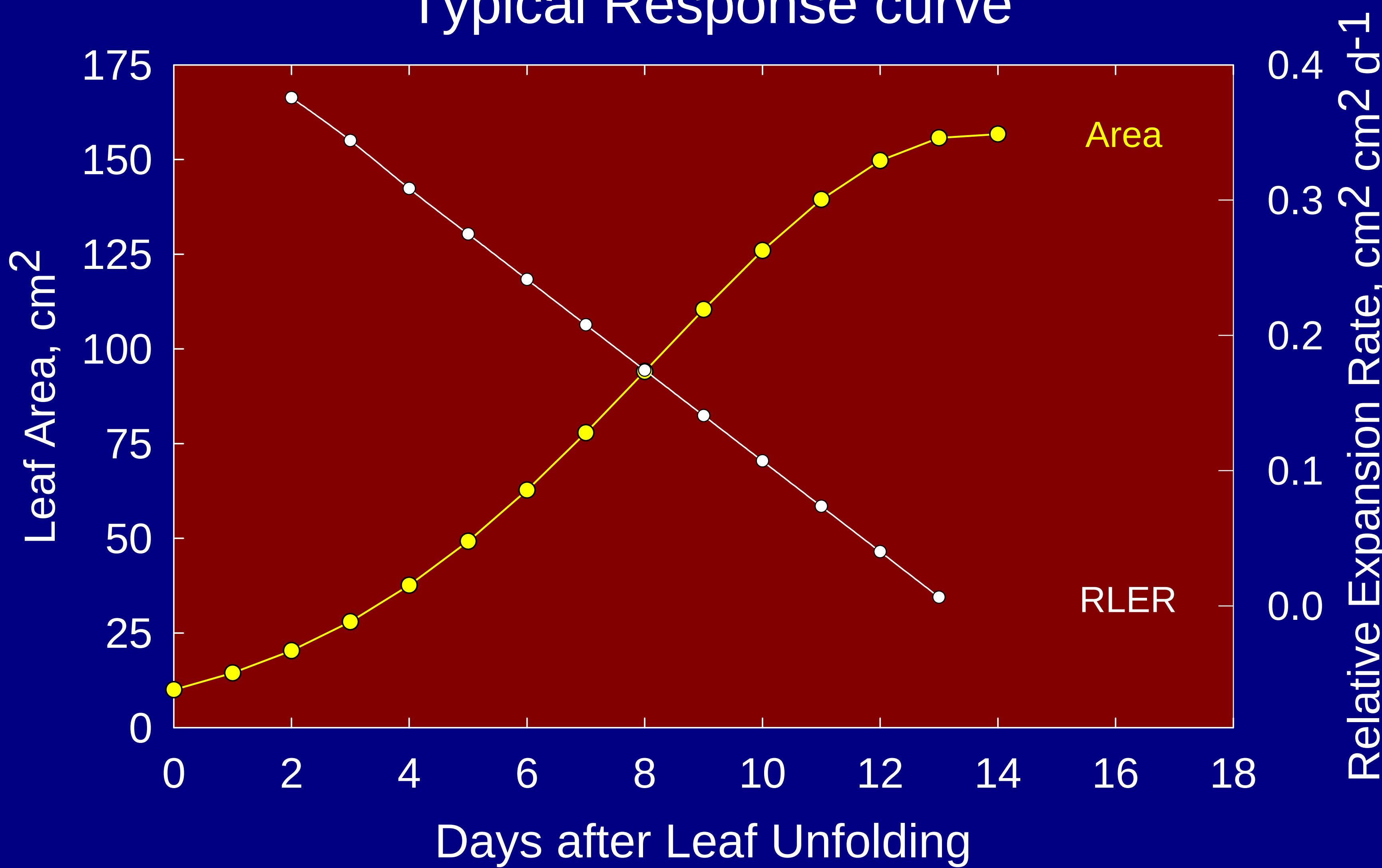


Crop Growth

Understanding leaf growth rates

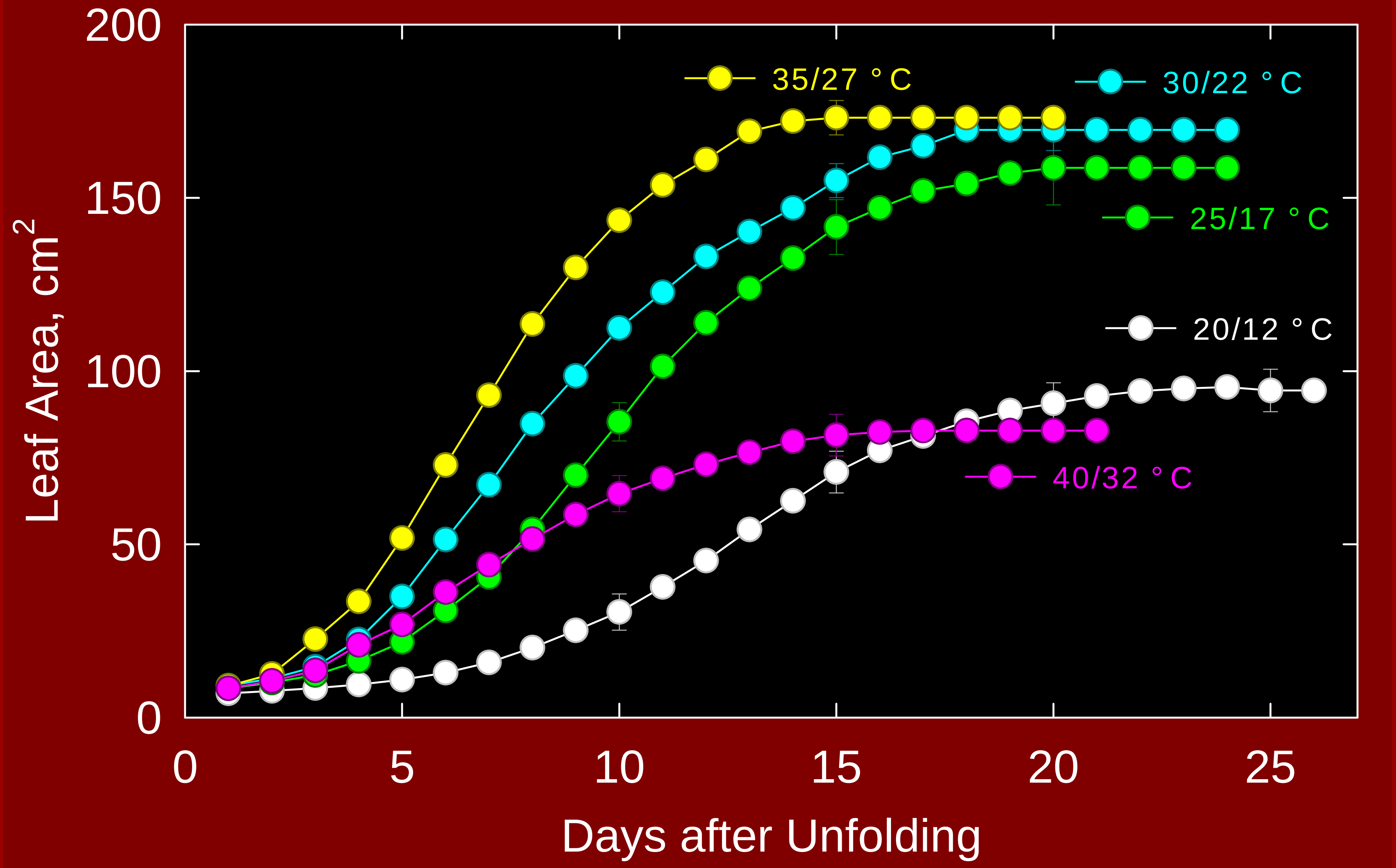
Growth - Leaf Expansion

Typical Response curve



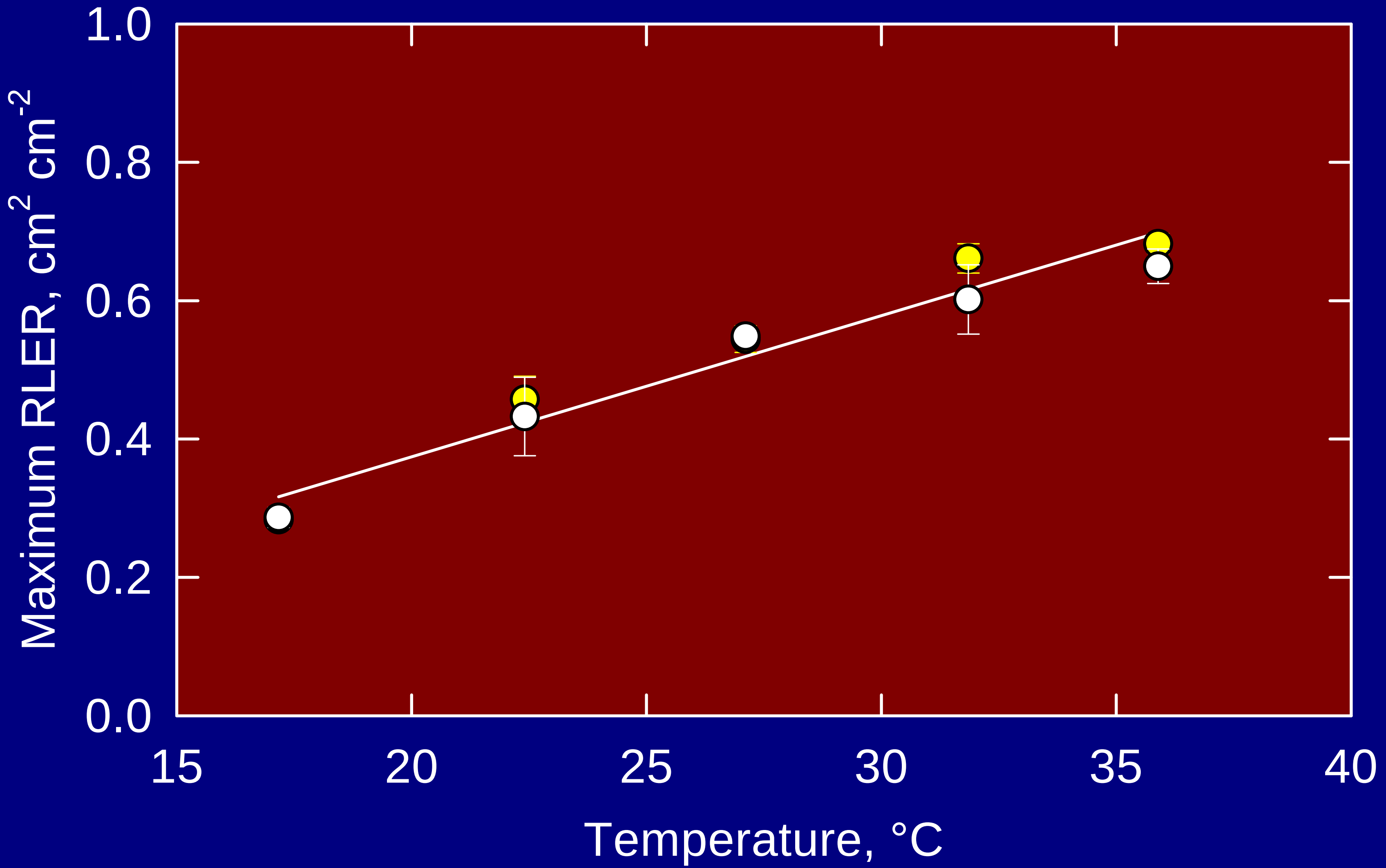
Temperature – Leaf Growth

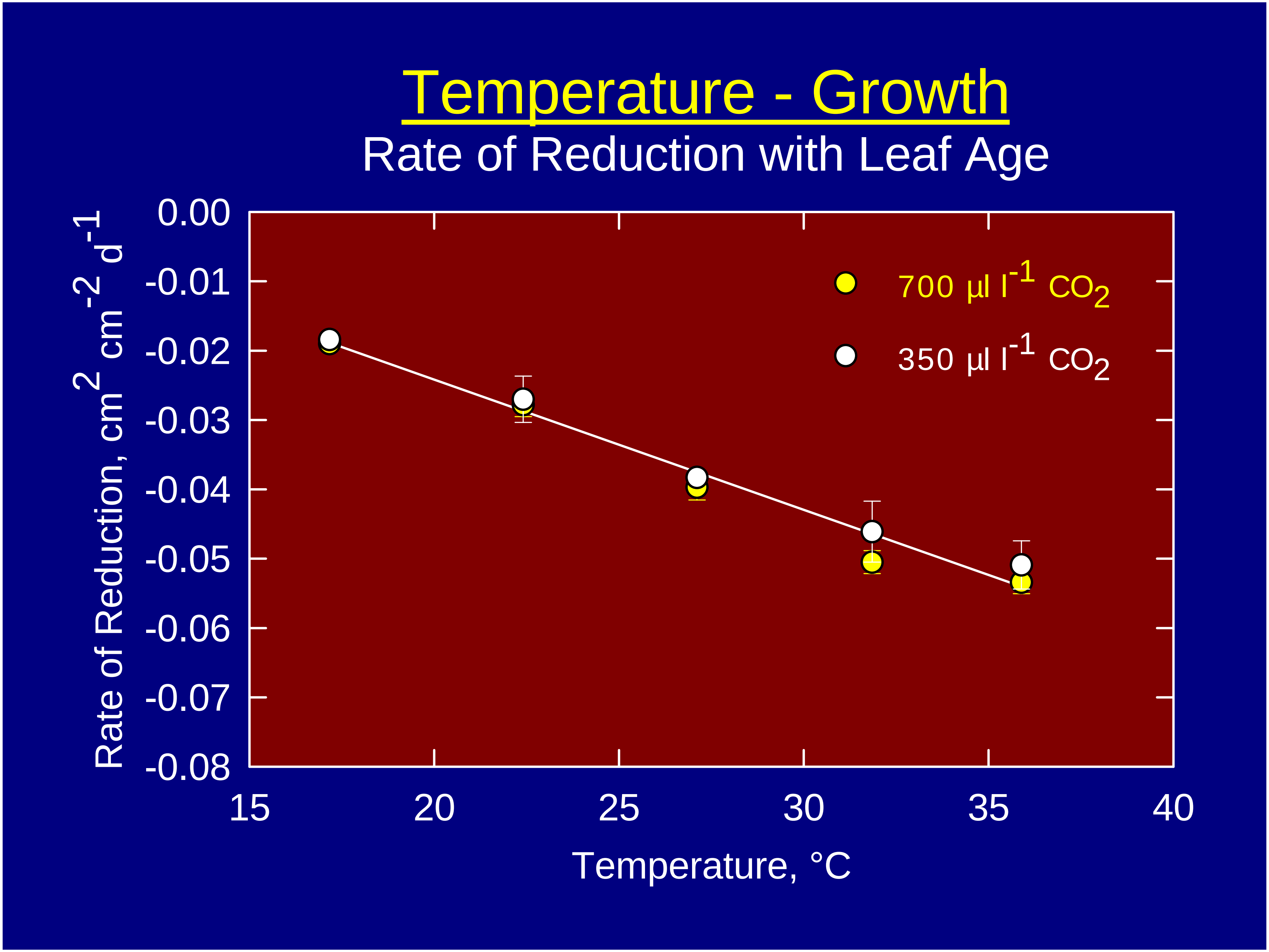
5th Leaf on the Mainstem



Temperature - Growth

Maximum Leaf Expansion Rates

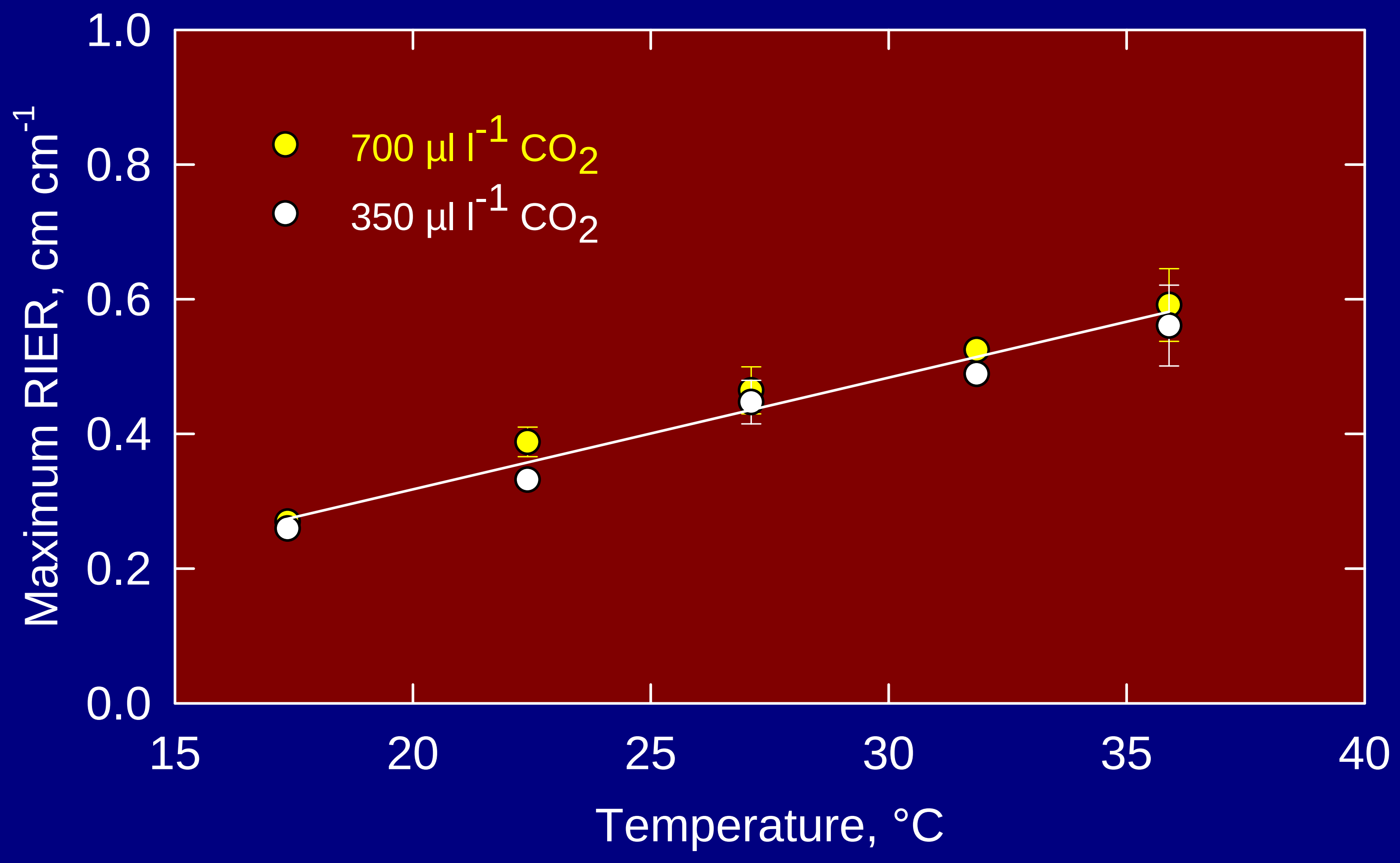




Temperature - Growth
Rate of Reduction with Leaf Age
700 µl l-1 CO2
350 µl l-1 CO2
Rate of Reduction, cm2 cm-2 d-1
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
15
20
25
30
35
40
Temperature, °C

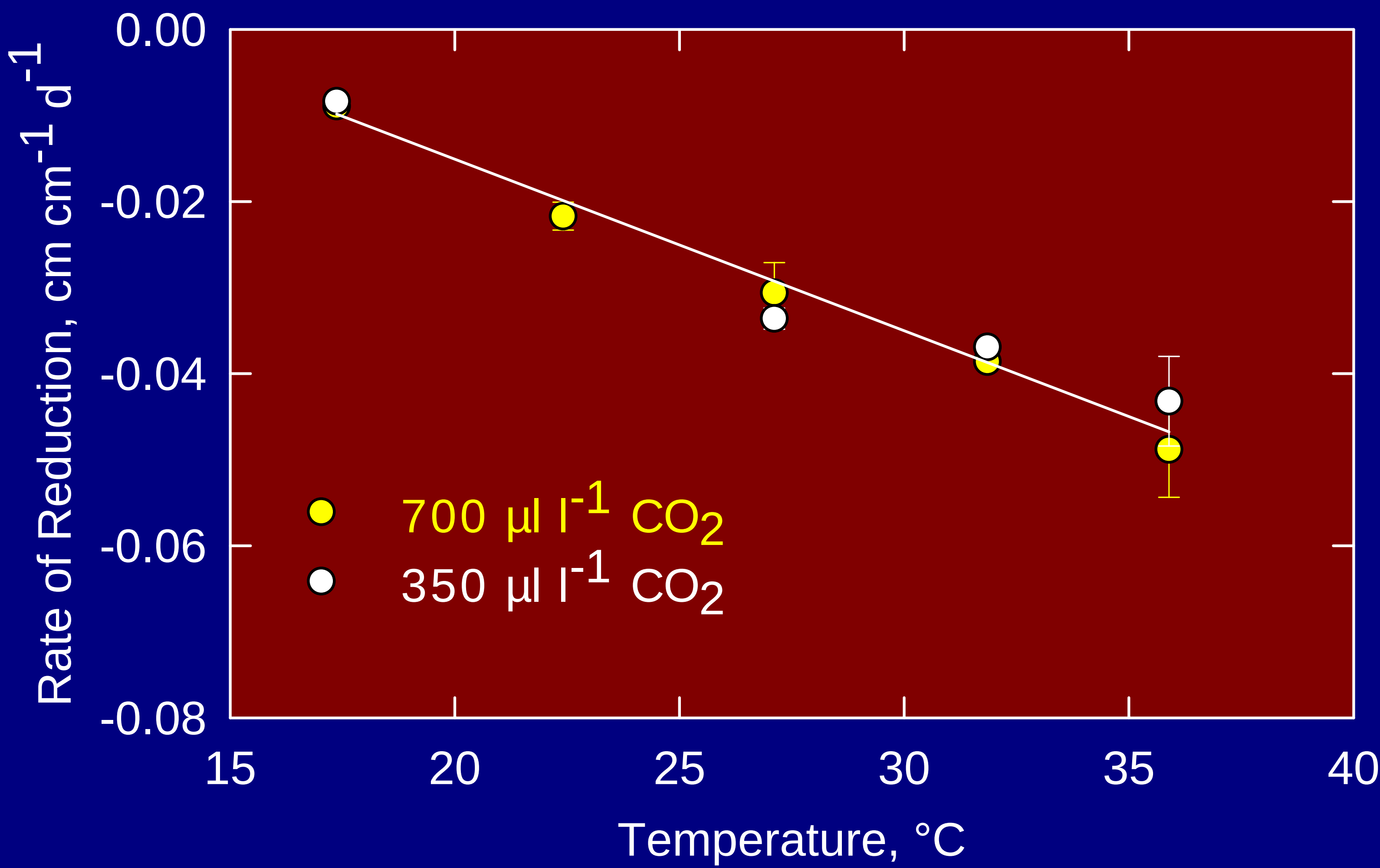
Temperature - Growth

Maximum Internode Extension Rates



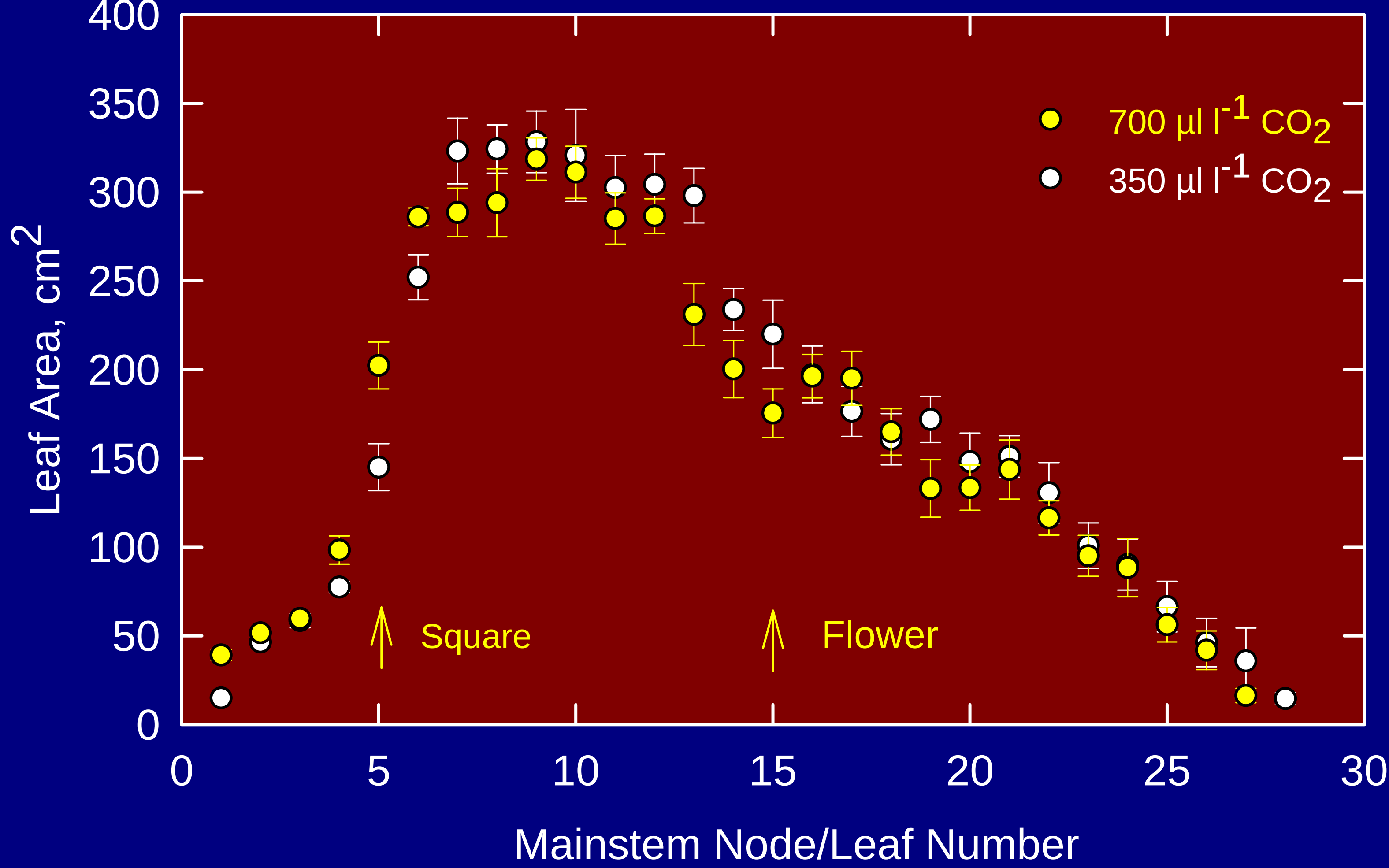
Temperature - Growth

Internode - Rate of Reduction with Age



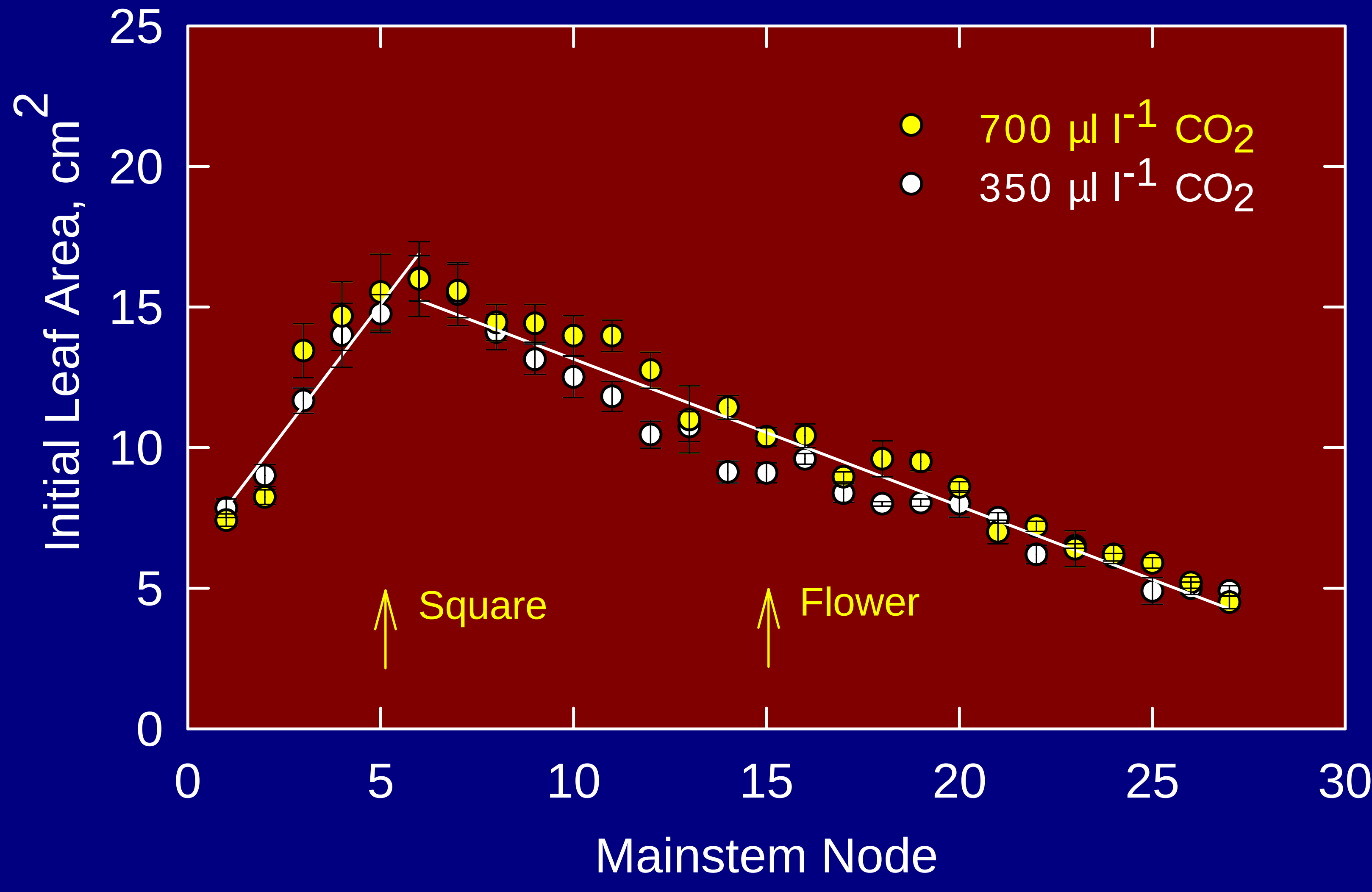
Temperature - Growth

Mainstem Leaf Area



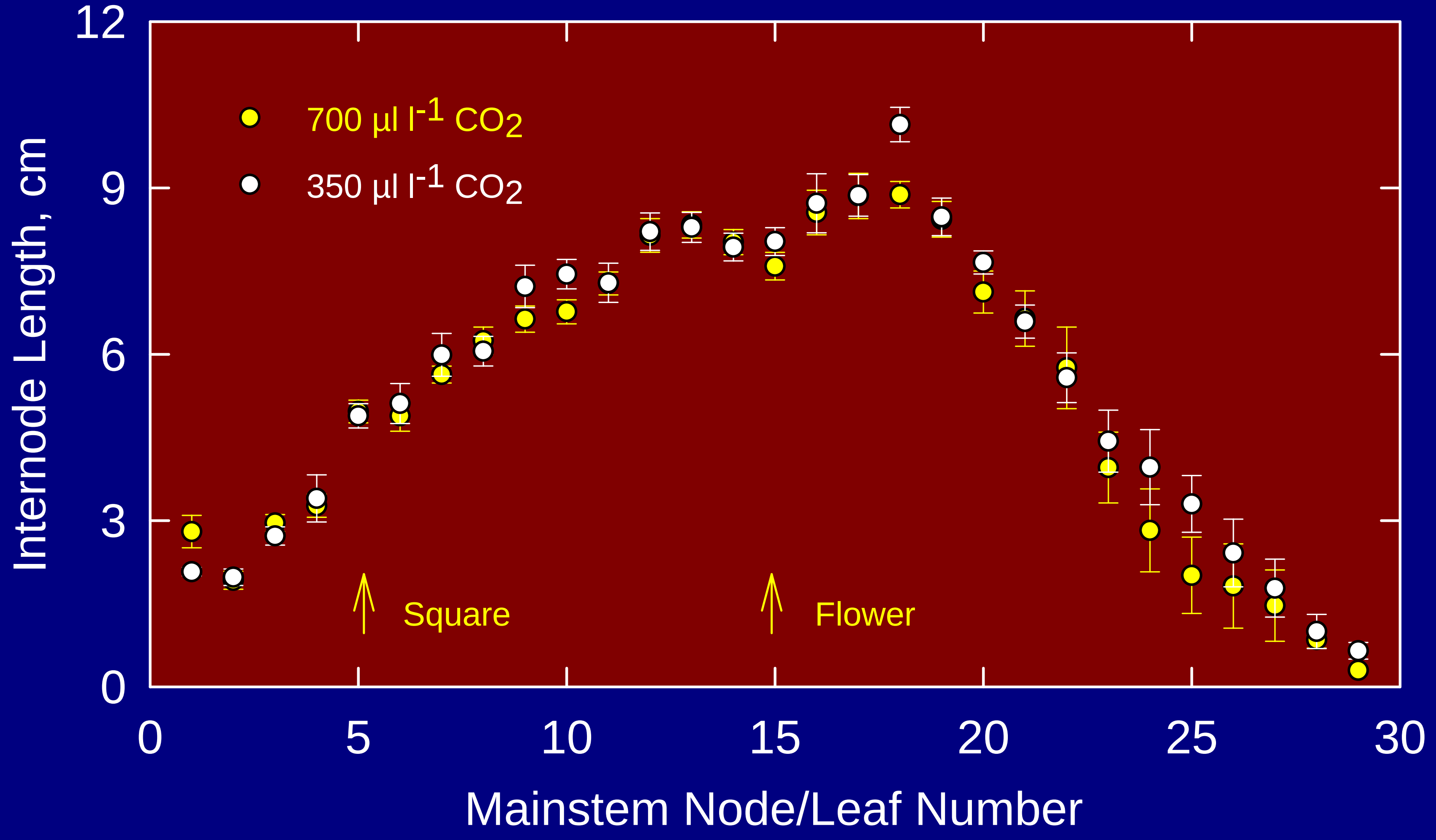
Temperature - Growth

Leaf Area at Leaf Unfolding



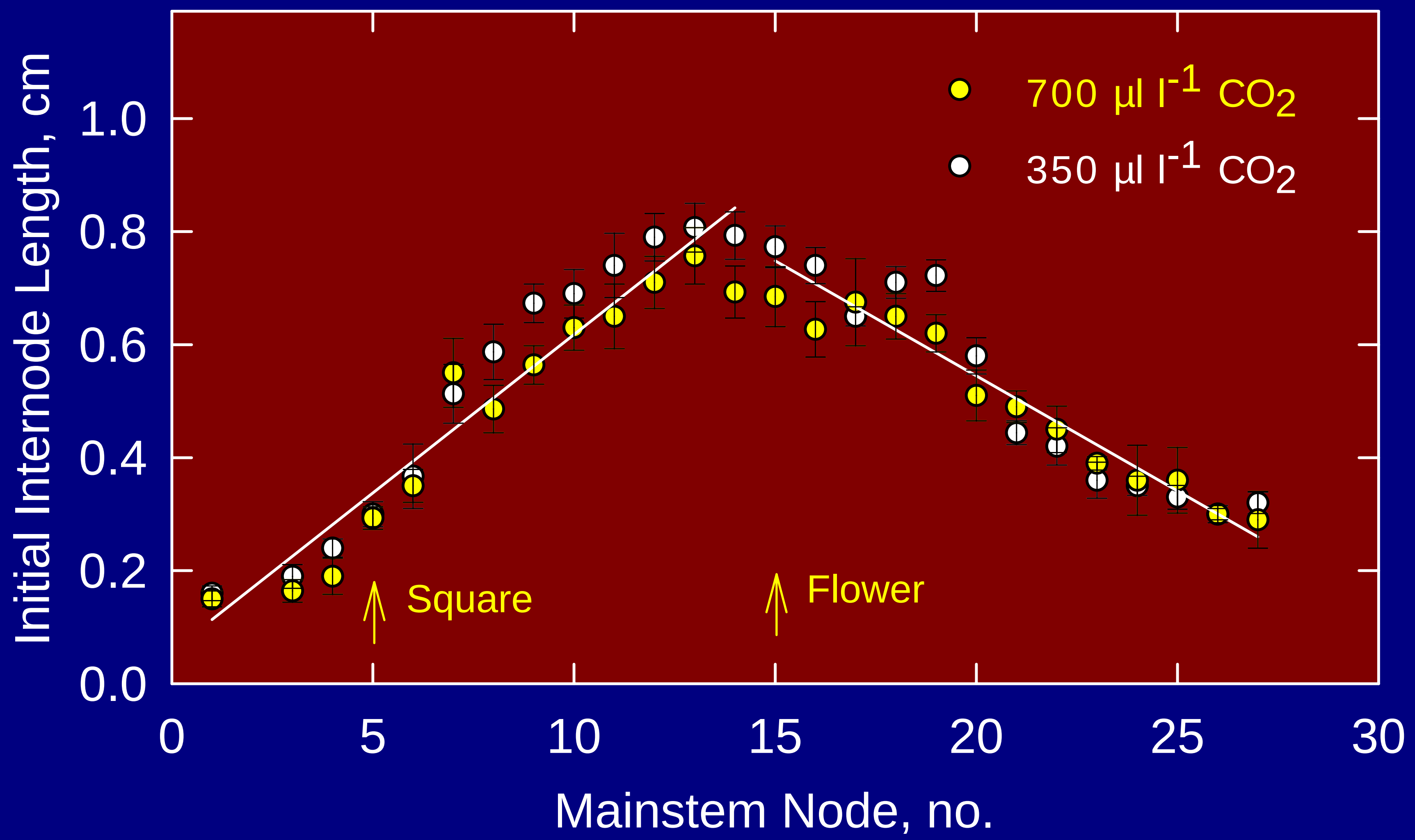
Temperature - Growth

Mainstem Internode Lengths



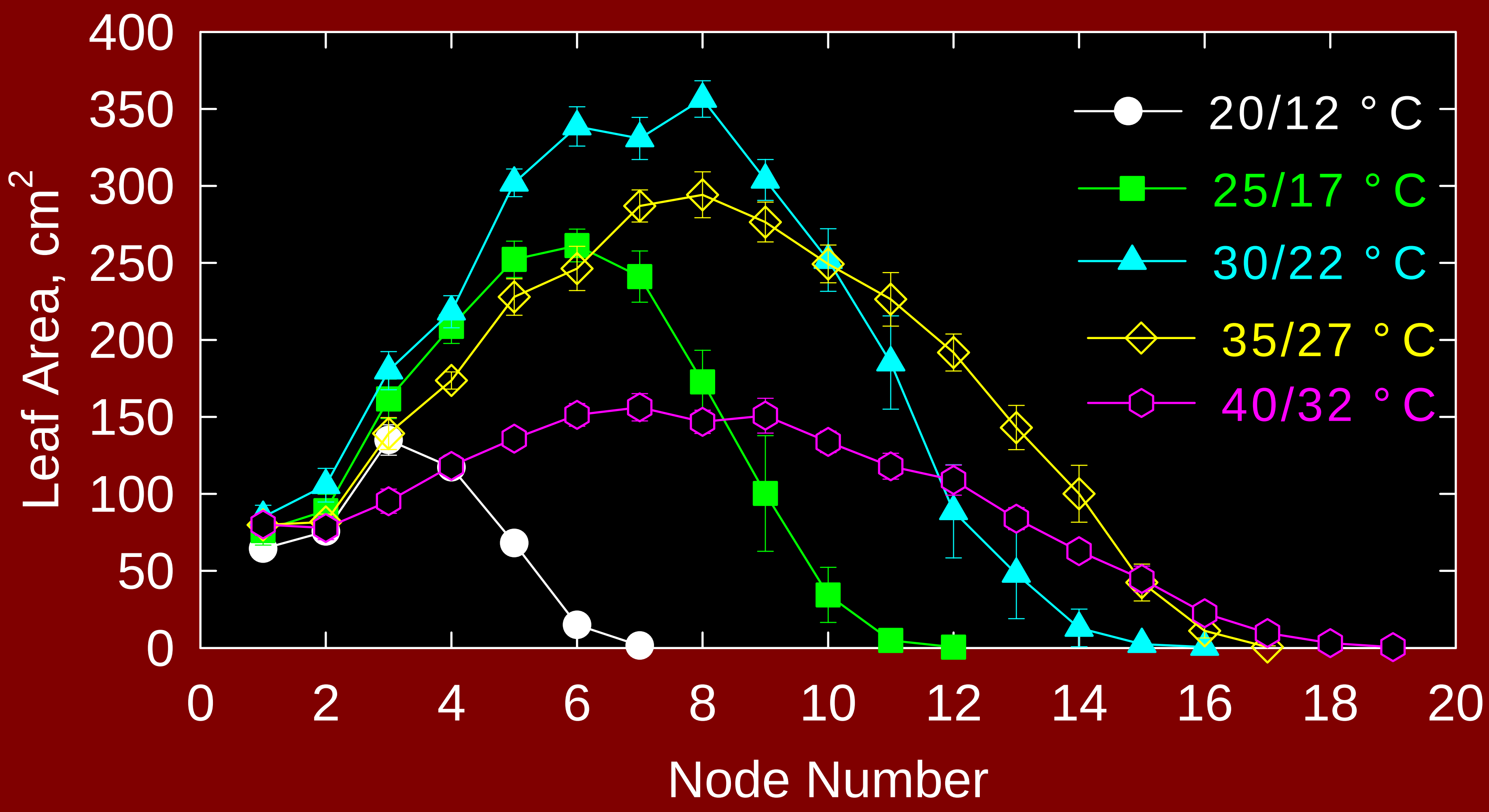
Temperature - Growth

Internode Lengths at Leaf Unfolding



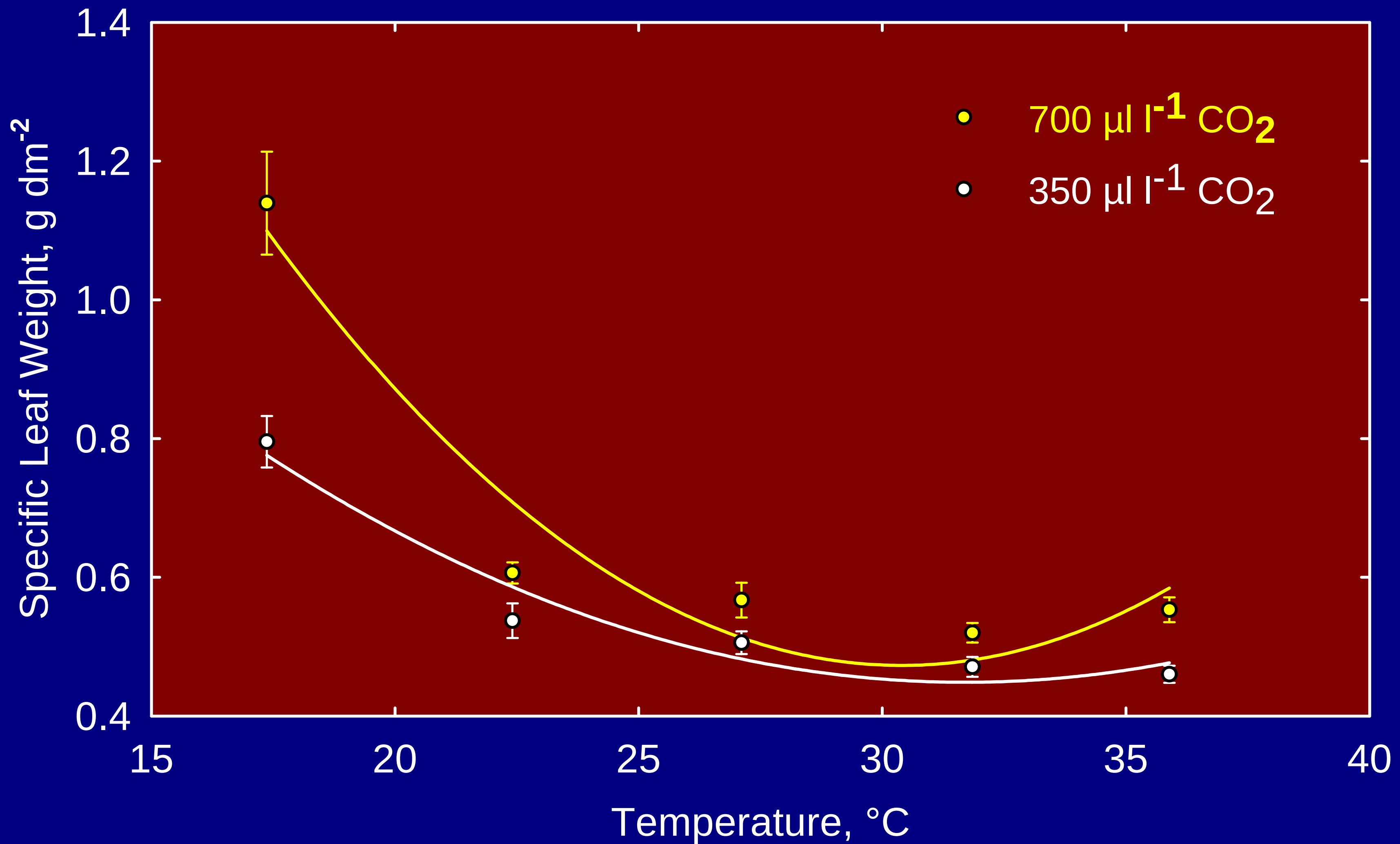
Temperature - Leaf Growth

Profile of Mainstem Leaf Sizes (70 DAE)



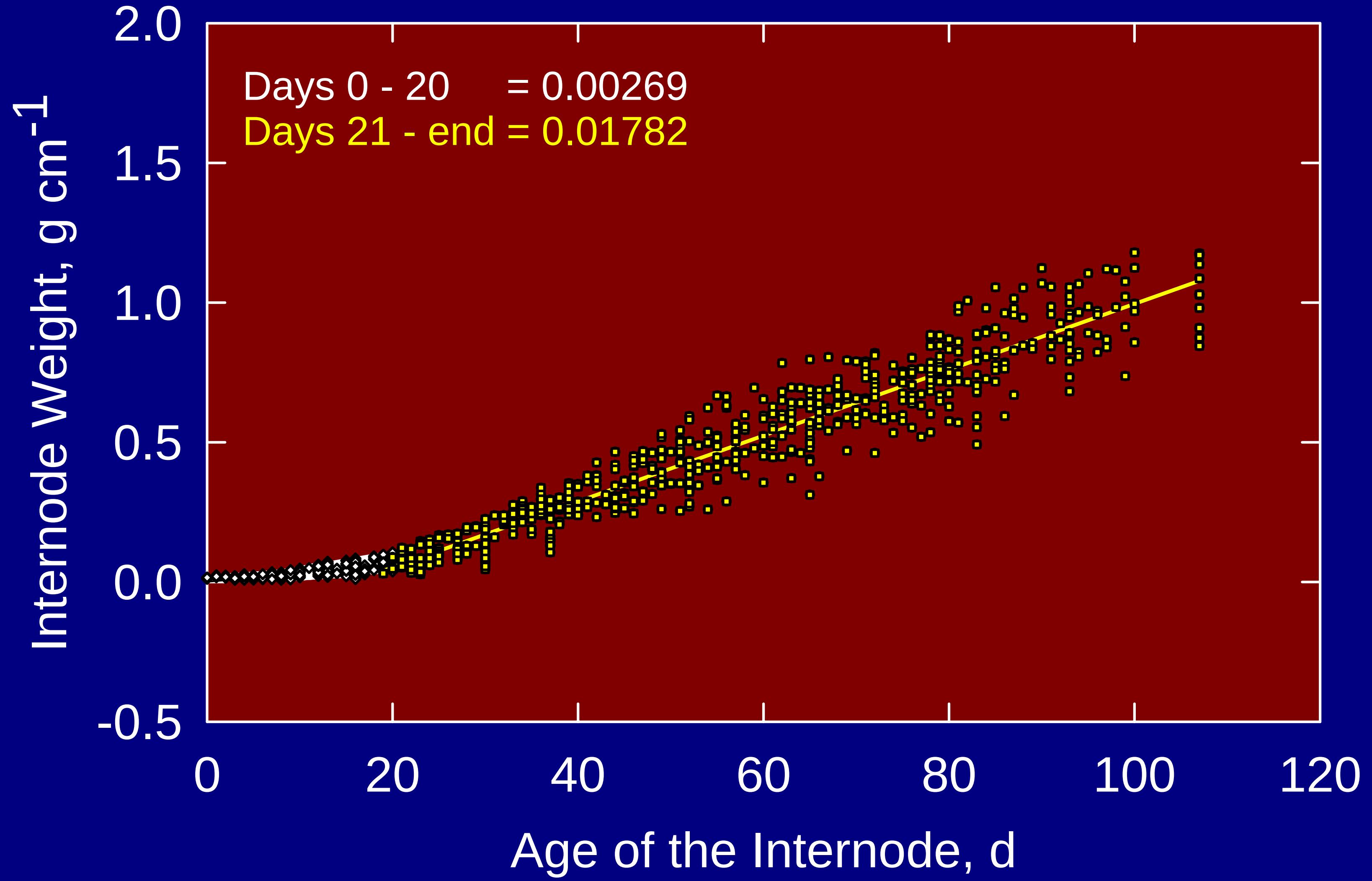
Temperature - Growth

Specific Leaf Weight

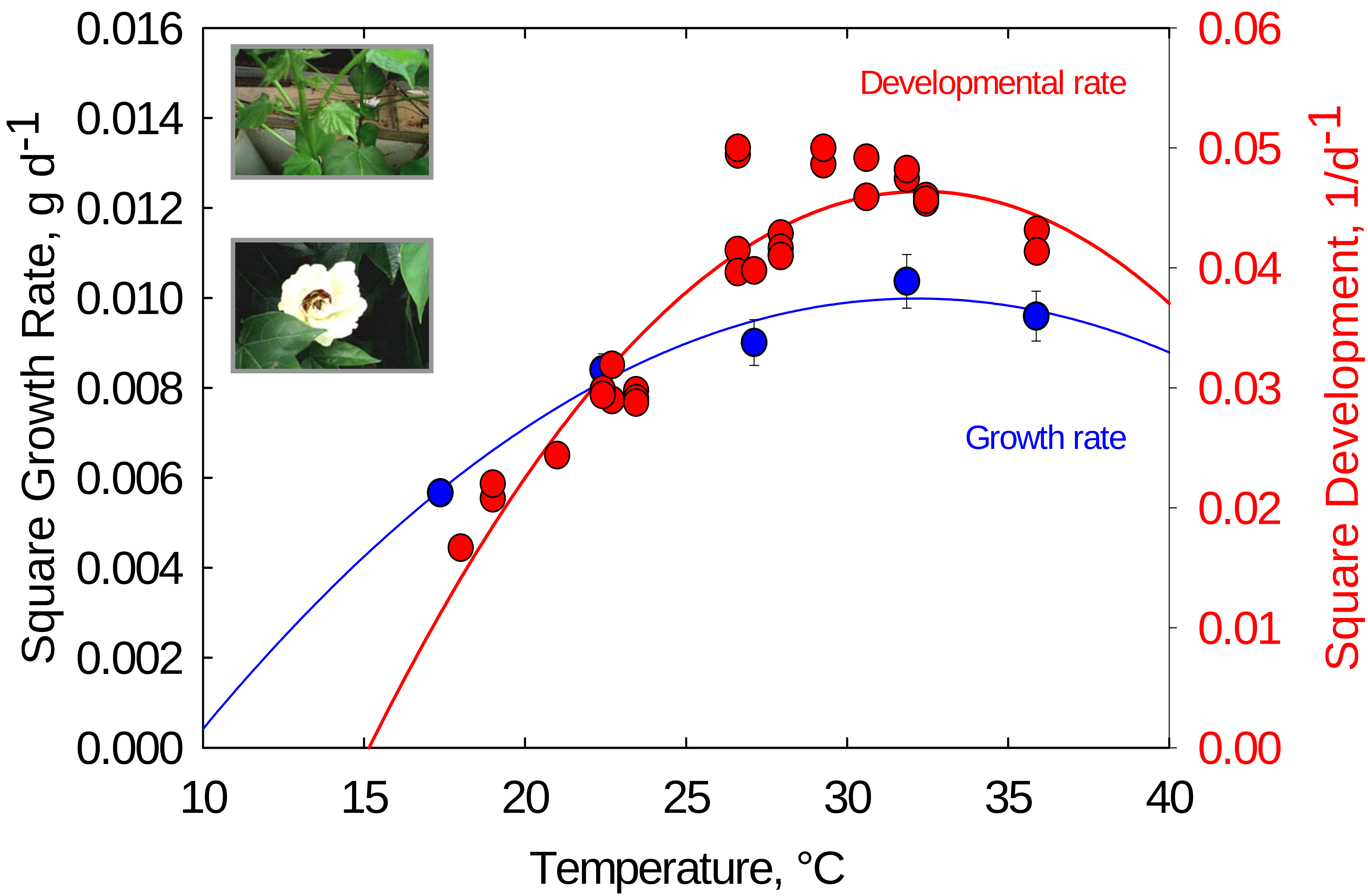


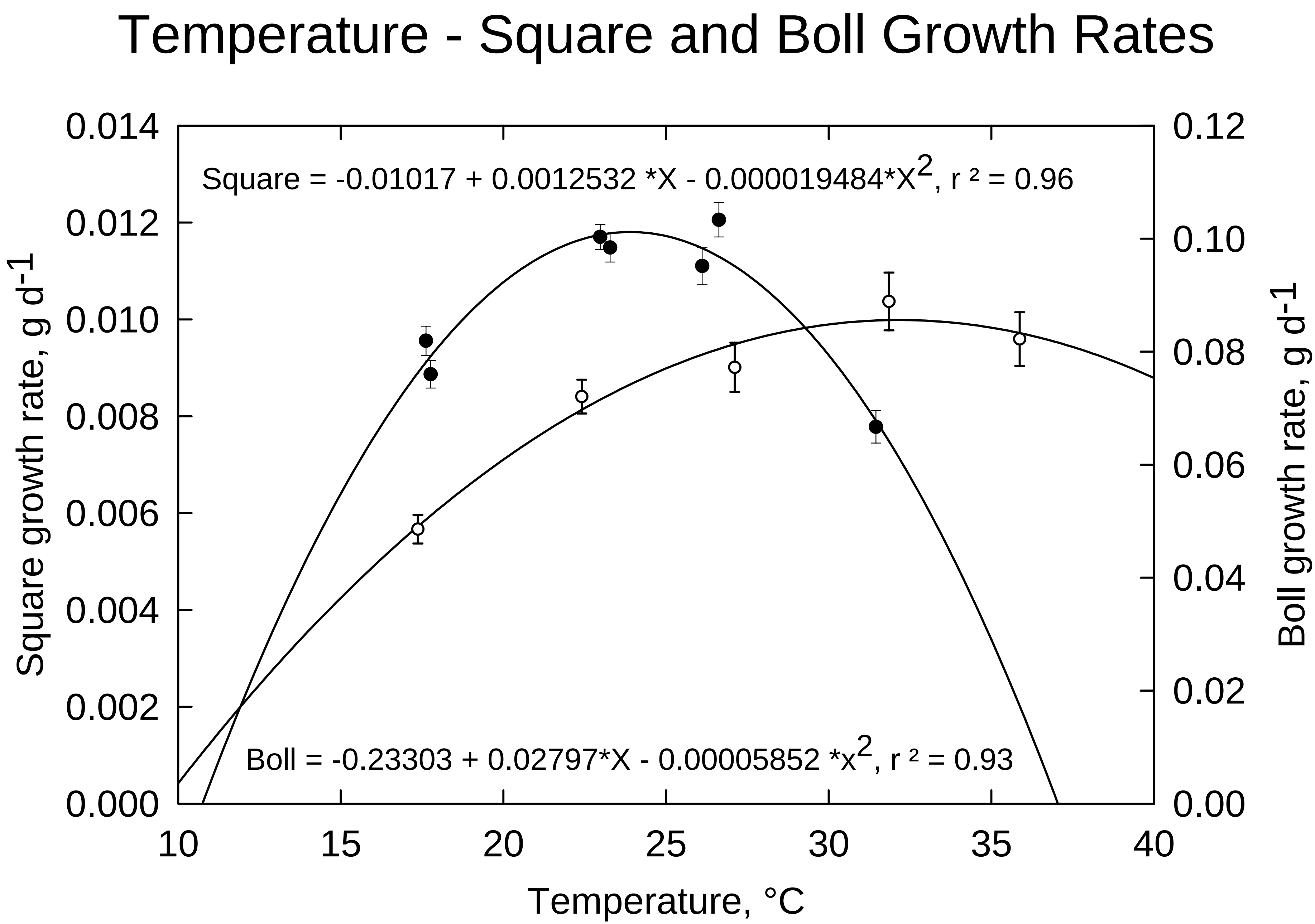
Growth - Mass Accretion

Internodes

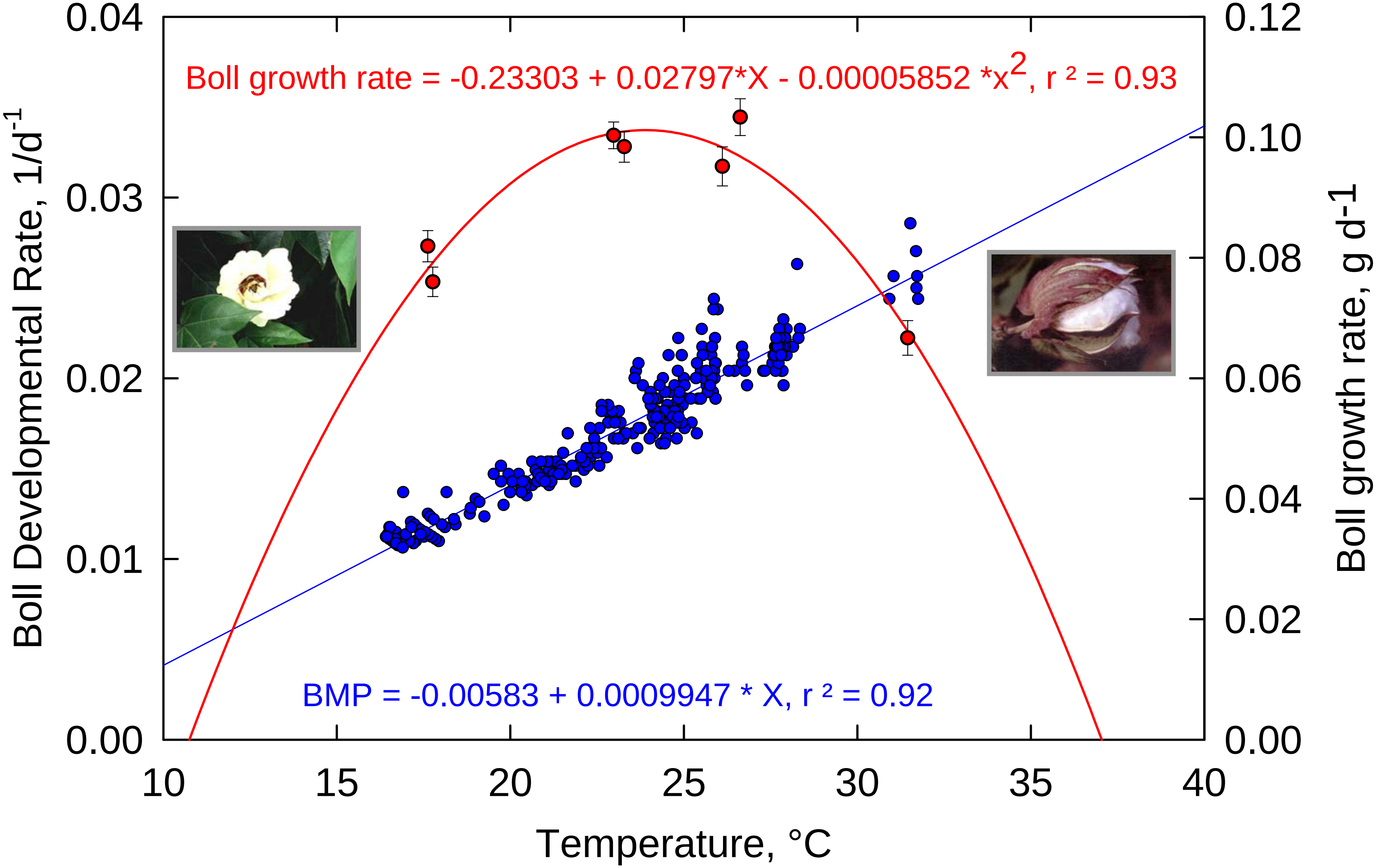


Temperature - Square Growth and Development



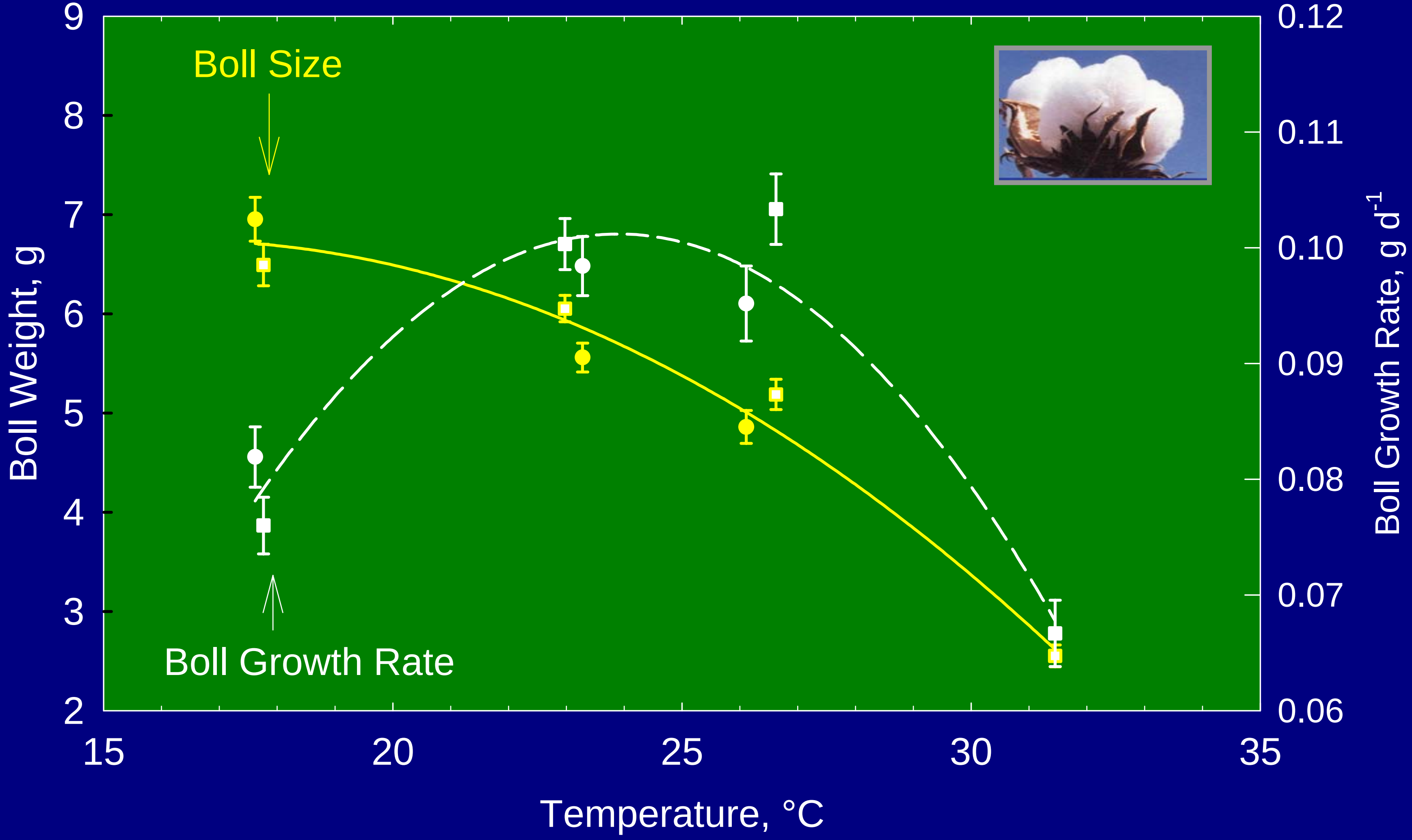

Temperature - Square and Boll Growth Rates
Square = -0.01017 + 0.0012532 *X - 0.000019484*X2, r ² = 0.96
Boll = -0.23303 + 0.02797*X - 0.00005852 *x2, r ² = 0.93
Square growth rate, g d-1
Boll growth rate, g d-1
Temperature, °C
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0.12
0.10
0.08
0.06
0.04
0.02
0.00
10
15
20
25
30
35
40

Temperature - Boll Growth and Development



Temperature - Boll Growth

Boll Size and Growth Rate

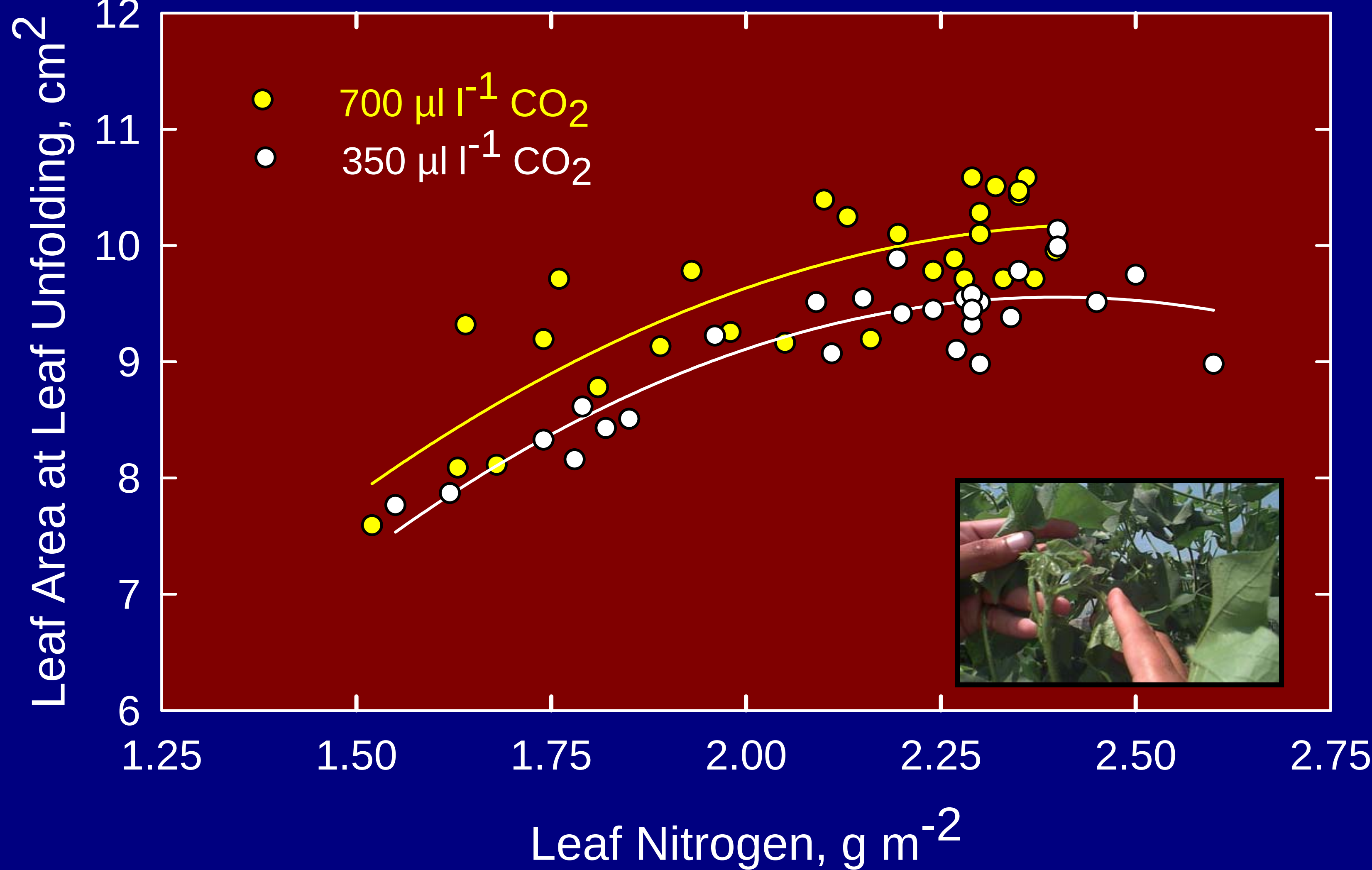


Cotton Growth

Stress Environments

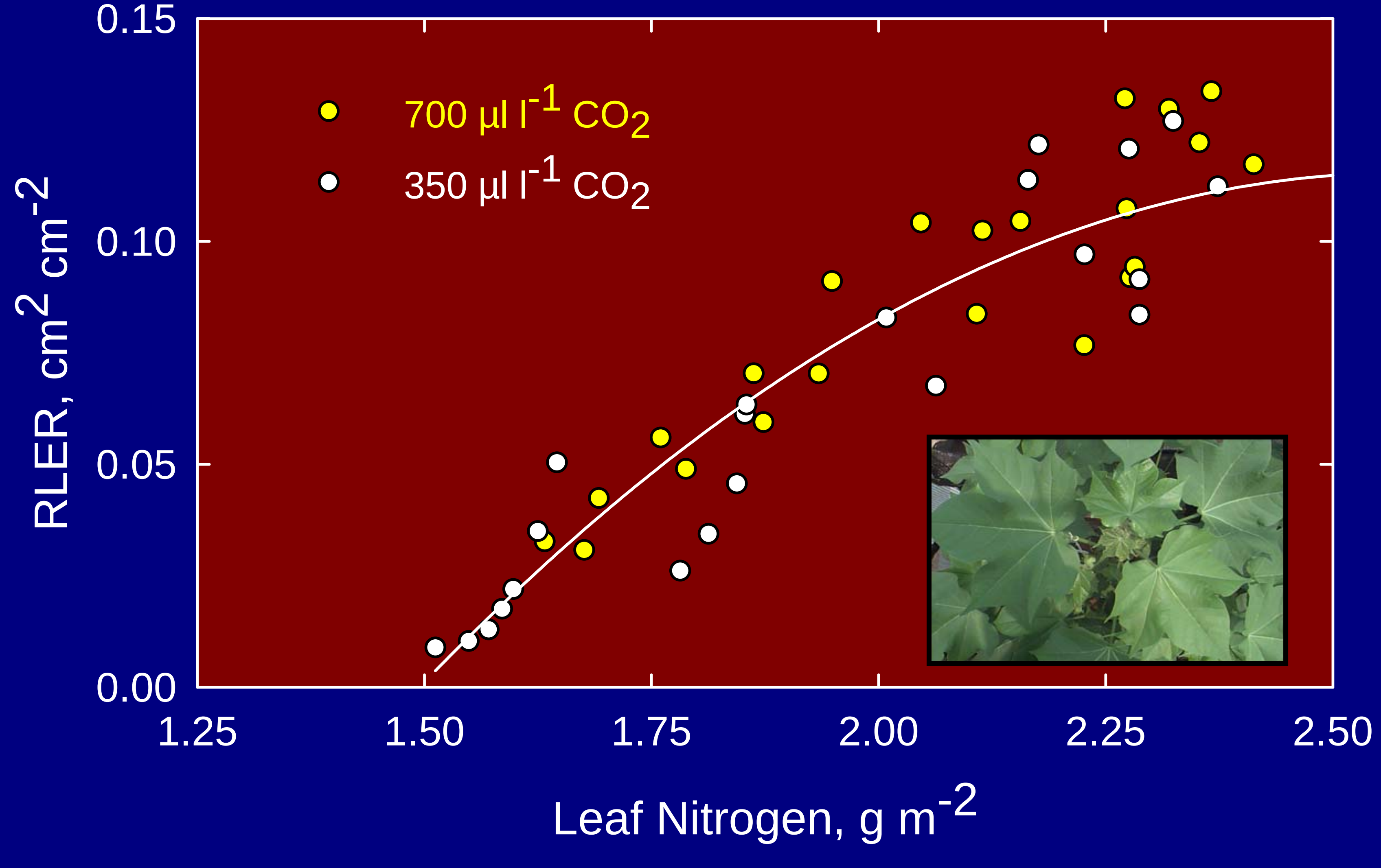
Nitrogen - Growth

Leaf Area at Leaf Unfolding



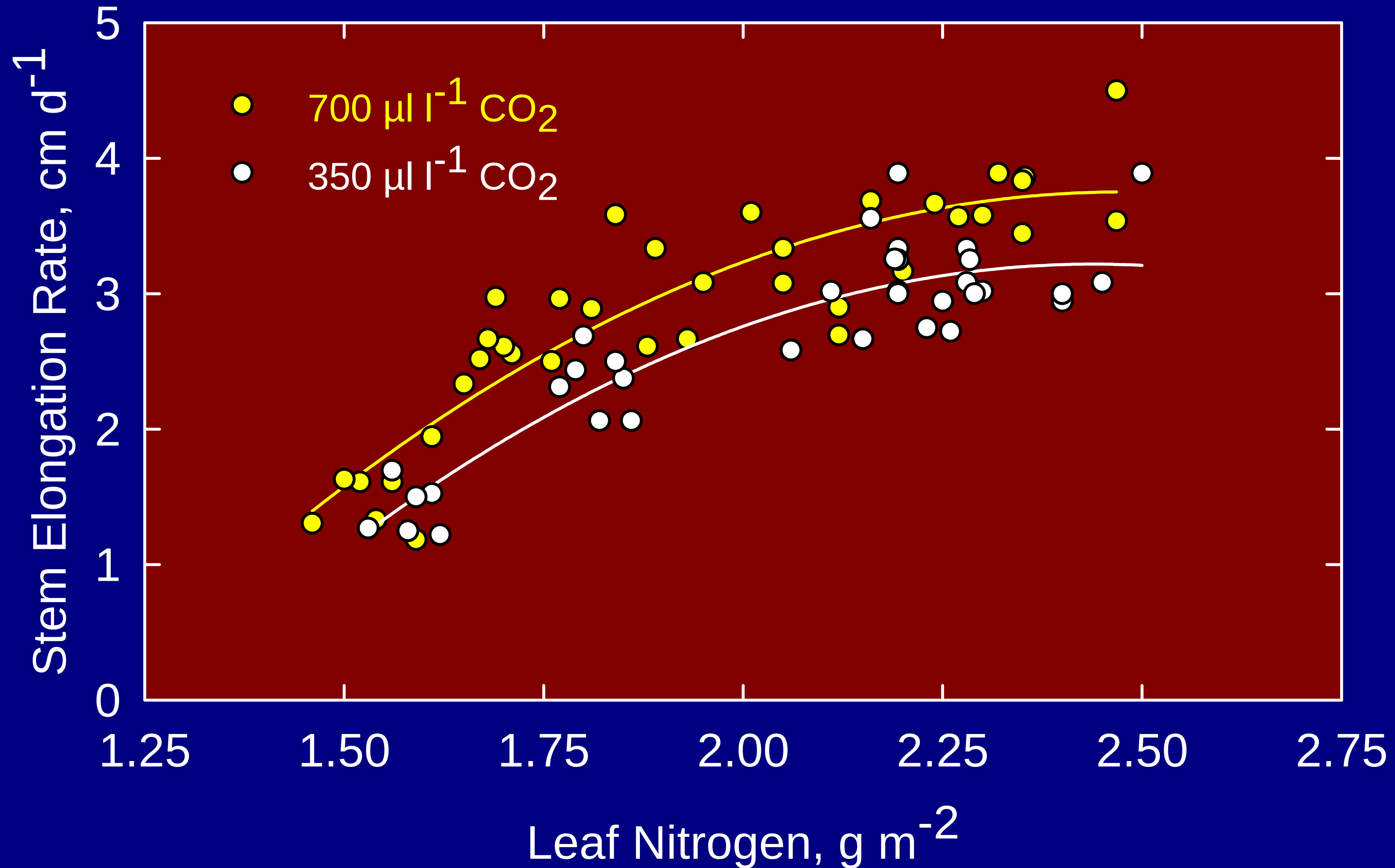
Nitrogen - Growth

Leaf Expansion Rates



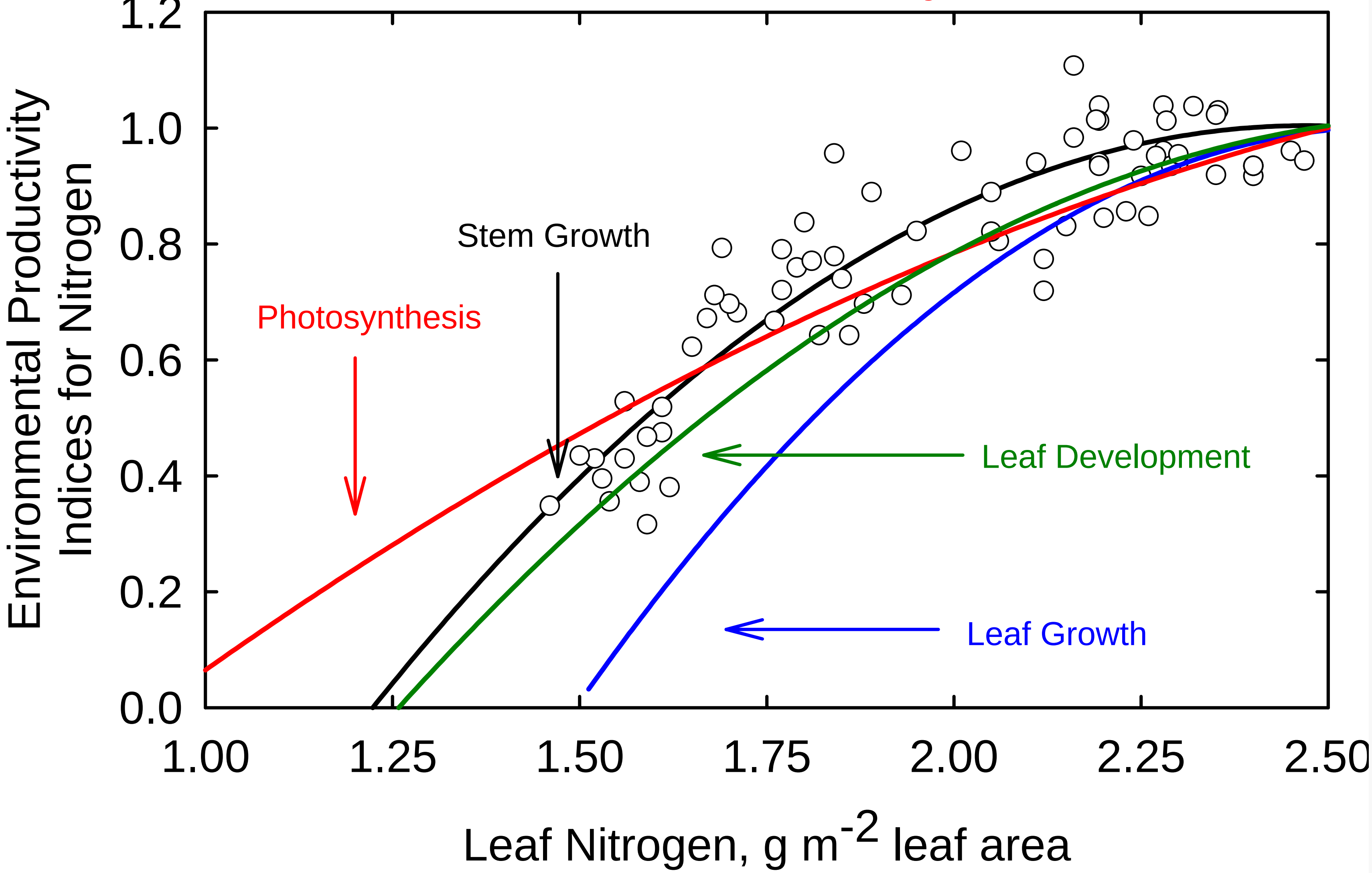
Leaf Nitrogen - Growth

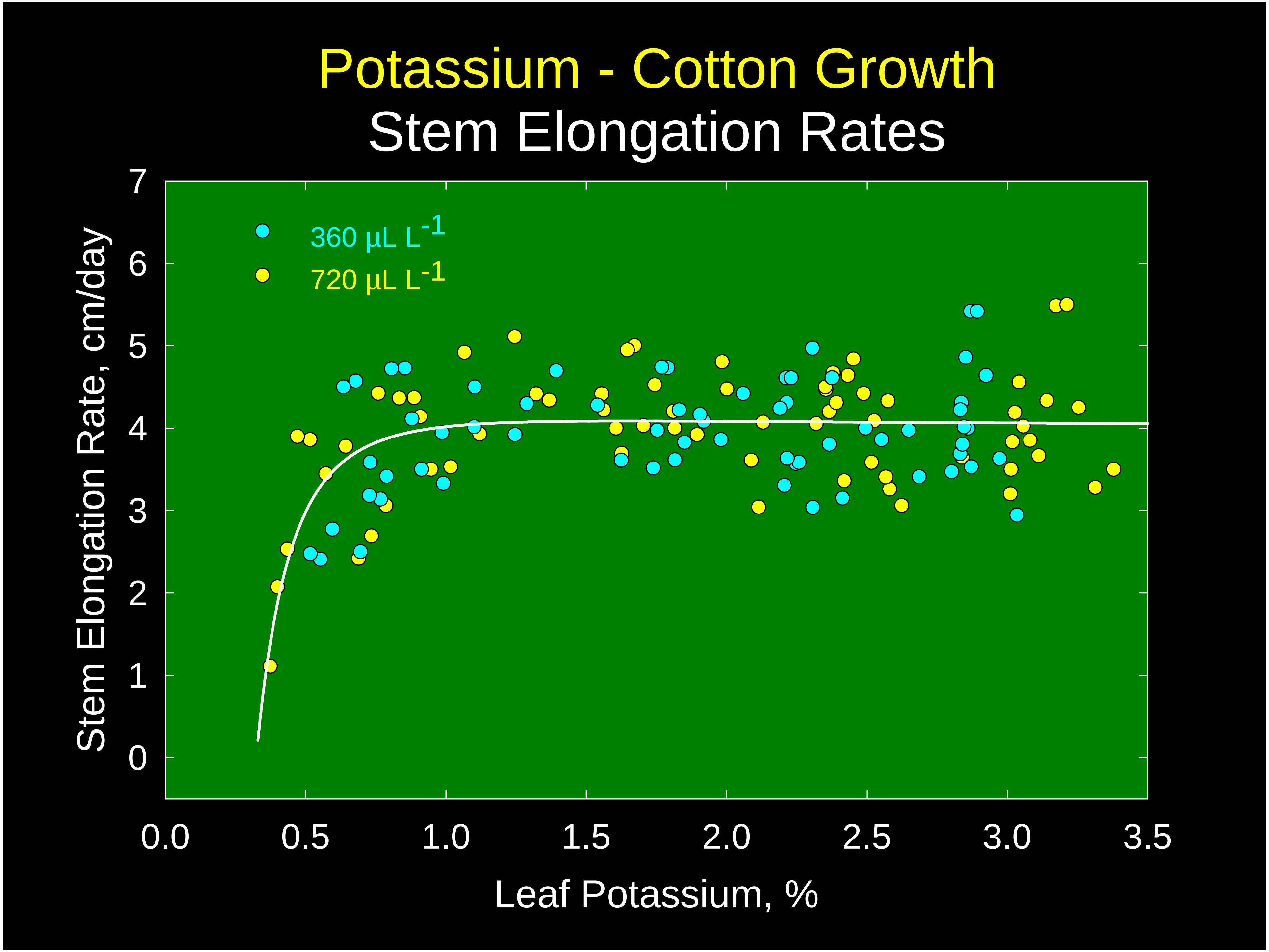
Stem Elongation Rates



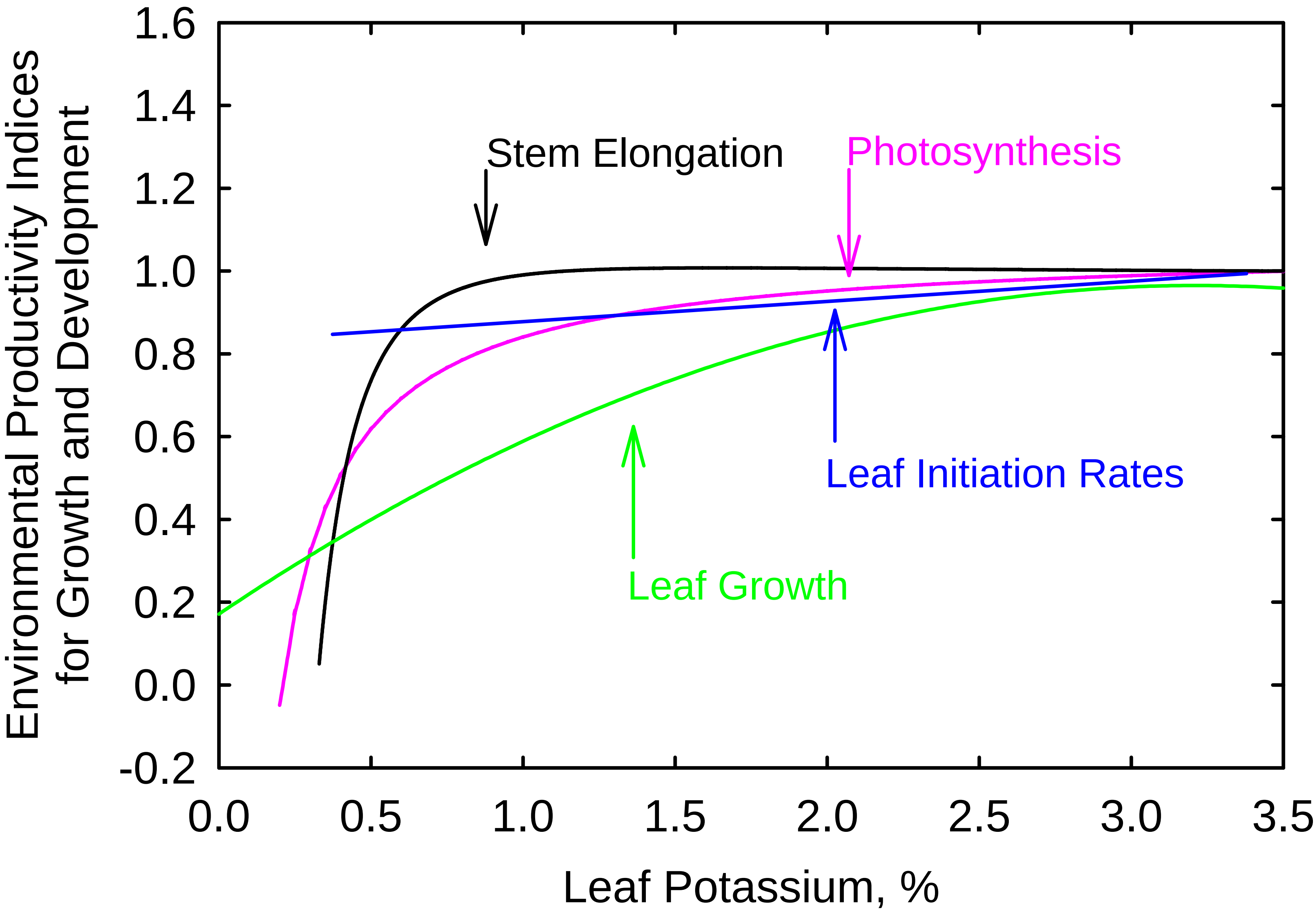
Modeling the Effects of Nitrogen on Cotton Growth and Development

Environmental Productivity Indices



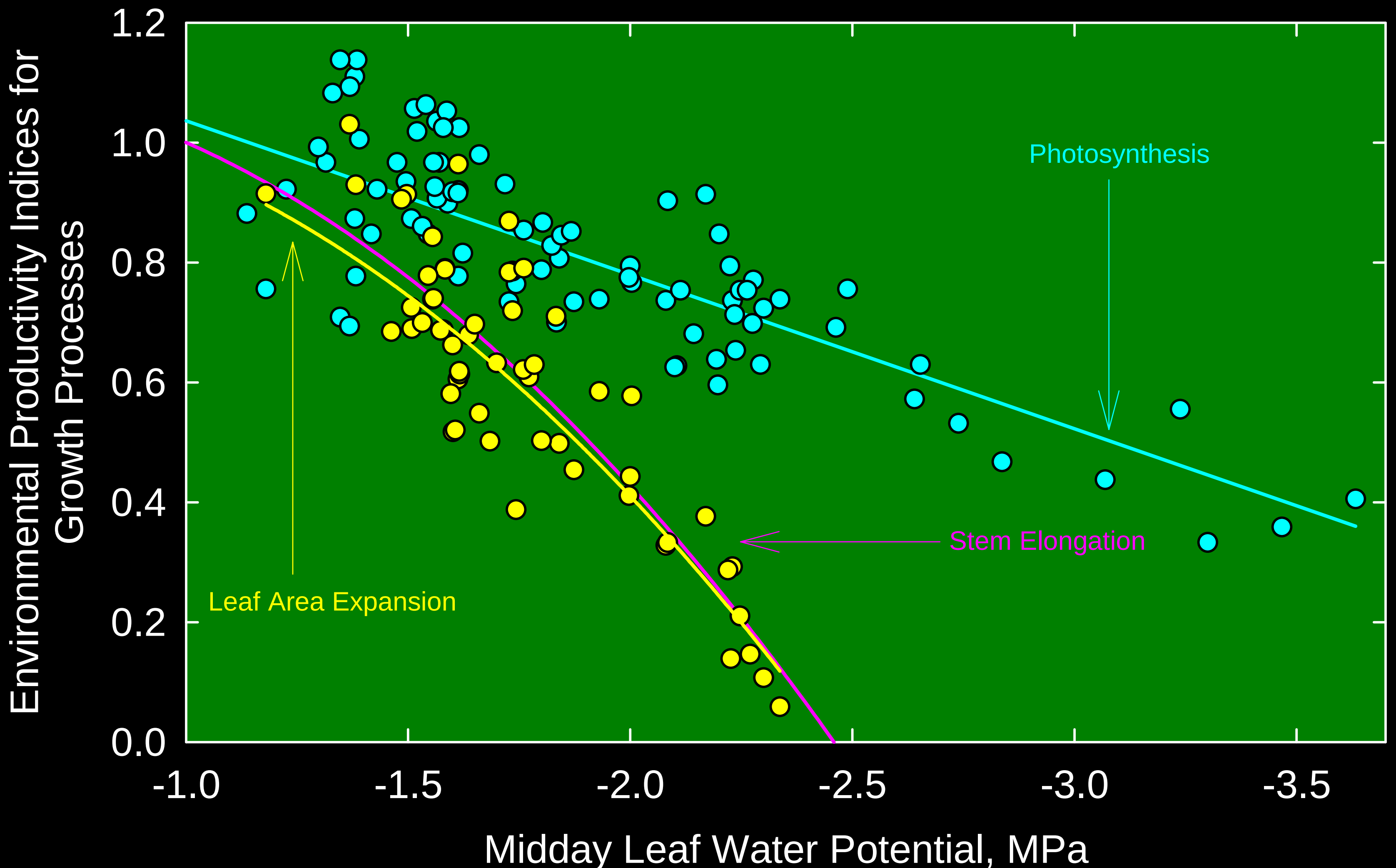

Potassium - Cotton Growth
Stem Elongation Rates
$360\ \mu L\ L^{-1}$
$720\ \mu L\ L^{-1}$
Stem Elongation Rate, cm/day
0
1
2
3
4
5
6
7
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Leaf Potassium, %

Potassium - Cotton Growth and Development
Environmental Productivity Indices

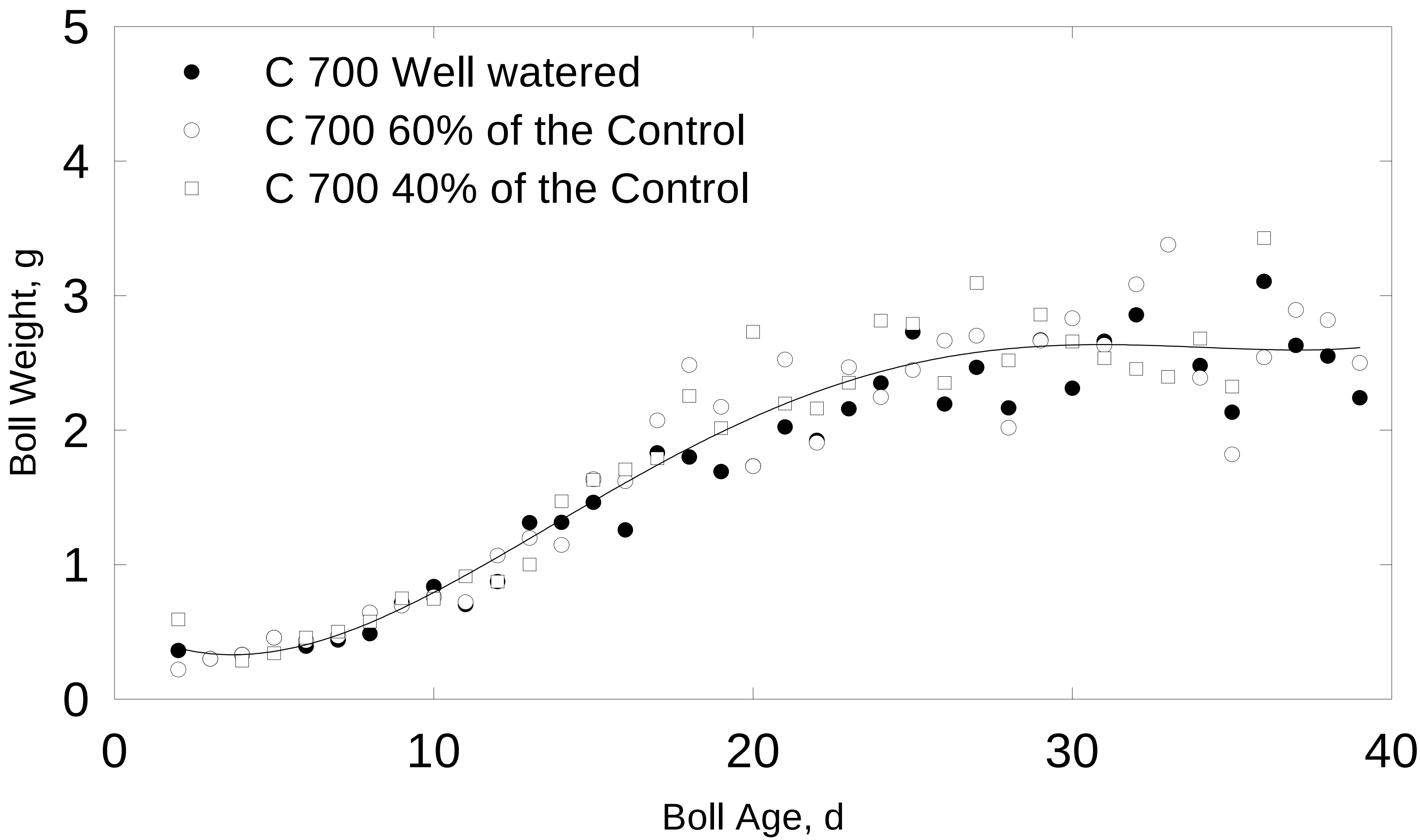


Environmental Productivity Indices for Various Processes

Response to Water Deficits

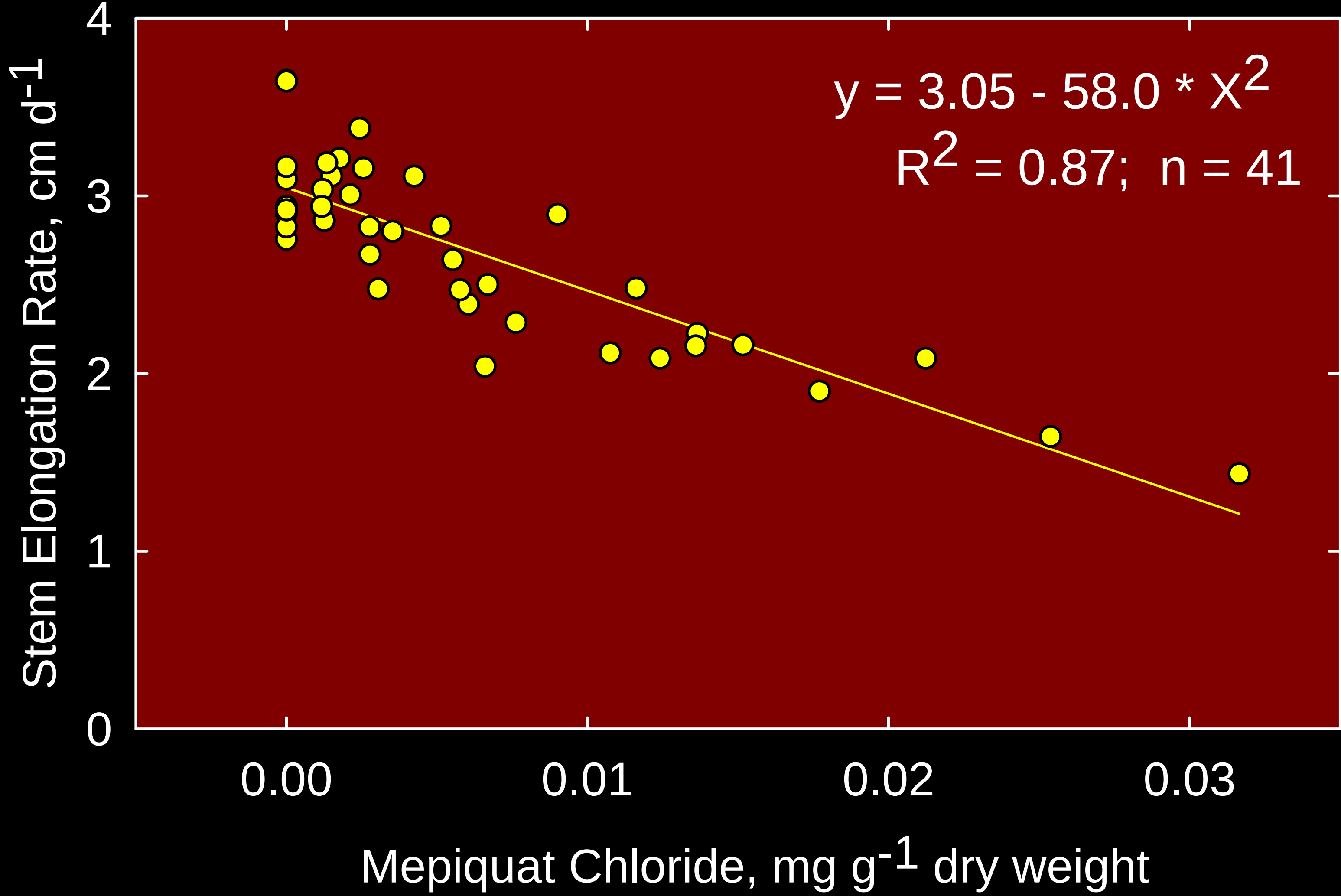


Quantifying the Effects of Environmental Factors on Crop Growth – Water Stress on Fruit Growth



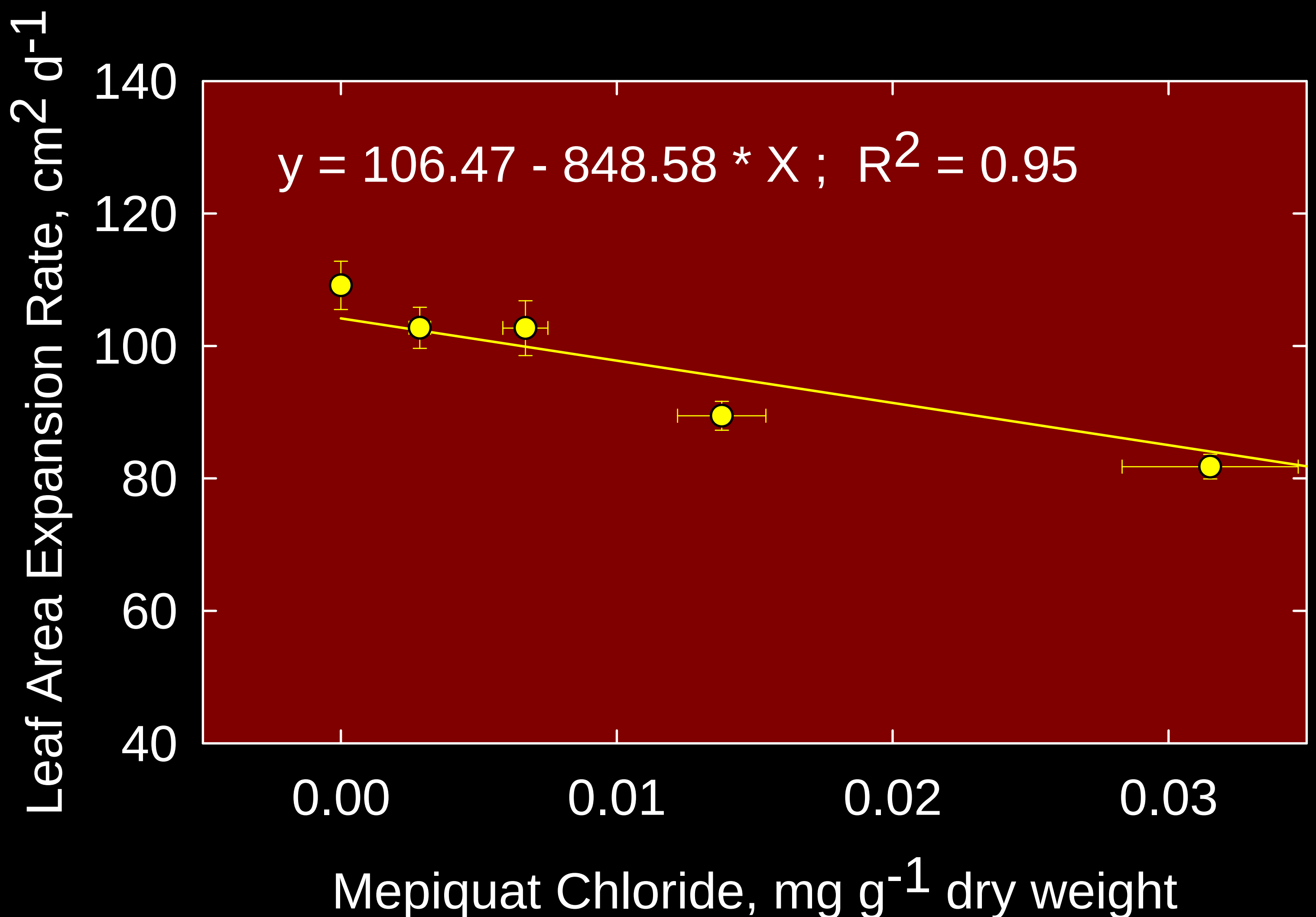
Mepiquat Chloride - Cotton Growth

Plant Height - Stem Extension Rate



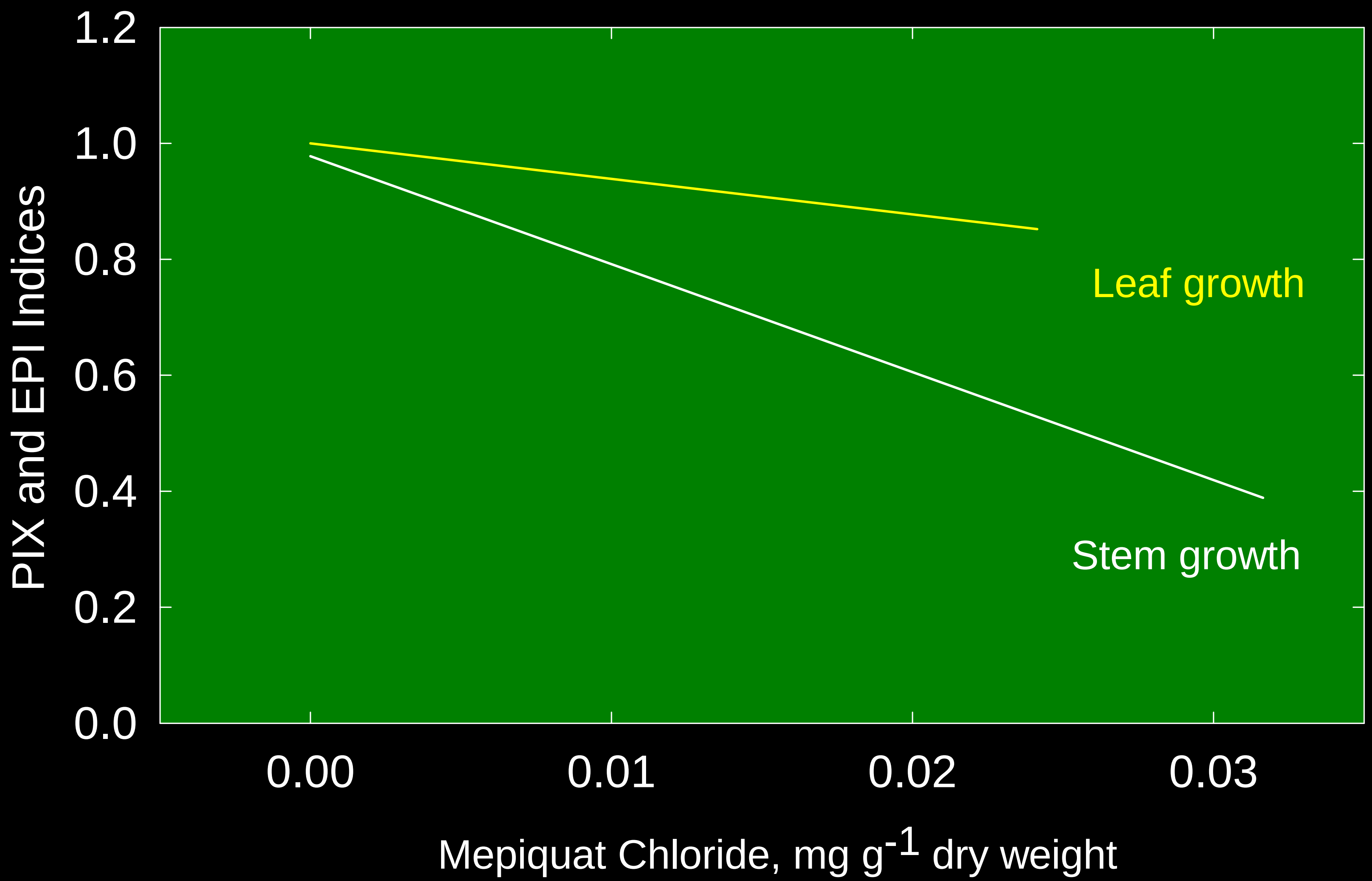
Mepiquat Chloride - Cotton Growth

Leaf Area Development



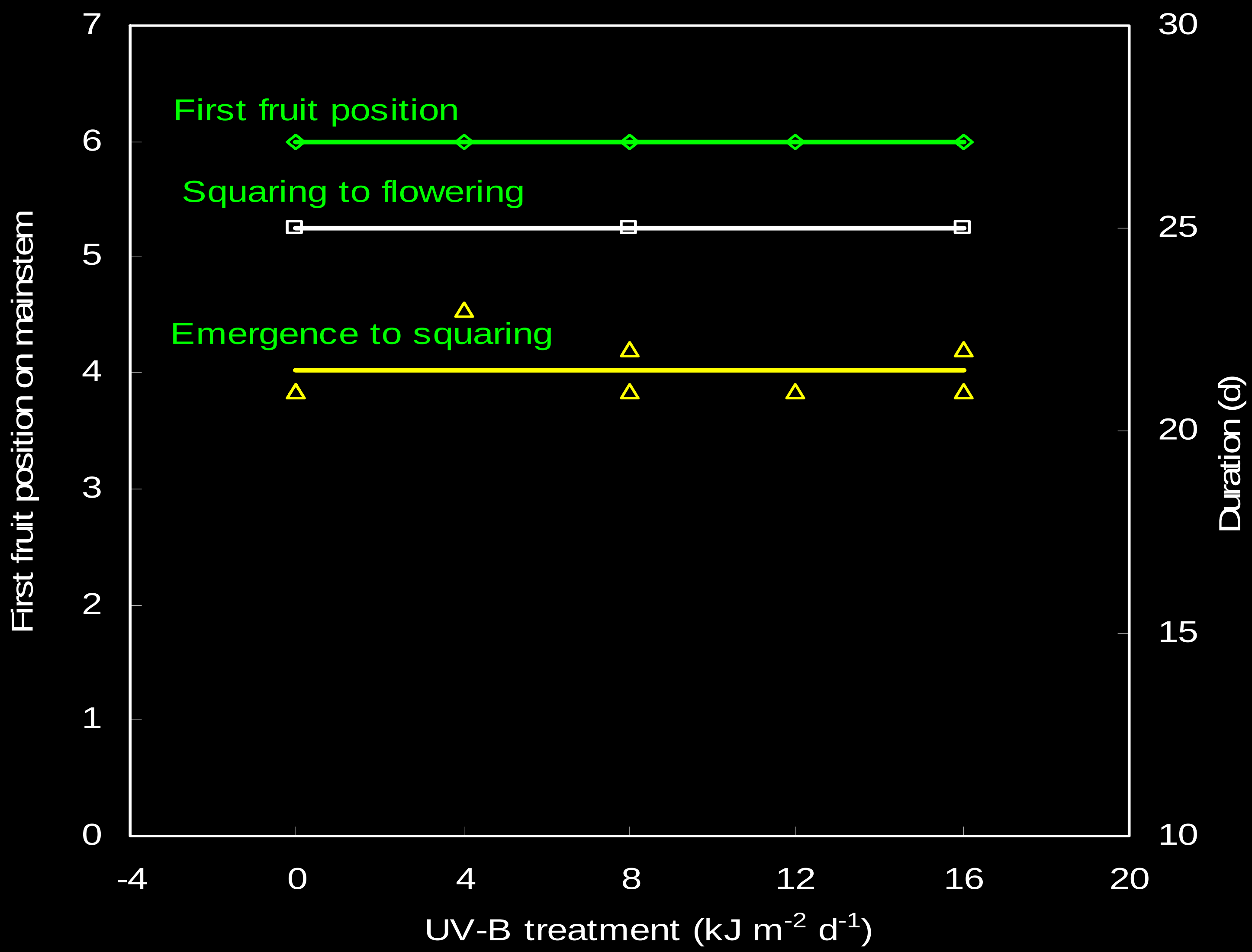
Mepiquat Chloride (PIX) - Growth

EPI Factors



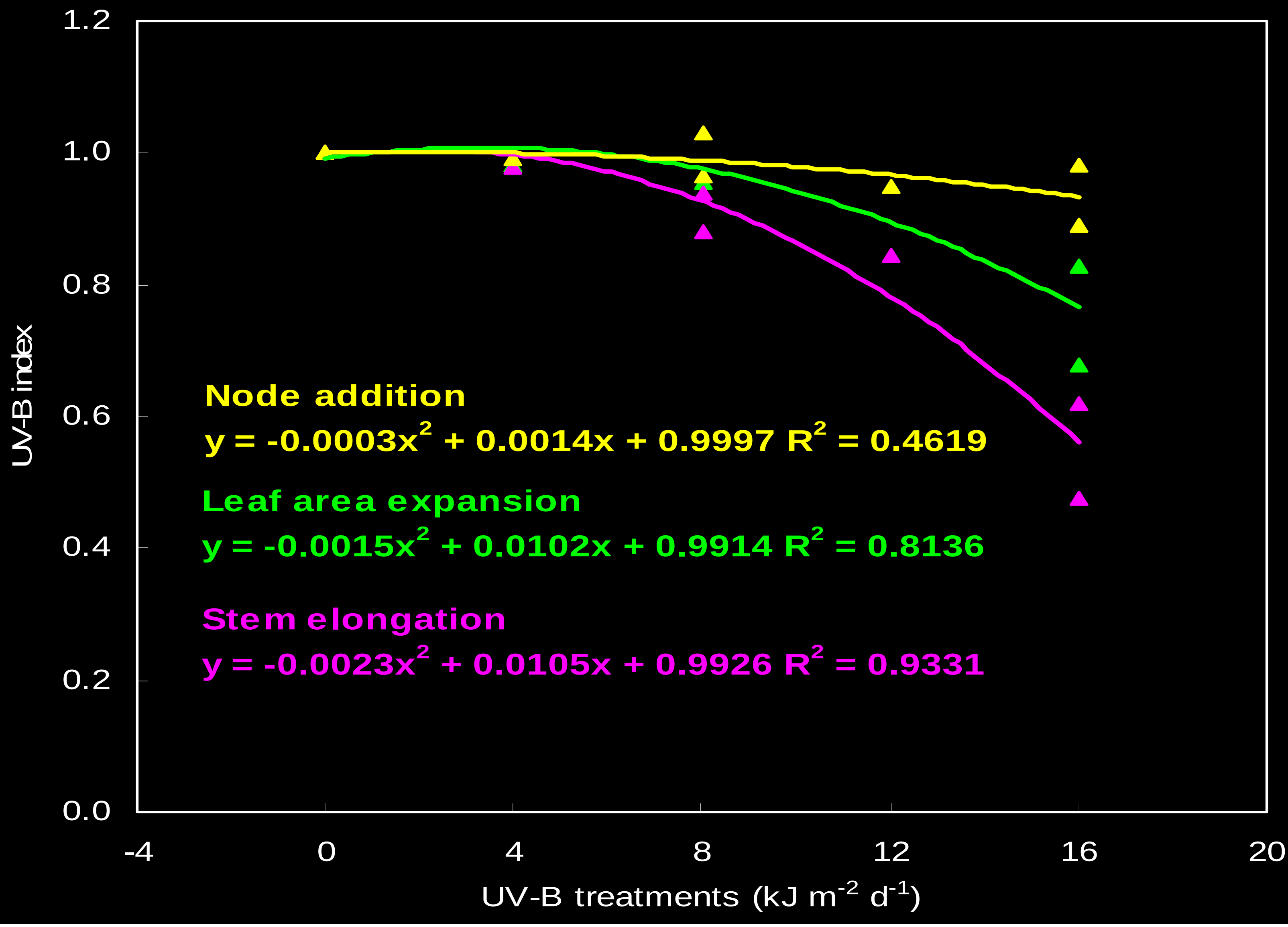
UV-B Radiation – Growth

EPI Factors for various growth Processes



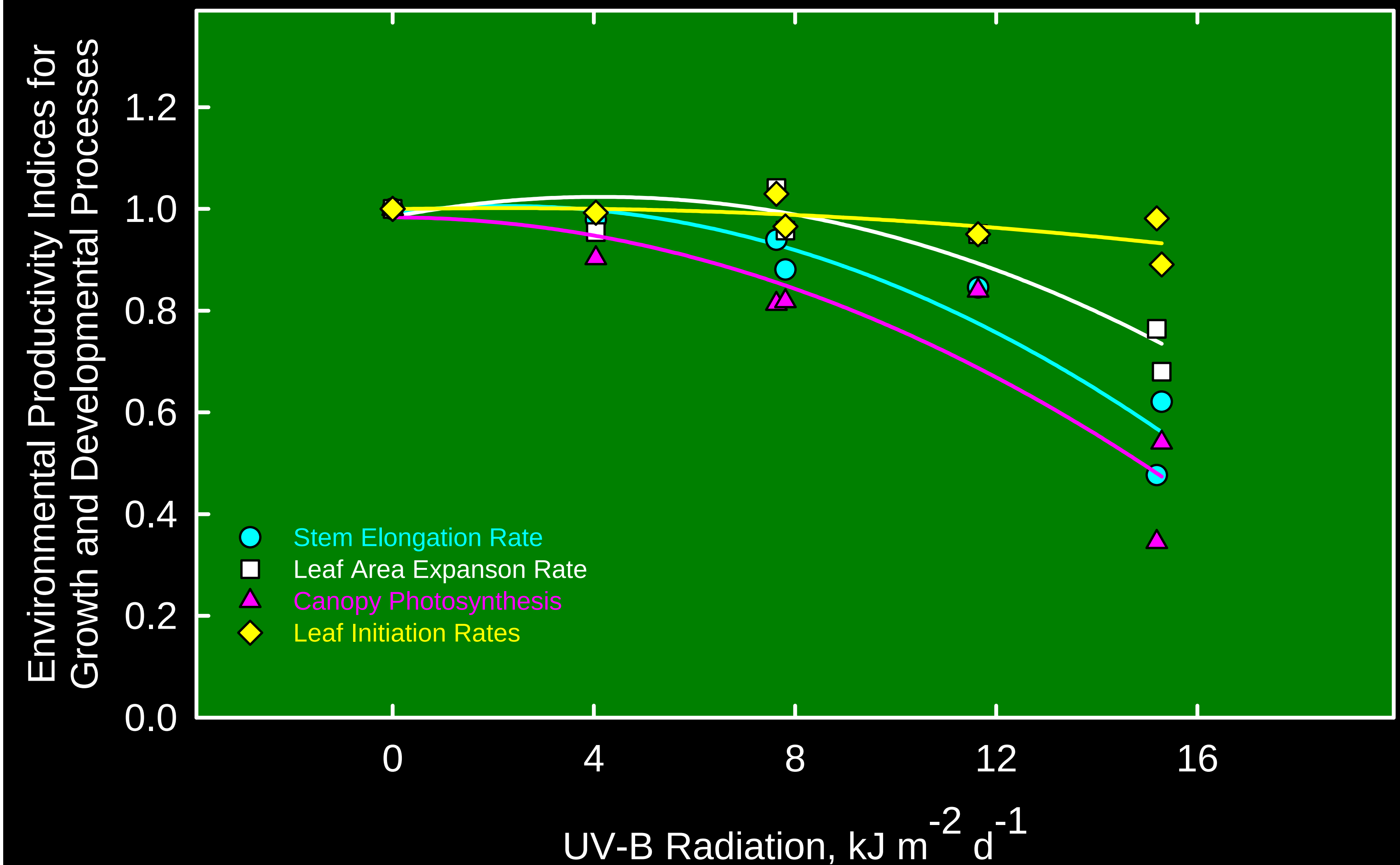
UV-B Radiation – Phenology

EPI Factors for various Developmental Processes



UV-B Radiation – Cotton Growth

EPI Factors for various growth Processes



Quantifying the Effects of Environmental Factors Crop Growth

For stem elongation and leaf area expansion:

1. First, we need calculate the potential as a function of temperature under optimum conditions.

2. Then, we need decrease that potential based on environmental factors using the EPI concept for growth.

Actual = Potential value (function of temperature) * EPI-Water * EPI-N * EPI-K * EPI-PIX * EPI UVB.

Quantifying the Effects of Environmental Factors on Crop Growth

For stem, leaf, square and boll weight (mass accretion):

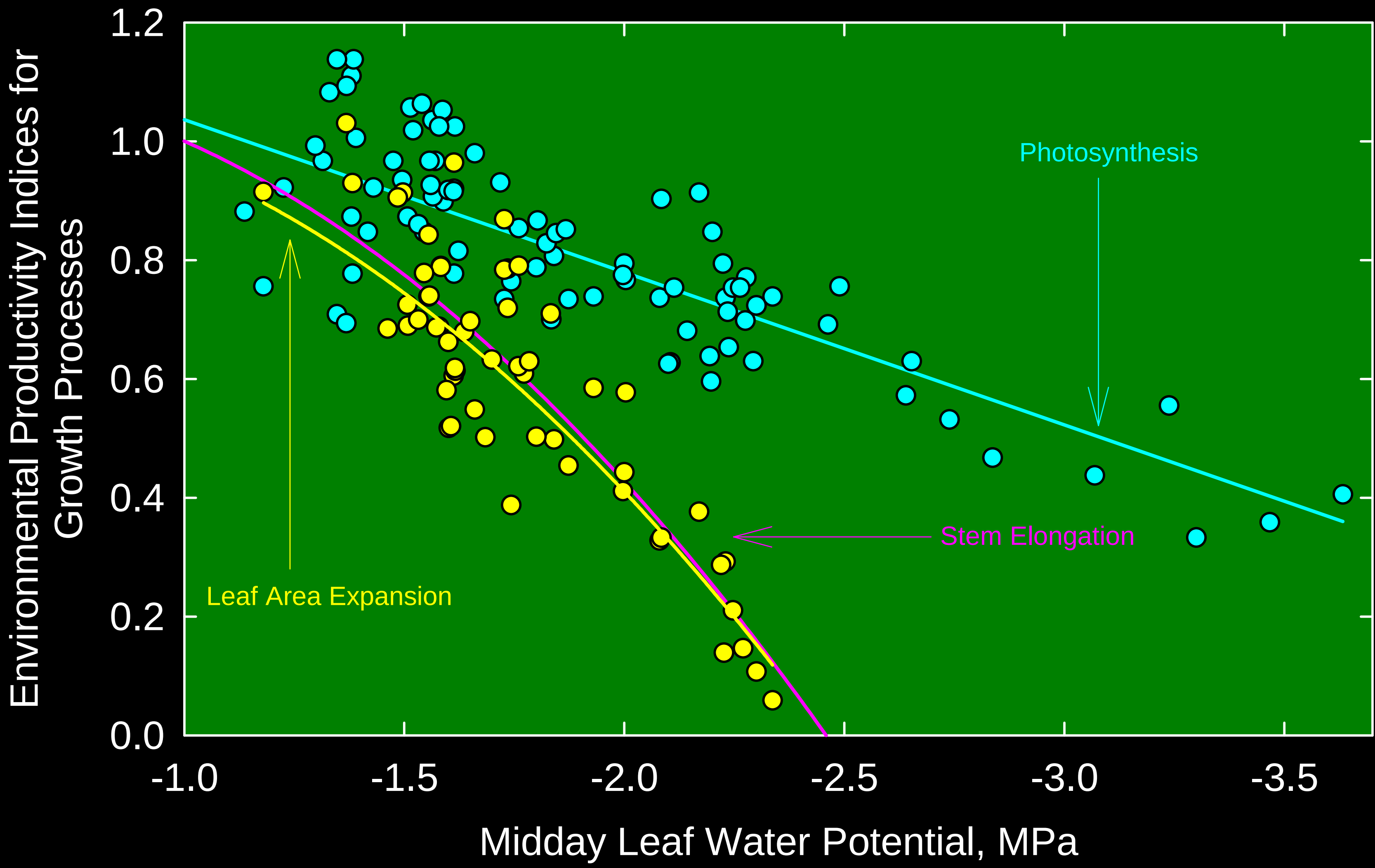
1. We calculate the potential as a function of temperature.

2. Then, decrease that potential based on stress factors only if the reduction is in addition to- or greater than the environmental factor on photosynthesis. Otherwise, we will be accounting the stress effects twice for the dry weight gain; once through a direct effect of environmental factor on photosynthesis and second time through EPI-growth.

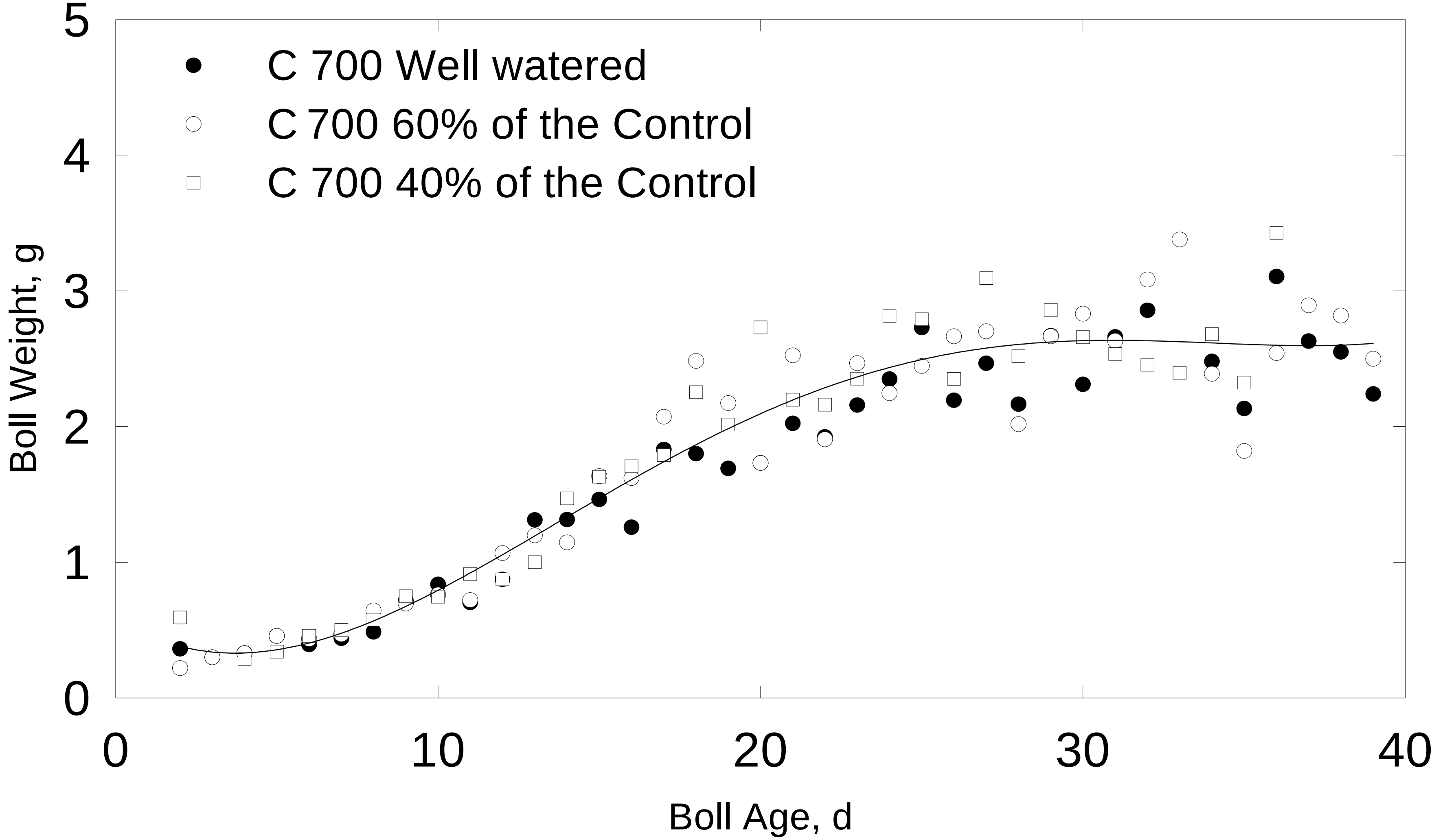
Actual = Potential value (function of temperature) * EPI-Water * EPI-N * EPI-K * EPI-PIX * EPI UV-B, only if they affect on top of environmental factor effects on photosynthesis.

Environmental Productivity Indices for Various Processes

Response to Water Deficits



Quantifying the Effects of Environmental Factors on Crop Growth – Water Stress on Fruit Growth



Quantifying the Effects of Environmental Factors Crop Growth

For modeling or quantification of stem extension or elongation:

We need:

1. Internode node length at node initiation.

2. The effect of environmental factors on those lengths.

3. The potential extension rate parameters (slope and intercept as a function of temperature)

4. The EPI-growth factors to decrease those potentials.

Quantifying the Effects of Environmental Factors Crop Growth

For modeling leaf area development:

We need:

1. Leaf areas at leaf unfolding

2. The effect of environmental factors on those areas

3. The potential expansion rate parameters (slope and intercept as a function of temperature)

4. The EPI-growth factors to decrease those potentials.

Quantifying the Effects of Environmental Factors Crop Growth

For modeling leaf and internode, square and boll growth rates (mass accretion):

We need:

The potential expansion rate parameters as a function of temperature.

Crop Growth and Development

Growth and Environment

- The growth (rates) organs or the plant as whole is in general very complex.

- Understanding the effects of environmental factors on crop growth, and quantifying their effects on these vital processes will provide meaningful insight on how a crop will grow in natural environment.

- Environmental productivity index concept is very effective and helpful in understanding and in quantifying the multiple stress factors on crop growth and in modeling.