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.
Plant Growth and Development

- Plant growth is *modular* in nature.
- Modular growth and development depends upon functional *meristems*.
- *Meristematic cells are totipotent*.
- Modules undergo primary and secondary growth.
- Modules respond to the environment in a *programmable manner*.
- Quantifying and understanding plant module responses to the environment is important to develop management tools.
Plant Growth and Development

Modular growth depends on functional meristems
Plant Growth and Development

- Crop phenology
- Crop growth
  - Shoot (leaves, stems and fruiting structures)
  - Roots
- Crop growth and development – Species variability
- High temperature injury
Environmental Productivity Indices for Crop Growth and Development

Crop Phenology
Cotton Developmental Aspects

Seed development:
- Emergence: 5 - 10 days
- Square development: 30 - 45 days
- Open boll development: 120 - 145 days
- Harvest: 140 - 180 days

GDD60s °F:
- GDD60 = 50
- Harvest: 2600

Developmental stages:
- Pin-head to match-head to candle to flower
- Day 1 to Day 3

Square development:
- Pollen & fertilization
- Flower

Boll development:
- Day 6 to Day 60
- Fiber, motes

Seed:
- GDD60s °F = 50
- Harvest: 2600
Environmental and Cultural Factors Influencing Crop Phenology

- **Atmospheric Carbon Dioxide** (indirect)
- **Solar Radiation** (indirect)
- **Photoperiod** (direct on flowering, no effect on day-neutral plants such as modern cotton cultivars)
- **Temperature** (direct)
- **Water** (indirect)
- **Wind** (indirect)
- **Nutrients (N, P and K)** (direct & indirect)
- **Growth Regulators (PIX)** (indirect)
Canopy Development Over the Growing Season

- Seed
- Germination
- Emergence
- Square
- Flower
- Open boll
- Mature Crop
Impact of Weather on Plant Growth - Mississippi State - 1992

Temporal Trends in Plant Height - Simulated and Observed
Impact of Weather on Plant Growth - Mississippi State - 1992

Temporal Trends in Mainstem Nodes - Simulated and Observed
Terminology and Definitions

Phenology:

- Phenology is the study of periodic biological phenomena.
- It refers to like events such as the time intervals between mainstem or branch leaves on a plant, time intervals between two successive flower buds or flowers on a branch, 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. It involves qualitative changes in form, structure and general state of the complexity of the plant. Phenostages or the developmental processes are irreversible.
Growth:

- Growth, on the other hand, is an irreversible increase in length, area, or weight of plants as a whole or individual organs that is quantitative.

- Distinction between phenology (development) and growth may be blur at some times.
Terminology and Definitions

Phenology:

Plastochnrons and phyllochrons:

The time interval between two successive leaf primordia formation at the tip of a growing meristematic region of stem or branch is defined as the plastochron. For this study, we need at least a light microscope and take anatomical sections of stems or branches to estimate the time intervals.

If the time interval refers to two successive leaf tip appearance or leaf unfolding, it is known as the phyllochron. If the leaf tip appearance or leaf unfolding is defined as a discrete size or event, then it can be examined visually without a microscope.

Also, phyllochron or leaf appearance rates are easy to verify in the field.
Crop phenology or development is driven by temperature and modulated by nutritional demand, particularly leaf development/supply.

Temperature and photoperiod are the two main environmental factors that determine flowering in young and established plants.

Winter annuals and biennials as well as the buds of some woody species (e.g. Peach) require a cold season in order to flower normally. In other words, they have a chilling requirement (temperatures below 3°C to 13°C, ideally 3 to 15°C for weeks). This process is called vernalization.

If this process is too short or interrupted by warming above 15°C, then the effect will be cancelled or extended.
Crop Phenology – Climate Change

- If the climate in the future is more variable, then we can expect seasonal fuzziness and variation in extreme conditions. And this phenomenon may pose a serious problem for certain crops, particularly for those crops that require vernalization.

- All crops have minimal, optimal and maximum temperature limits for each phenological event.

- These limits vary depending upon the phenological or developmental event, even within a crop or species.

- Floral initiation in commercially-grown cotton varieties, for example, is mostly governed by temperature, and is relatively insensitive to photoperiod.

- The major reproductive events (sowing to emergence, emergence to square initiation, square to flower and flower to open boll) are all directly governed by temperature to which they were exposed.
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
Quantifying the Effects of Environmental Factors on Crop Growth

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

\[
\text{EPI-phenology} = \text{Temperature (potential)} \times \text{Nutrient Index (C, N, P, K)} \times \text{Water index} \times \text{PPF Index} \times \text{PGR Index etc.,}
\]

First, we have to define the potential phenology for given species or cultivar. Potential phenology is defined as the rate of development that takes place at a range of temperatures under optimum environmental conditions (optimum water and nutrient conditions).
Then, we have to account for all the environmental factors limiting to obtain that potential.

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

All the indices, range from 0 when it is totally limiting phenology and 1 when it does not limit phenology, represent the fractional limitation due to that particular factor. Therefore, phenological rates will be slower as the effect of that particular stress becomes more severe.
Quantifying the Effects of Environmental Factors Crop Phenology

This way allows one to quantify the effect of environmental factors limiting crop development or phenology in a multi-stress environment or in field conditions.
It is difficult to build process-level or application-oriented crop models from data collected from the field because many factors often simultaneously affect rates of crop development and growth processes, and because many environmental and biological factors are covariants.

This makes it literally impossible to reasonably assess the causes and effects with accuracy. Instead, it is most appropriate to develop relationships or models with data from controlled-environments and validate such relationships or models with data from the field.

Again, the environmental variables in the controlled-environments, including radiation should be close to the radiation received in the field conditions, and must be not-limiting or well-defined and controlled for the given variable under consideration.
Time from seed to germination defined as radicle of half the length of the seed and time from germination to emergence of the seedling above the ground are defined as a discrete events.

Time from emergence to square of 3-mm size is defined as a discrete event known as squaring in cotton.

The day of flower is a discrete event again. Cotton flowers are yellow or creamy – white on the first day, and then turn pink the next day.

The day of boll-opening again is a discrete event. The day when one can see the lint through the sutures of carpel wall or burr in cotton is defined as open boll.
Temperature - Maximum Seed Germination

\[ y = -125 + 15.391X - 0.2862X^2; \quad r^2 = 0.79 \]
Temperature – Rate of Seed Germination and Emergence

Germination
Emergence

$y = -0.9228 + 0.0931X - 0.001528X^2; r^2 = 0.92$

$y = -0.3158 + 0.0319X - 0.0005228X^2; r^2 = 0.92$
Schematic Representation of Cotton Plant Development
Temperature - Phenology
Emergence to Squaring - Species Variation

Temperature, °C

Developmental Rate, 1/d⁻¹

- Upland
- Pima

Temperature, °C
Temperature - Phenology

Square to Flower, Flower to Open Boll

Developmental Rate, 1/d⁻¹

Temperature, °C

Square to Flower

Flower to Open Boll
Temperature - Major Phenostages of Cotton

Temperature, °C

Days between Events

Emergence to Square
Square to Flower
Flower to Open boll
Parameters for quadratic equations regressing daily developmental rates of major cotton phenological events \((y)\) as functions of average temperature \((x)\), and correlation coefficients \((r^2)\).

\((y = a + bx \text{ or } y = a + bx + cx^2)\)

<table>
<thead>
<tr>
<th>Event</th>
<th>Regression parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>Seed to germination</td>
<td>-0.9228</td>
</tr>
<tr>
<td>Seed to emergence</td>
<td>-0.3158</td>
</tr>
<tr>
<td>Emergence to square</td>
<td>-0.1265</td>
</tr>
<tr>
<td>Square to flower</td>
<td>-0.1148</td>
</tr>
<tr>
<td>Flower to open boll</td>
<td>-0.00583</td>
</tr>
</tbody>
</table>

An example of how to calculate time to 1st square formation in cotton from a changing average temperature is shown. The daily development (Y) for cotton plants to reach 1st square from emergence can be calculated as a function of temperature (X) as follows: Daily developmental rate.

\[ Y = -0.1265 + 0.01142 \times X - 0.0001949 \times X^2, \quad r^2 = 0.95. \]

<table>
<thead>
<tr>
<th>Days Since emergence</th>
<th>Average Temperature, °C</th>
<th>Days to 1st square at that temp.</th>
<th>Daily developmental rate</th>
<th>Cumulative value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>32.89</td>
<td>0.030408</td>
<td>0.030408</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>62.85</td>
<td>0.015912</td>
<td>0.046320</td>
</tr>
<tr>
<td>3</td>
<td>Below the threshold</td>
<td>No development</td>
<td>0.046320</td>
<td>0.046320</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>41.77</td>
<td>0.02394</td>
<td>0.070260</td>
</tr>
<tr>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td>1.0 or &gt;1.0</td>
</tr>
</tbody>
</table>
EPI – Phenology: 
• Using the functions described earlier, the simulated dates of major phenological events for cotton for 30 years.
• Notice year-to-year variability in days for major phenological events caused by variation in temperature conditions during those stages of crop development.
Applying Environmental Productivity Index to Crop Phenology

Observed vs. Simulated – Major Phenological Events

Observed number of days to the event

Simulated number of days to the event

Emergence to 1st square

Emergence to 1st flower

Emergence to 1st open boll

slope = 1.001; $r^2 = 0.95$
Heat units, expressed in growing degree-days (GDD), are frequently used to describe the timing of biological processes.

The basic equation used is:

\[
GDD = [(T_{\text{max}} + T_{\text{min}})/2 - T_{\text{base}}]
\]

Where \( T_{\text{max}} \) and \( T_{\text{min}} \) are daily maximum and minimum air temperatures, respectively, and \( T_{\text{base}} \) is the base temperature for a given developmental event or process of a crop where the development is zero.
• Two methods or interpretations have been reported in the literature.

Method 1:

\[ \text{GDD} = \frac{(\text{maxT} + \text{minT})}{2} - \text{Tbase} \]

If \( \frac{(\text{maxT} + \text{minT})}{2} < \text{Tbase} \), then \( \frac{(\text{maxT} + \text{minT})}{2} = \text{Tbase} \)

This approach seems to be the most widespread method used for calculating GDD in small grain crops such as wheat, barley and several other crops.

Notice that the comparison to Tbase occurs after calculating avgT.
Method 2:

\[ GDD = \left( \frac{\text{max}T + \text{min}T}{2} - \text{Tbase} \right) \]

where if maxT < Tbase, then maxT = Tbase,

and if minT < Tbase, then minT = Tbase.

Some times a variation of method 2 is also used:

\[ GDD = \left( \frac{\text{max}T + \text{min}T}{2} - \text{Tbase} \right), \text{ where if } \text{min}T < \text{Tbase}, \text{ then } \text{min}T = \text{Tbase}. \]

Notice that the comparison to Tbase is made before calculating avgT by comparing maxT and minT or minT to Tbase individually.

This approach has also been used to calculate GDD in crops such as corn as well as in other crops.
Temperature – Phenology – Growing Degree-day Concept

- Not recognizing the discrepancy between methods can result in confusion and add error in quantifying relationships between heat unit accumulation and timing of biological events in crop development.

- Therefore, when describing and presenting the data on GDD’s, description of method used and the base temperature are very important so that others can correctly interpret and apply reported results in their situation.

## Temperature – Phenology

Can We Apply Growing Degree Days (GDD) Concept to Upland Cotton at a Range of Temperatures?

<table>
<thead>
<tr>
<th>Event</th>
<th>GDD from a 12 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence to square</td>
<td>380</td>
</tr>
<tr>
<td>Square to Flower</td>
<td>392</td>
</tr>
<tr>
<td>Flower to open boll</td>
<td>730</td>
</tr>
<tr>
<td>Open boll to crop maturity</td>
<td>392</td>
</tr>
<tr>
<td>Emergence to crop Maturity</td>
<td>1894</td>
</tr>
</tbody>
</table>
Temperature - Phenology
Emergence to Squaring - Species Variation

Temperature, °C

Developmental Rate, 1/d-1

- Upland
- Pima

Temperature, °C
Temperature - Phenology

Square to Flower, Flower to Open Boll
Crop Phenology
Phyllochron intervals – Mainstem and branches

Developing mainstem and fruiting branch nodes and leaves are important aspects of overall crop development because these developmental aspects determine the number of leaves produced, and thus canopy development and light interception, particularly prior to canopy closure.

In cotton, phyllochron is defined as the day when 3 main veins appear clearly on an unfolding leaf. Defined in this way, leaf appearance or phyllochron can be used as discrete event.
Cotton Developmental Aspects
Crop Phenology – Pre-squaring, Flowering and Post-Flowering Leaf Developmental Rates: Cotton

Days leaf per leaf

Mainstem Node Number

- 700 µl l⁻¹ CO₂
- 450 µl l⁻¹ CO₂
- 350 µl l⁻¹ CO₂

26.4°C
Crop Growth and Development - Environment
Response to Temperature

4-week old cotton seedlings
<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Developmental Rate, 1/d⁻¹</th>
<th>Mainstem</th>
<th>Fruiting Branches</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.033, 30.3, 0.0271, 36.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.1916, 5.0, 0.1057, 9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0.3324, 3.0, 0.1584, 6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.4314, 2.3, 0.1852, 5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>0.4965, 2.0, 0.1860, 5.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Parameters for quadratic equations regressing daily leaf developmental rates of mainstem or branches (y) for cotton as functions of average temperature (x), and correlation coefficients ($r^2$).

$\quad (y = a + bx + cx^2)$

<table>
<thead>
<tr>
<th>Event</th>
<th>Regression parameters</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>$r^2$</td>
<td></td>
</tr>
<tr>
<td>Mainstem leaves</td>
<td>-0.6698</td>
<td>0.05700</td>
<td>-0.0006765</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>Branch leaves</td>
<td>-0.3645</td>
<td>0.03389</td>
<td>-0.00051890</td>
<td>0.84</td>
<td></td>
</tr>
</tbody>
</table>
Applying Environmental Productivity Index to Crop Phenology

Observed vs. Simulated – Mainstem Nodes

Profiles = 14, Slope = 0.98
Temperature - Phenology

Leaf and Internode Expansion Duration Rates

Temperature, °C

Developmental Rate, 1/d⁻¹

Temperature, °C

Developmental Rate, 1/d⁻¹
Parameters for quadratic equations regressing daily leaf area expansion or internode elongation duration rates ($y$) for cotton as function of average temperature ($x$), and correlation coefficients ($r^2$).

$$ (y = a + bx + cx^2) $$

<table>
<thead>
<tr>
<th>Event</th>
<th>Regression parameters</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>r$^2$</td>
<td></td>
</tr>
<tr>
<td>Leaves</td>
<td>-0.09365</td>
<td>0.01070</td>
<td>-0.0001697</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>Internodes</td>
<td>-0.04312</td>
<td>0.007383</td>
<td>-0.0001046</td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>
# Cotton Phenology – Potential Rates

\[ Y = a + bx \text{ or } a + bx + cx^2 \]

<table>
<thead>
<tr>
<th>Major life cycle events:</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence to square</td>
<td>-0.1265</td>
<td>0.01142</td>
<td>-0.0001949</td>
<td>0.98</td>
</tr>
<tr>
<td>Square to flower</td>
<td>-0.1148</td>
<td>0.00967</td>
<td>-0.0001432</td>
<td>0.94</td>
</tr>
<tr>
<td>Flower to open boll</td>
<td>-0.00583</td>
<td>0.000995</td>
<td>--</td>
<td>0.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leaf addition rates:</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainstem Leaves</td>
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<td>0.84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leaf and internode expansion duration rates:</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>r²</th>
</tr>
</thead>
<tbody>
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<td>0.007383</td>
<td>-0.0001046</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Nitrogen - Phenology
Phyllochron Rates - Mainstem

Leaf Nitrogen, g m\(^{-2}\)

Developmental Rate, 1/d\(^{-1}\)

700 µl l\(^{-1}\) CO\(_2\)
350 µl l\(^{-1}\) CO\(_2\)
Modeling the Effects of Nitrogen on Cotton Growth and Development

Environmental Productivity Indices

Leaf Nitrogen, g m\(^{-2}\) leaf area

Leaf Growth
Leaf Development
Stem Growth
Photosynthesis

Environmental Productivity Indices for Nitrogen

Leaf Nitrogen, g m\(^{-2}\) leaf area
Potassium – Cotton Growth

Visual Symptoms

>3.05

1.15

0.94

0.39

0.30
Potassium and Phenology

Leaf unfolding rates

Leaf Potassium, %

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5

Leaf Unfolding rate per day

0.0 0.2 0.4 0.6 0.8

360 µL L⁻¹

720 µL L⁻¹

Leaf Unfolding rate per day

Leaf Potassium, %

Potassium and Phenology

Leaf unfolding rates

Leaf Potassium, %

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5

Leaf Unfolding rate per day

0.0 0.2 0.4 0.6 0.8

360 µL L⁻¹

720 µL L⁻¹
Potassium - Cotton Growth and Development

Environmental Productivity Indices

Leaf Potassium, %

Leaf Growth

Stem Elongation

Photosynthesis

Leaf Initiation Rates

Leaf Growth

Environmental Productivity Indices for Growth and Development

Leaf Potassium, %
Phenology – UV-B Radiation - Cotton

1st fruiting node, squaring, and flowering intervals

Emergence to squaring

First fruit position

Squaring to flowering

First fruit position on mainstem

Duration (d)

UV-B treatment (kJ m\(^{-2}\) d\(^{-1}\))
UV-B Radiation – Phenology
EPI Factors for various Developmental Processes

Node addition
\[ y = -0.0003x^2 + 0.0014x + 0.9997 \quad R^2 = 0.4619 \]

Leaf area expansion
\[ y = -0.0015x^2 + 0.0102x + 0.9914 \quad R^2 = 0.8136 \]

Stem elongation
\[ y = -0.0023x^2 + 0.0105x + 0.9926 \quad R^2 = 0.9331 \]
Water Stress – Phenology
Canopy and air temperature differential

![Graph showing the relationship between leaf water potential and canopy-air temperature differential.](image-url)
Environmental and Cultural Factors Influencing Crop Growth

- Atmospheric Carbon Dioxide (indirect)
- Solar Radiation (indirect)
- Photoperiod (direct effect on photoperiod-sensitive plants - flowering)
- Temperature (direct)
- Water (indirect)
- Wind (indirect)
- Nutrients (N, P and K) (direct & indirect)
- Growth Regulators (PIX) (indirect)
Carbohydrate Stress

Light Interception
Turgor
Solar Radiation
Leaf Minerals

Photosynthesis

C Supply

C Stress

Temperature
Age
Turgor

Growth Potential of
Roots, Stems, Leaves
Squares and Bolls

C Demand
Nitrogen Stress

Root Density
Temperature
Soil N and Water

N Uptake
Plus Plant N Reserves

N Supply

Temperature
Age
Turgor

Growth Potential of Roots, Stems, Leaves Squares and Bolls

N Demand

N Stress

N Supply

N Stress
Nutritional Stress

- Nitrogen Stress
- Carbohydrate Stress
- Delay Morphogenesis
- Determine Actual Organ Growth
- Fruit and Leaf Abscission
Phenology and Developmental Rates
Dealing with cultivar variability

![Graph showing the relationship between temperature and developmental rates, with curves for Early - Faster, Original, and Late - slower]

- Temperature, °C
- Rate of Development, 1/d⁻¹
- Emergence to Square
Temperature and Phenology
Emergence to Square - Species and Varietal Variability

Temperature, °C

Emergence to square, d

- Upland, c.v. DPL 50
- Upland, c.v. DES 119; DPL 5415
- Pima, c.v. S-6
Crop Phenology – Summary

✓ Phenology refers to the development, differentiation, and initiation of organs. It involves both like (adding leaves on mainstem and branches) and unlike events such as seed to germination, germination to emergence, emergence to square, square to flower, flower to open boll, and open boll to crop maturity) events.

✓ Phenological events respond to the environment in a programmable manner, and therefore the events are predictable – can be modeled.

✓ Phenology involves qualitative changes in form, structure, and general state of complexity of the plant.

✓ Major phenological events such as emergence to square, square to flower and flower to open boll are all temperature dependent and are not typically affected by other environmental factors in photoperiod insensitive crop such as modern cultivated cotton cultivars grown in the US.
Therefore, we can estimate these events more accurately by temperature alone. However, any factor that affects canopy temperature such as water stress can modify these events or response functions.

Seed germination and emergence will not only depend on temperature, but also on other factors such as soil moisture, seed placement (depth) etc.

Also, photoperiod in day-length sensitive plants such as soybean can affect flowering, but not the other events.

Phyllochron or leaf addition rates on the mainstem and branches are primarily governed by temperature, but modulated by other factors such as UV-B, water stress, nutrient stresses through their effects on photosynthesis (Supply) and growth conditions such as weight and sizes of various organs (that determine demand).
Therefore, we can estimate the potential as a function of temperature under optimum growing conditions, and then modify that potential based on EPI factors or demand/supply concept.

Again, leaf addition rates go hand-in-hand with internode addition rates on mainstem and branches.

Leaf and square addition rates on fruiting branches go hand-in-hand so that we can use one function to predict those events.

Once the leaves and internodes are initiated, then their duration of expansion are more or less dictated temperature independent of position the plant.

Similarly, once the squares are formed, then their duration of growth are dependent on temperature conditions.
Accurate prediction of crop developmental events will assist farm managers in adjusting sowings of the crop so that the most critical stages of crop growth occur during periods of favorable weather.

Also, accurate prediction crop growth stages is also needed for several other management decisions such as scheduling water, nutrient, pesticide, growth regulator, crop termination chemical applications, etc.

Crop simulation models need accurate functional algorithms so that the models can be used for several different area:
- Crop growth stage forecasts
- Management and policy decisions
- Natural resource management decisions
- Climate change forecasts, etc.
Crop Phenology – Suggested Reading


