Light Interception and Plant Growth

Physiological Determinants of Crop Growth

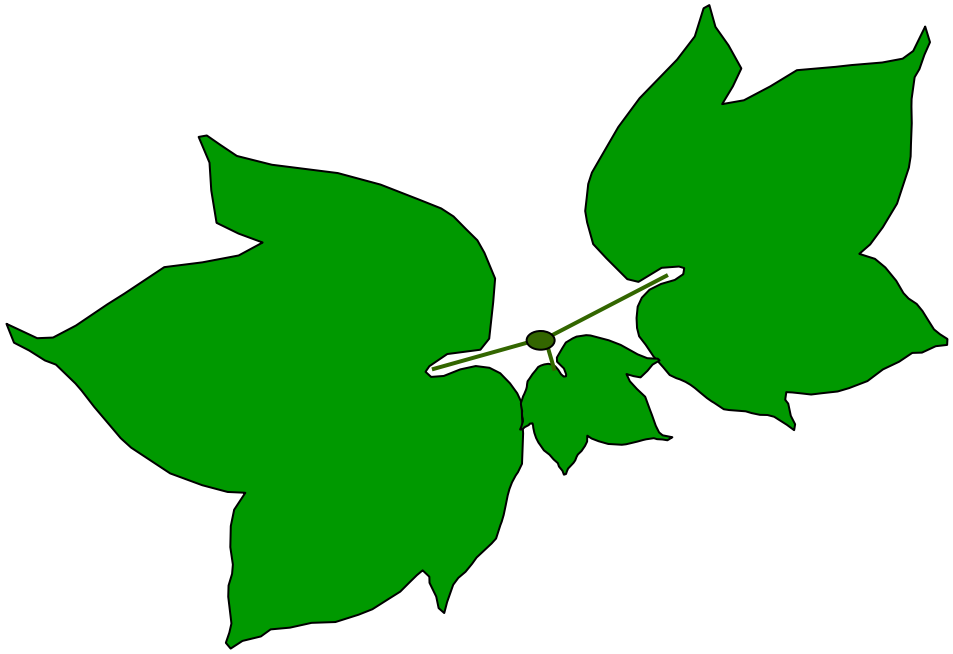
- D.A. Charles-Edwards (Academic Press, 1982)
  - "The acquisition of knowledge of the potential yield of a crop…are objectives of almost all agricultural research."
  - "Mathematical models allow us to formalize hypotheses…about environmental effectors of crop performance."
  - In order to understand plant/environment interactions, we must have a basis or framework for evaluating our influence on crops.

Physiological Determinants of Crop Growth

- Determinants of Growth
  - Determinants are elements that identify or define something.
    - Light Interception
    - Light Use Efficiency
    - Dry Matter Production & Loss
    - Duration of Growth
    - Dry Matter Partitioning

Single Plant Light Interception

- Single layer of leaves - 0° Sun Angle

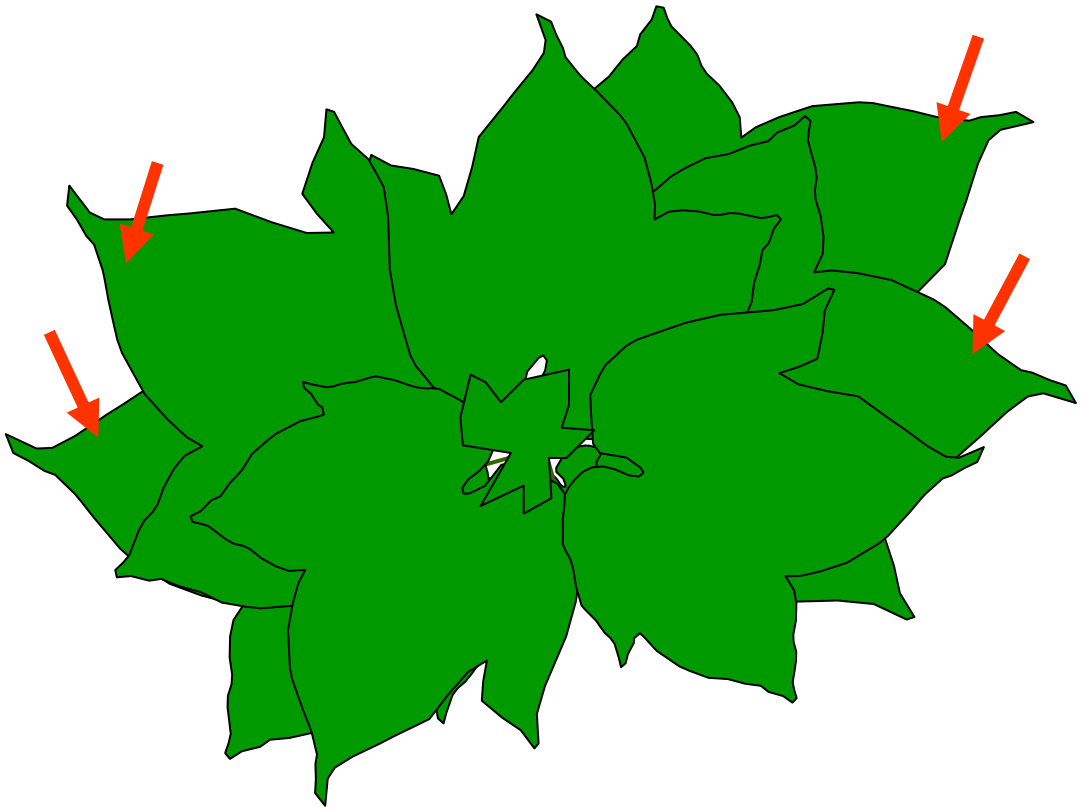


With no overlapping leaves, light interception by a plant in a day (LI) is a function of plant's leaf area (LA) and the daily light intensity (S) as follows:

$$LI = LA \times S$$

Layers and Light Interception

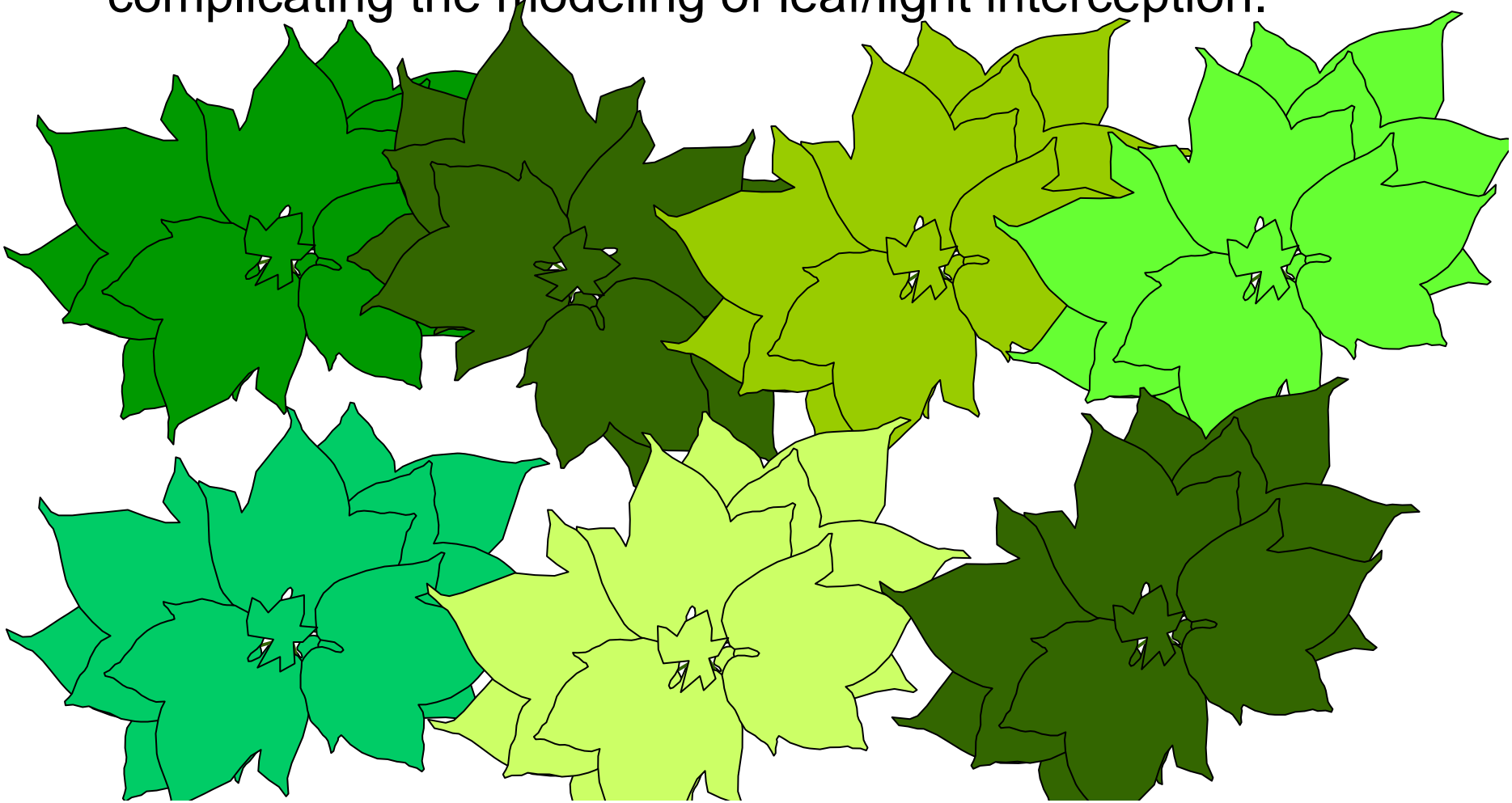
- As layers of leaves are added, shading occurs within the canopy. At this point, light interception becomes more complicated.



Still just one plant with sun straight overhead

Light interception in a community

- Now we have interplant and intraplant shading as well as gaps where sunlight penetrates the canopy further complicating the modeling of leaf/light interception.



Leaf Area in a community

- Since leaf area distribution is complicated, from a crop ecology point of view, the term Leaf Area Index (LAI) is used.

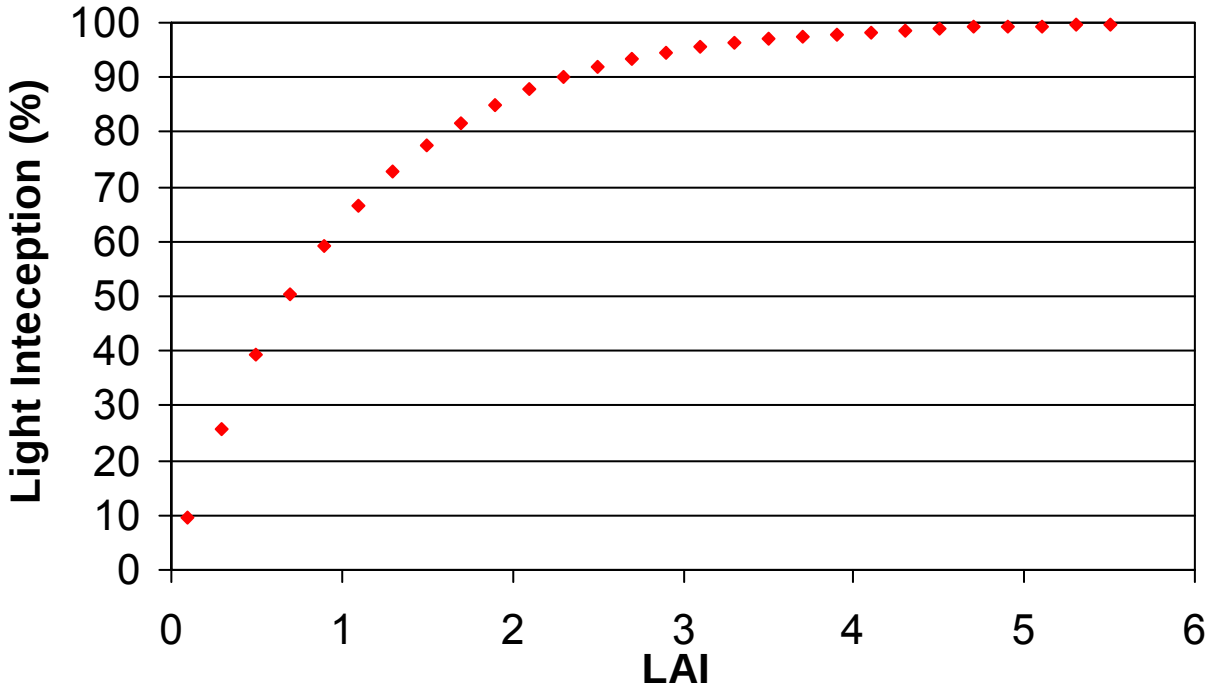
$$LAI = \frac{\text{Leaf area } (m^2 \text{ or } cm^2)}{\text{Land area it was measured above } (m^2 \text{ or } cm^2)}$$

Example: What is the LAI when 4500 cm² of leaf area was measured from 6 plants cut from 1 meter of row from soybeans grown in 0.5 m rows.

$$\frac{4500\ cm^2}{1\ m \times 0.5\ m} \times \frac{1\ m^2}{10000\ cm^2} = 0.9$$

LAI and Light Interception

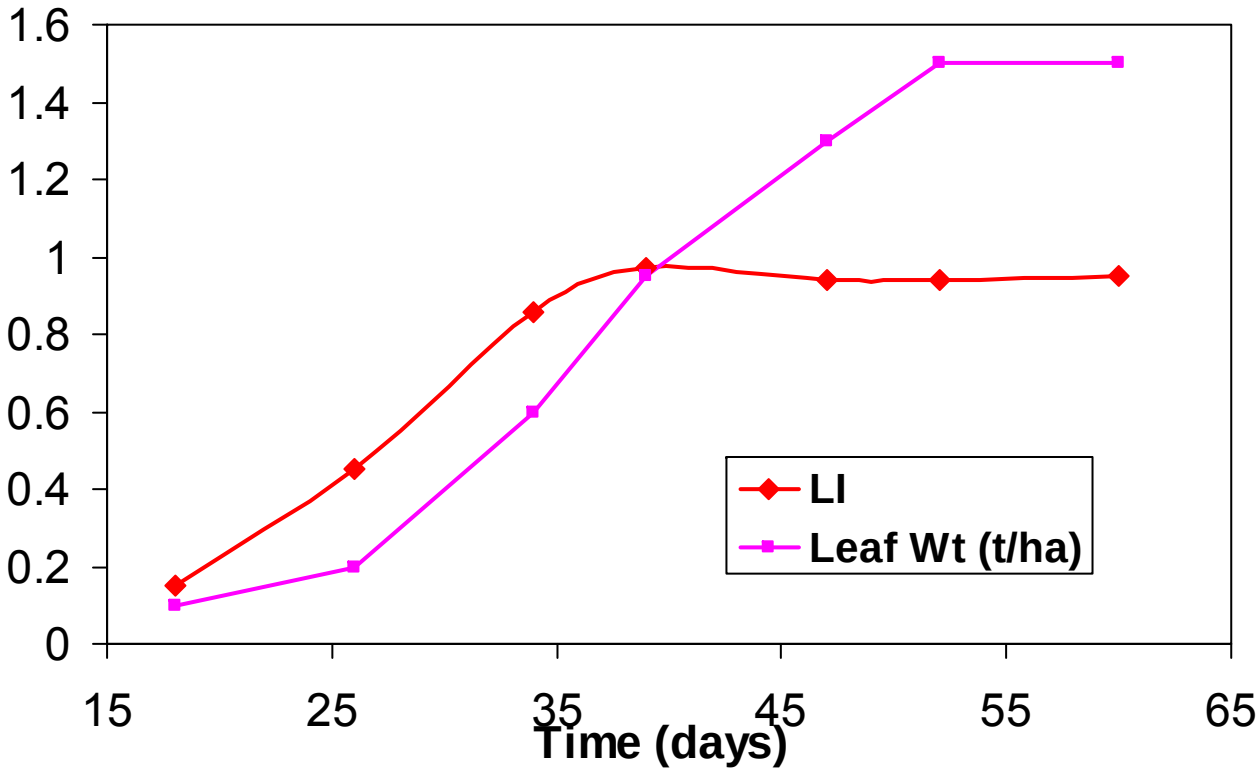
- What is the relationship between LAI and light interception (%)?
  - Linear, quadratic, or a plateau?



Critical LAI?

LI and Growth

- How are LI and leaf growth and development related?



Light Use Efficiency

- Crop growth rates are a function of:
  - Photosynthetic rates (μg C/unit leaf area)
  - Respiration losses by existing tissue (μg C/g DM)
  - Leaf area intercepting light
- As a result, net canopy photosynthesis (LUE) can be written as:

$$\mathrm{LUE} = \mathrm{PS} - R$$

PS = Photosynthesis
R = Respiration

Light Use Efficiency Constants

Crop	ε
	(g dry matter MJ^{-1})
Rice	4.2
Corn	3.4
Sunflower	2.6
Cotton	2.5
Clover	1.6
Soybean	1.3

Reason for species differences?

Dry Matter Production

- Daily accumulated light interception and the light use efficiency constant can be used to calculate daily dry matter production

$$\text{Dry Matter Increase} = \text{LUE} \times \text{LI}$$

DM = daily dry matter production (g/m^2)
LUE= Light use efficiency constant (g/MJ)
LI = Light energy intercepted by the crop (MJ/m^2)

Seasonal Matter Production

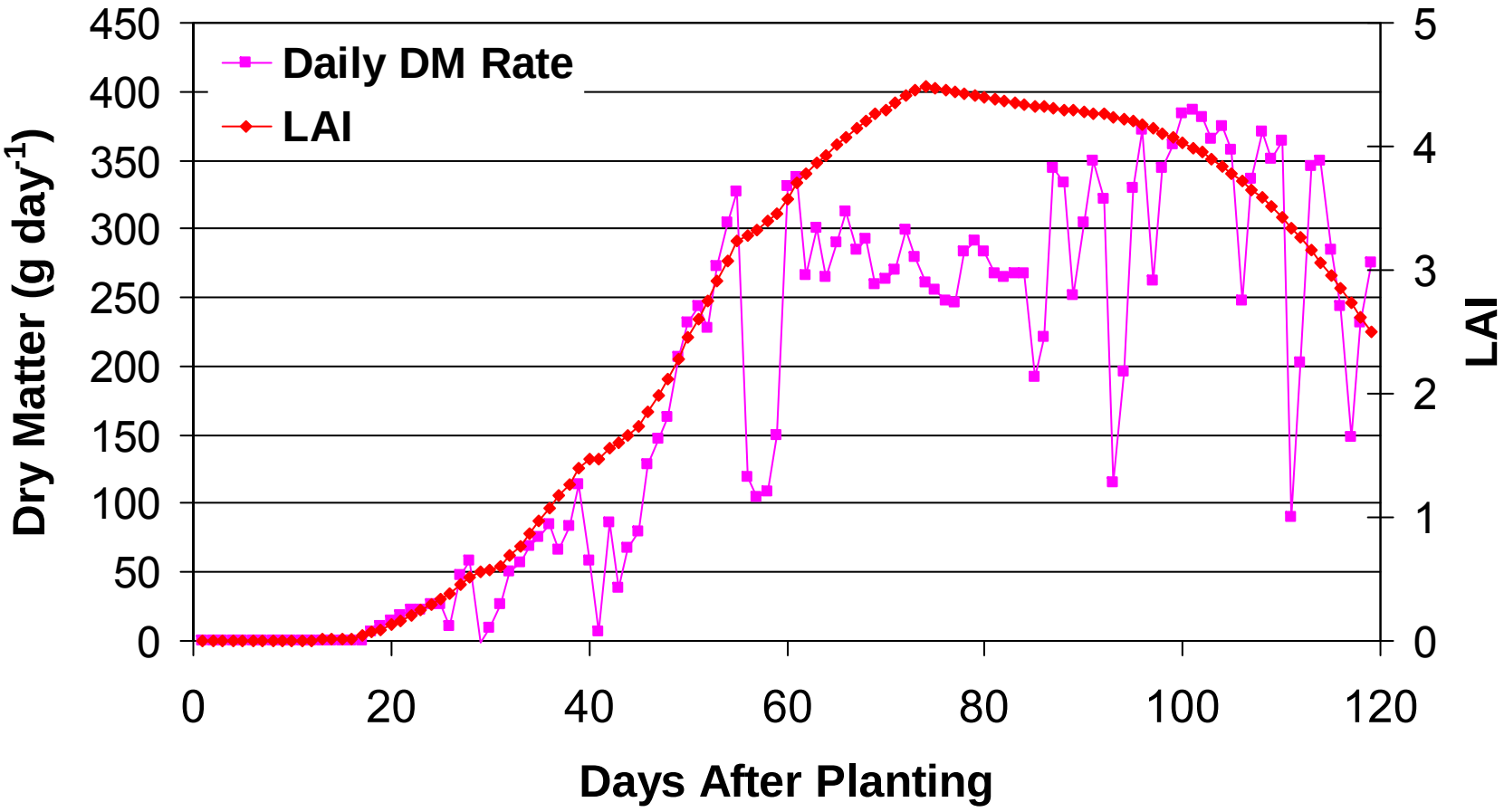
- For seasonal dry matter production, we simply sum the daily dry matter production amounts.

$$\sum_{n}^{1} \mathrm{DM} = \mathrm{LUE} \times \mathrm{LI}$$

DM = daily dry matter production (g/m^2)
LUE = Light use efficiency constant (g/MJ)
LI= Light energy intercepted by the crop (MJ/m^2)

Now daily crop growth rate (LUE x LI) and duration of growth (n) are the two factors controlling final net dry matter accumulation.

Daily Dry Matter



Dry Matter Distribution

- Dry Matter Distribution change as the plant develops.

	Leaves	Stem	Root	Grain
	Partitioning Coefficients			
Emergence to GPD	0.60	0.03	0.37	0.0
GPD to Silking	0.47	0.38	0.08	0.0
Grain fill	0.0	0.0	0.0	1.00

Derived from CERES-Maize

Leaf Partitioning Drives DM Accumulation

- Daily DM accumulation is:

$$\mathrm{D.M.} = \mathrm{LUE} \times \mathrm{LI}$$

DM = daily dry matter production (g/m^2)
LUE = Light use efficiency constant (g/MJ)
LI = Light energy intercepted by the crop (MJ/m^2)

- LI is a function of Leaf area:

$$\mathrm{LI} = s_a * \mathrm{W_L} * \mathrm{S}$$

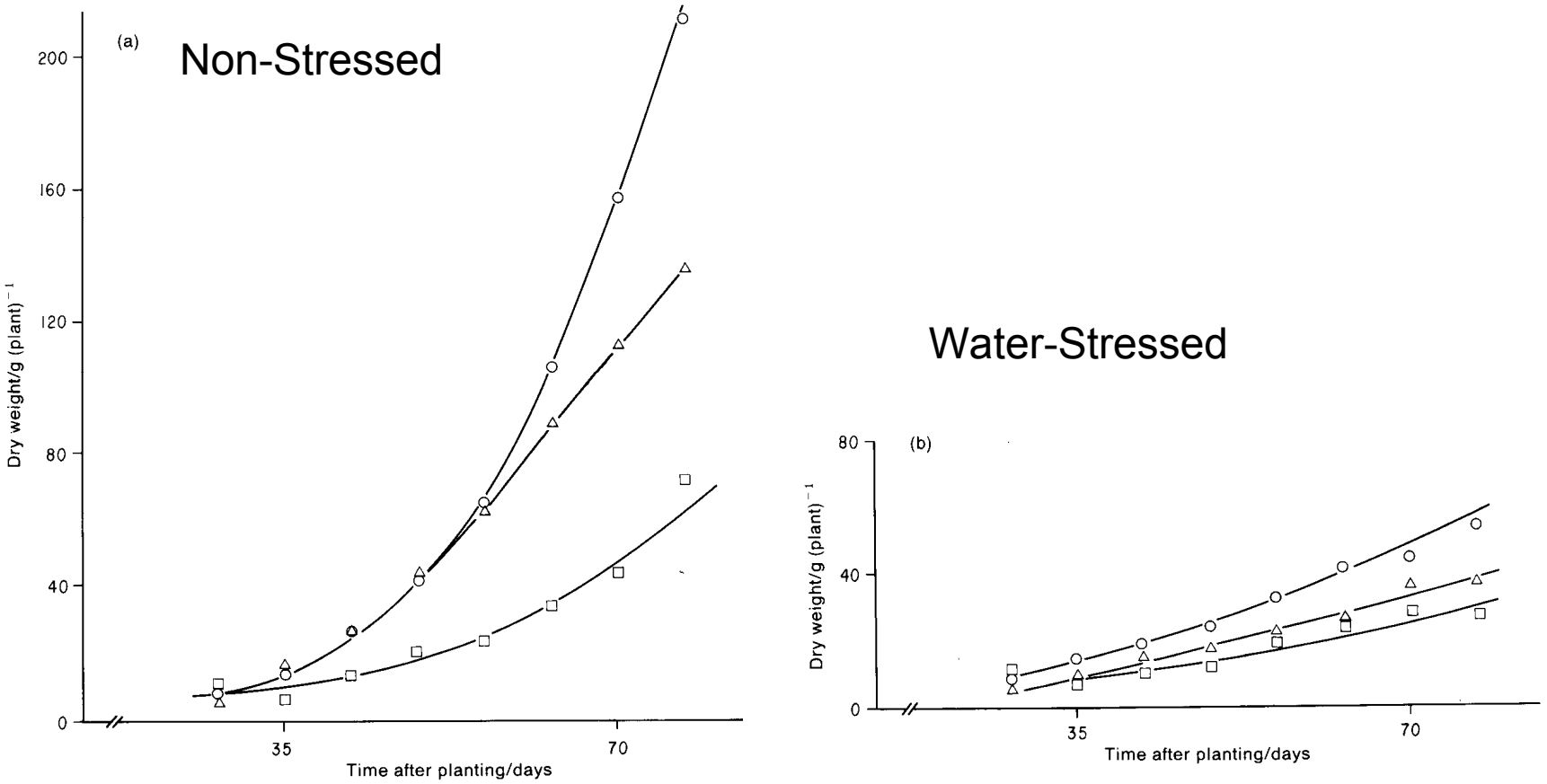
S_a = specific leaf area (m^2 g^{-1})
W_L = leaf weight (g)
S = Daily light integral (MJ/m^2)

- Daily change in DM is:

$$\Delta DM = s_a W_\mathrm{L} S(1 - \gamma W_L)$$

γ = leaf senescence factor (%)
γW_L = Daily leaf loss (g)

Water Stress and DM

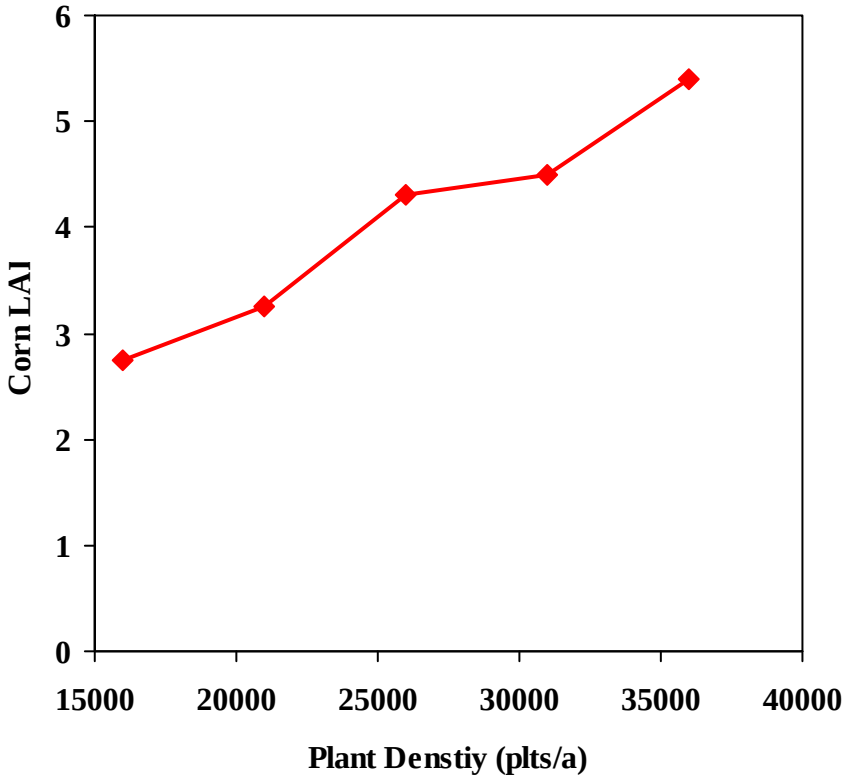


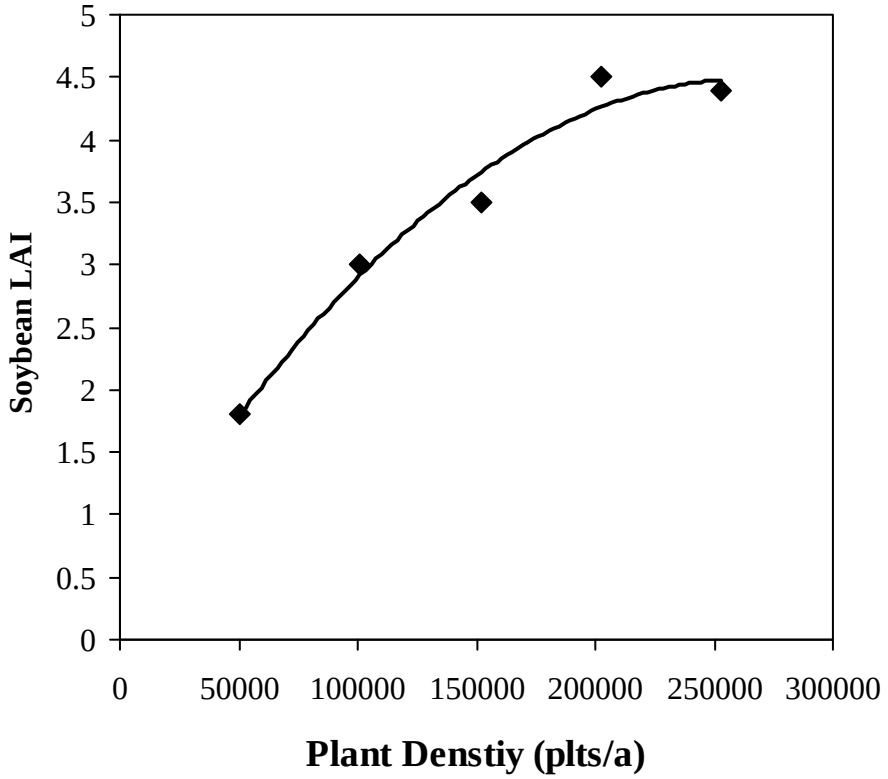
From Charles-Edwards, 1982

Management and Light Interception

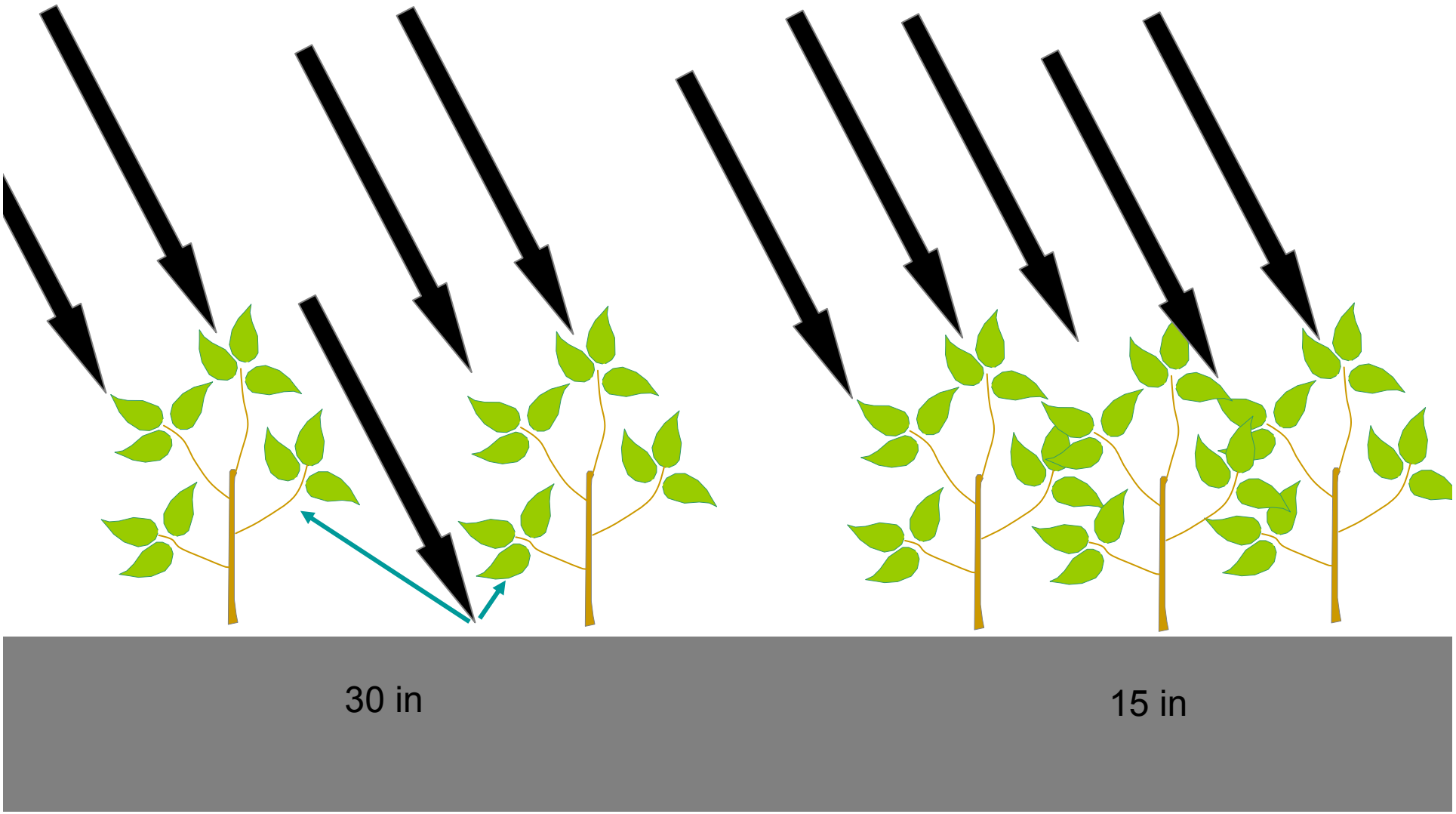
- Management practices that alter light interception by a canopy
  - Plant population
  - Row spacing
  - Plant height
  - Planting configurations

Plant Density and LAI

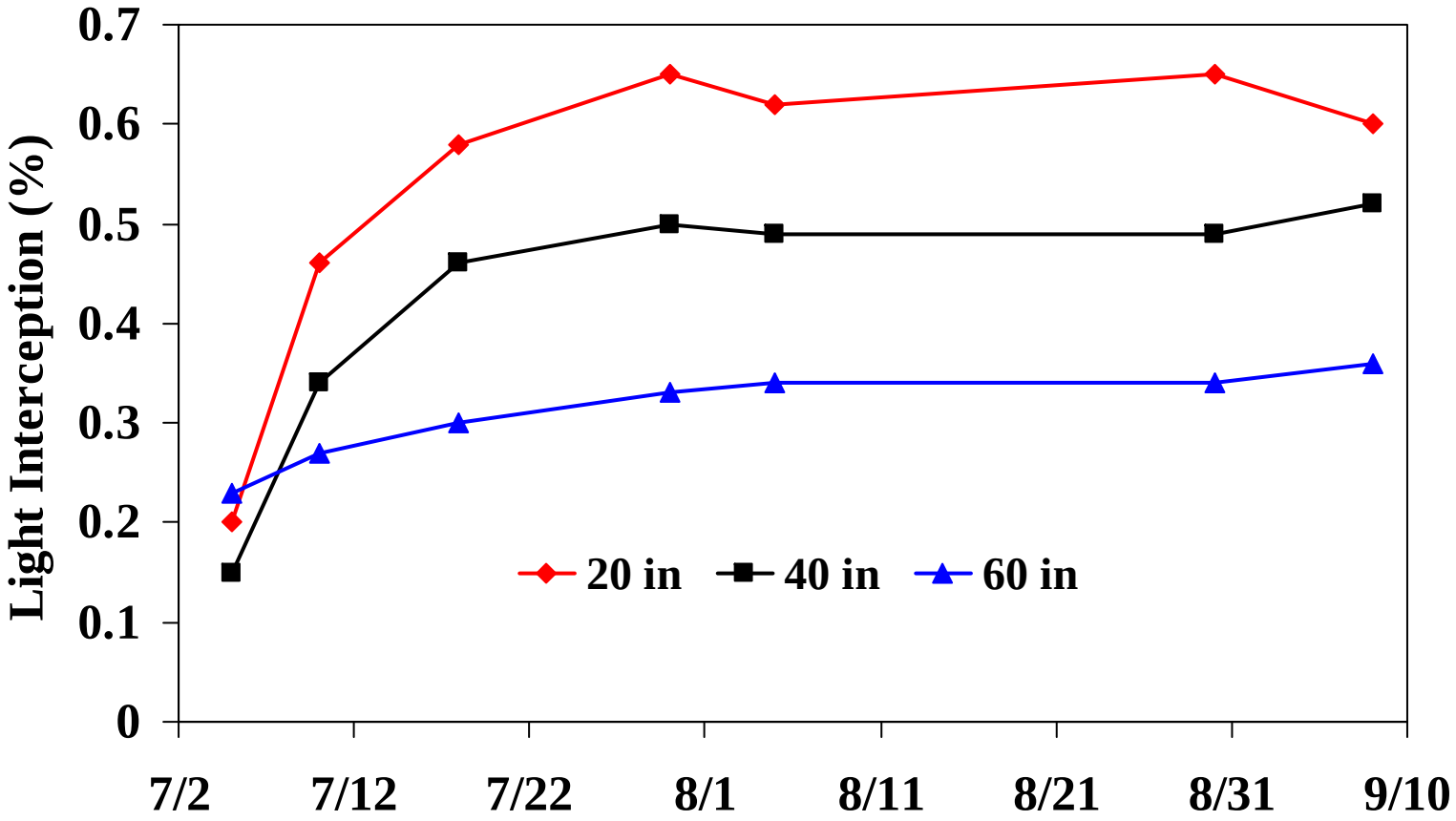




Light and Row Spacings



Light Interception



Clump Planting

Photo courtesy of B.A. Stewar

Summary

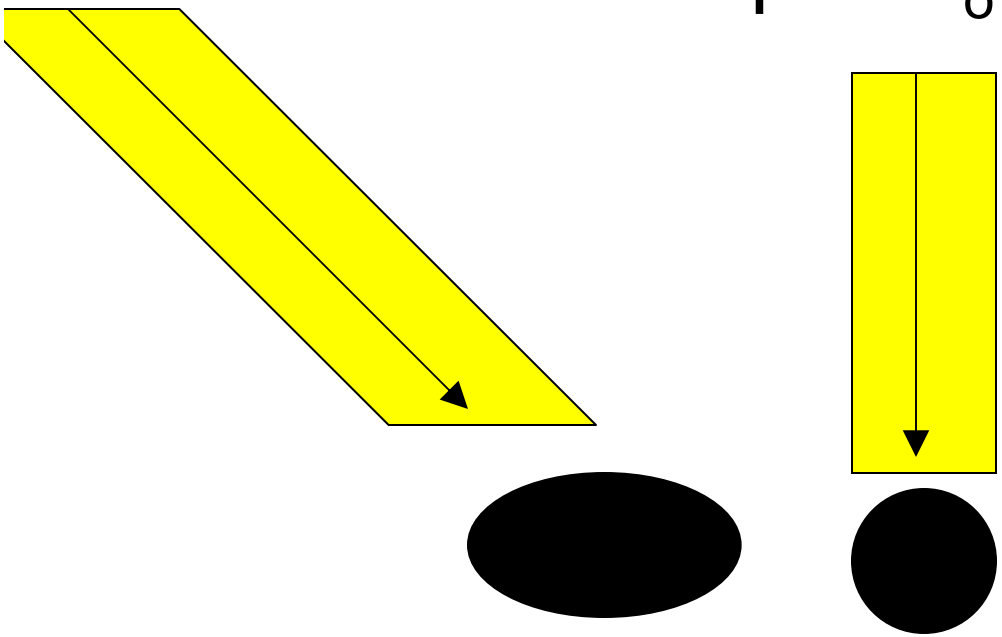
- Crop growth can be defined by five physiological determinants:
  - Light Interception, Light use efficiency, dry matter production and loss, duration of growth, and dry matter partitioning.
- Light interception can be modeled based on plant LAI in most cropping situations.
- Light use efficiency is a function of plant species.
- Dry matter production is a function of light interception and light use efficiency summed over the growth cycle of a plant.
- We can influence light interception by our choice of crops, row spacing, and planting geometry.

Light Duration

- The amount of time that a leaf is exposed to light
  - Varies based on daylength (day of year)
    - Total number of hours of daylight is called a photoperiod.
  - Influence by location on the earth (latitude)

Light Intensity

- The irradiance or illuminance falling on a surface is related to angle of the light and the surface.
- The relationship is $E_o = E * \cos(\theta)$



If we think of light as a column of energy, the contact area with a surface is either a circle or an ellipse.

At a 45° incidence angle, the contact area (ellipse) is approximately 1.9 times larger than the circular contact area at 0°.