

LECTURE OUTCOME

After the completion of this lecture and mastering the lecture materials, students should be able to

1. explain the definitions of “source” and “sink” in relation to assimilate partitioning.
2. explain two hypotheses describing how assimilate partitioning is regulated.
3. explain how harvest index, total biomass and yield can be affected by source/sink interactions.

LECTURE OUTLINE

- INTRODUCTION
 - Biomass Partitioning Concept
 - Empirical Approach
- MECHANISTIC APPROACH
 - Harvest Index (HI)
 - Plant Species
- SINK CAPACITY MODEL

1. INTRODUCTION

1. Definition

1. Biomass partitioning is often also defined as the process by which plants distribute their biomass (energy) amongst their different organs (leaves, stems, roots, fruits, etc.).
2. The terms "allocation" and "partitioning" are sometimes used interchangeably.
3. Allocation is a term used for the regulation of the distribution of fixed carbon into various metabolic pathways.
4. The mechanism which actually regulates the partitioning of dry matter at the whole plant level are still only poorly understood.

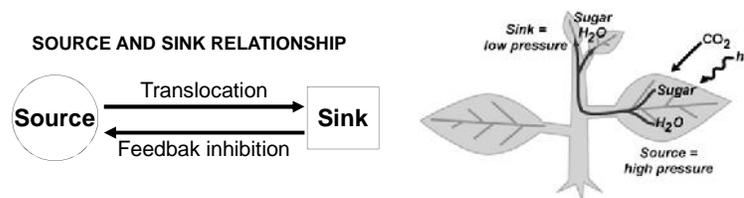
2. Mechanism

1. Several theories have been put forward to explain the mechanism by which dry matter is distributed among plant organs, but no unequivocal theory is available at present.
2. The partition of photosynthate from leaf source into several plant organs sinks is influenced by many factors such, among others, as;
 - a. Source strength of leaves to produce photosynthate to be translocated into various sinks.
 - b. Vascular bundles connecting leaf source to sinks that include sink position (sink distance from source and vertical configuration of pathways)
 - c. Sink strength that drives the flow of photosynthate from the source to the sinks
 - d. Number of sinks in relation to competition for photosynthate.
 - e. Molecules that function as signals

2. SOURCES AND SINKS

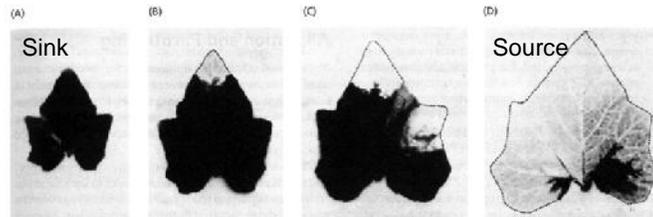
1. Source and Sink Organs

1. An organ is defined as a source or a sink based on the direction of net transport of assimilate associated with it.
 - An example of a source is a healthy, fully expanded, sunlit leaf.
 - Sinks include roots, shoot apical meristems, young expanding leaves and growing seeds and fruits.



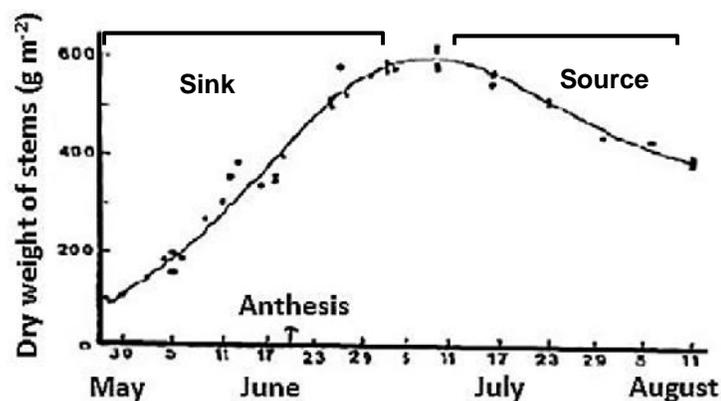
<http://www.biol.uni-erlangen.de/~bgayre/myweb/hydrostatic-small.gif>

2. Some organs may function as a sink during one stage of plant development, and as a source during another stage of development.
3. For instance, a young expanding leaf will initially import assimilates, but this same leaf will export assimilates at or before complete leaf expansion.



Autoradiographs of a leaf of summer squash (*Cucurbita pepo*), showing the transition of the leaf from sink to source status. In each case, the leaf imported ^{14}C from the source leaf on the plant for 2 hours (black accumulations). (A) The entire leaf is a sink, importing sugar from the source leaf. (B-D) The base is still a sink. As the tip of the leaf loses the ability to unload and stops importing sugar (as shown by the loss of black accumulations), it gains the ability to load and export sugar (From Turgeon, 1973).

4. The stem of wheat (and other grasses such as maize) can also function as both sink and source:



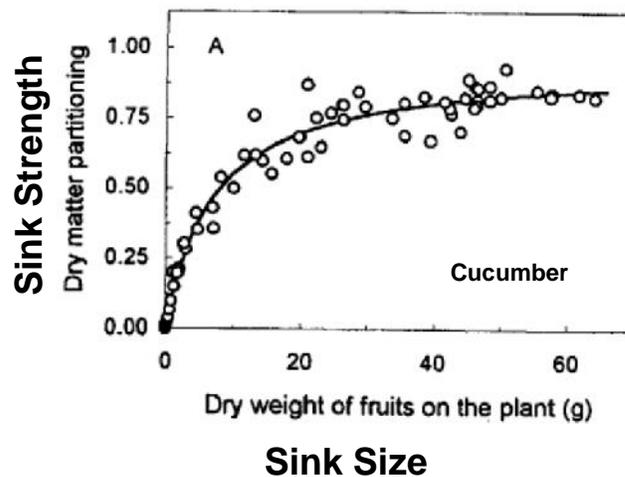
The figures illustrate this phenomenon the stem's transition from a sink to a source appears to occur at approximately 25 days after anthesis for the wheat crops studied.

2. Source and Sink Strength

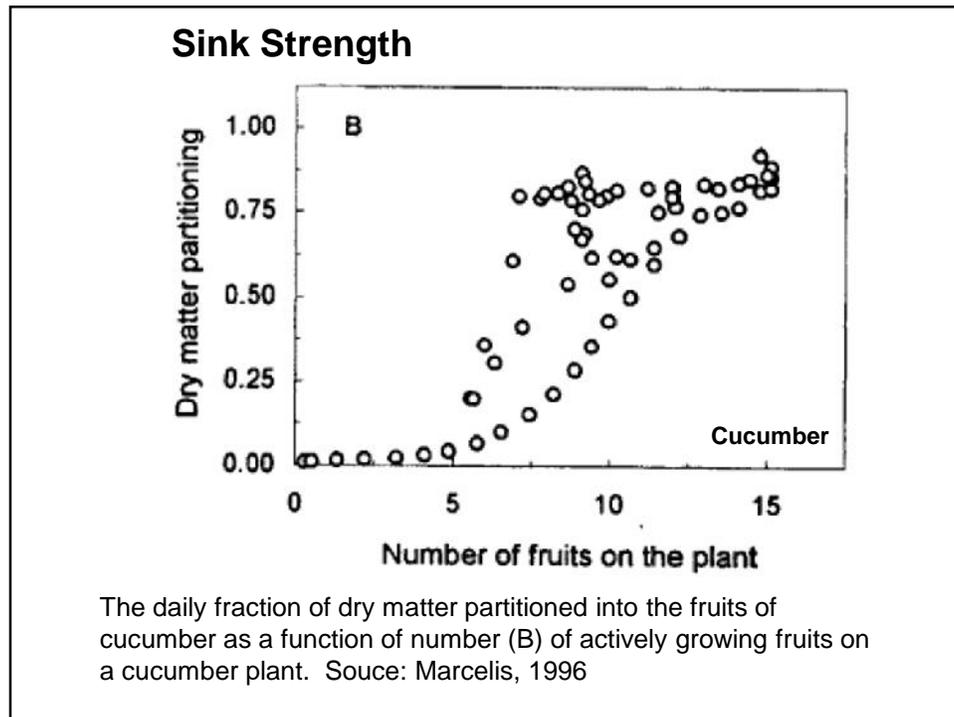
1. The quantity of photosynthate allocated to particular plant parts (sinks) is a function of source strength and sink strength.
2. Source strength is determined by source capacity and source activity, and sink strength is the product of sink size and sink activity as follows
Source strength = Source capacity x Source activity
Sink strength = Sink size x Sink activity
3. Source strength is the ability of photosynthetic organ to produce photosynthate (assimilate) with leaf area as source capacity and photosynthetic rate per unit leaf area as source activity.

4. Sink strength may be defined as the ability of a sink organ to import assimilates.
5. Sink capacity can be considered a physical constraint (i.e., the upper potential size and/or weight of the sink) or simply is the total biomass of the sink tissue,.
6. Sink activity may be defined as a physiological constraint upon the ability of a sink to achieve its potential size (the rate of photosynthate uptake per unit biomass of sink tissue).
7. Sink activity is a measure of how well a sink can mobilize assimilates and may involve the action of growth regulators such as auxin, cytokinin, and abscisic acid.

8. **Sink strength** may increase with increasing **sink size**, because of an associated increase in the size of the surface (membrane) area across which metabolites are transferred from the vascular system to the zone of utilization.
9. Dry matter partitioning into cucumber fruits correlates with the total fruit weight (sink size), which might indicate a correlation between sink size and sink strength.
10. However, the size often correlates with the age of an organ, which might have led to an apparent relationship between sink size and sink strength



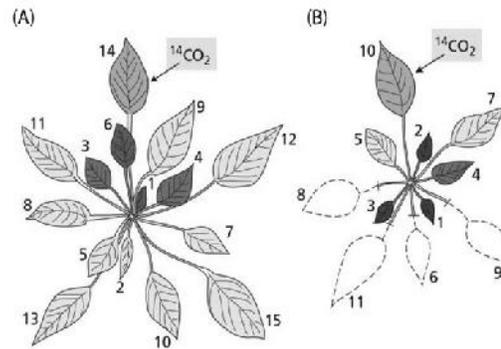
The daily fraction of dry matter partitioned into the fruits of cucumber as a function of total dry weight (A) of actively growing fruits on a cucumber plant



3. Proximity of Source and Sink

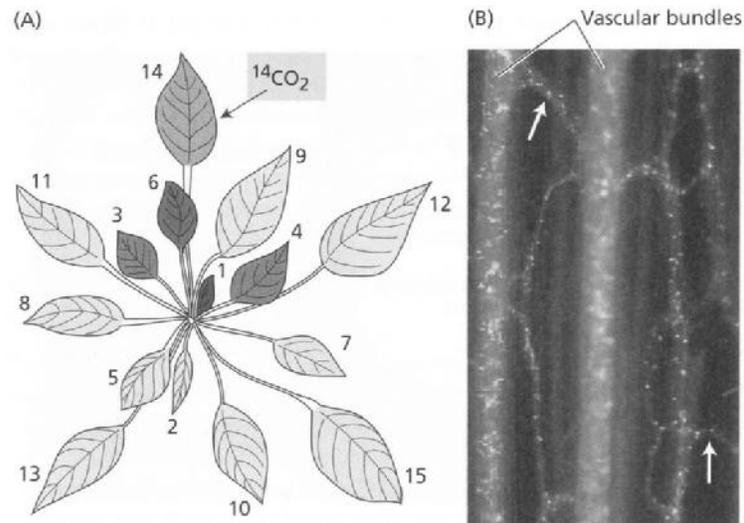
1. In many plants, upper leaves supply apical sinks and lower leaves supply the roots, whereas leaves in intermediate positions export assimilate both up and down the stem.
2. For large sinks such as fruits, the subtending leaf usually acts as the main supplier of assimilate. In certain plants, the arrangement of their vascular bundles causes unusual distribution patterns.
 - For instance, a kind of inverted behaviour is apparent in tomato since lower leaves export more assimilate to the apical sink than to the roots and upper leaves export more to the roots than to the apical sinks.

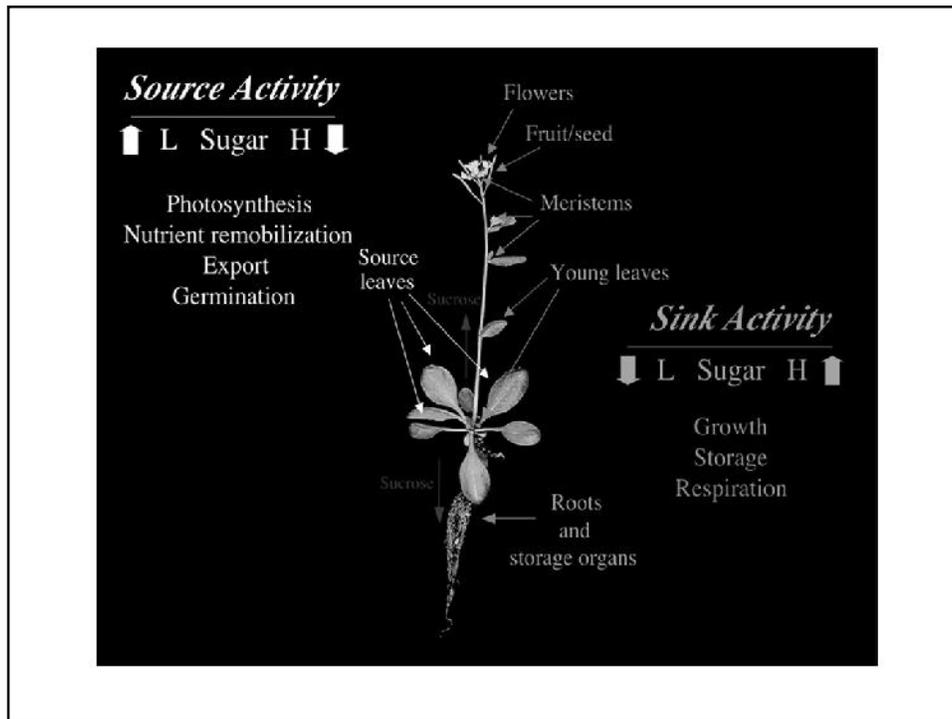
Source-to-sink patterns of phloem translocation. (A) Distribution of radioactivity from a single labeled source leaf in an intact plant. The distribution of radioactivity in leaves of a sugar beet plant (*Beta vulgaris*) was determined 1 week after $^{14}\text{CO}_2$ was supplied for 4 hours to a single source leaf (arrow).



The degree of radioactive labeling is indicated by the intensity of shading of the leaves. Leaves are numbered according to their age; the youngest, newly emerged leaf is designated 1. The ^{14}C label was translocated mainly to the sink leaves directly above the source leaf (that is, sink leaves on the same orthostichy as the source; for example, leaves 1 and 6 are sink leaves directly above source leaf 14). (B) Same as A, except all source leaves on the side of the plant opposite the labeled leaf were removed 24 hours before labeling. Sink leaves on both sides of the plant now receive ^{14}C -labeled assimilates from the source. (A and B based on data from Joy 1964.)

<http://6e.plantphys.net/ch/11/wt11.01/wt1001c.jpg>





3. MODELS OF PARTITIONING

1. The implementation of allocation processes still remains a weak point of current plant modeling.
2. Different approaches have been used to represent biomass partitioning in plant models including empirical coefficients, functional balance, allometric relationships, transport resistance (TR) and source-sink models (Roux *et al.* , 2001).
3. Biomass partitioning is primarily regulated by the sink strengths of the sink organs, while neither the source nor the transport path are dominating factors in regulating dry matter partitioning.

2. Moreover, it has been discussed that the **potential growth rate** may quantitatively reflect the sink strength of an organ. Based on these conclusions, dry matter partitioning in several crops has been modelled as a function of the potential growth rates of the plant organs.
3. In most models, the plant is considered to consist of a set of sink organs which derive their assimilates for growth from one common assimilate pool.
4. The utilization of assimilates in the sink can be related to the level of assimilates by a curvilinear relationship, obeying Michaelis-Menten kinetics (Patrick, 1988).

$$Y_i = \frac{Y_{\text{pot},i}A}{K_{m,i} + A} \quad S_i = \frac{S_{\text{pot},i}A}{K_{m,i} + A}$$

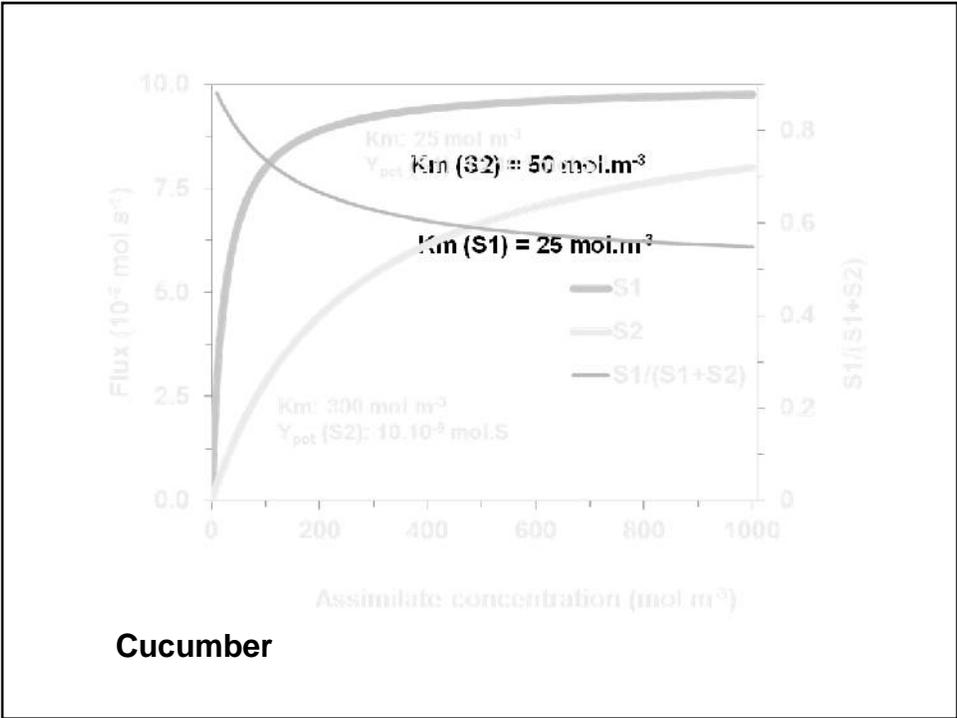
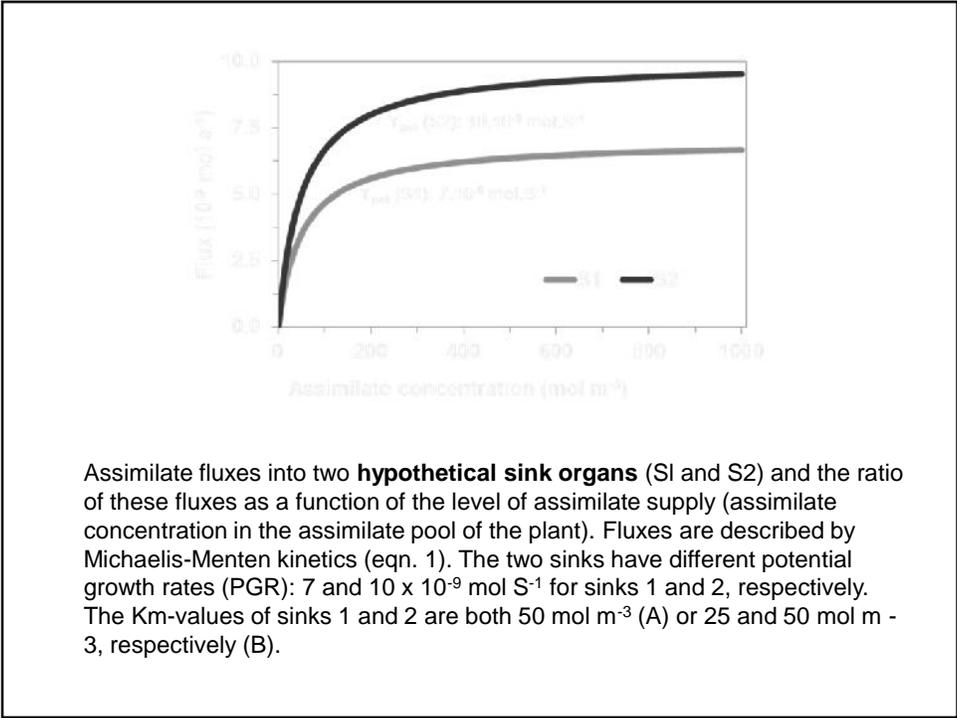
where

Y_i (S_i) is the flux for dry weight growth of organ i (including growth respiration);

$Y_{\text{pot},i}$ ($S_{\text{pot},i}$) is the flux for potential growth of organ i (including growth respiration), the maximum rate under the prevailing conditions for A \bar{c} ;

$K_{m,i}$ is the Michaelis-Menten constant, which determines the affinity for assimilates (low Km value means high affinity);

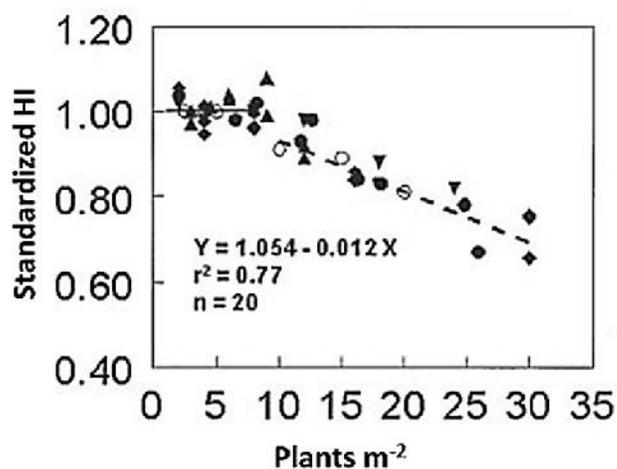
A is the level of assimilates available for growth.



4. HARVEST INDEX

1. Experimental Evidence

1. Harvest index (HI) is the proportion of the total or aboveground DM (dry matter) at physiological maturity that is allocated to the economic product (e.g., grain in rice, maize, wheat, and soybean).
2. Harvest index varies among
 - crop species (e.g., 55% for maize hybrids vs. 20% for canola varieties),
 - among genotypes within a crop species (e.g., 55% for North American maize hybrids, 40% for tropical maize cultivars, and 10-50% for maize inbred lines), and
 - among 'environments' in which it is measured, and HI is usually negatively affected by abiotic/biotic stresses.



Relative response of maize harvest index to plant population (environment) (Kiniry and Echarte, 2005)

3. Improving harvest index has been critical to advancing the yield potential of some important cereal crops.
 - For example, improvement of British wheat cultivars for about 100 years until 1970 was attributable almost exclusively to increased HI, although the genetic yield improvement since 1970 has been attributable predominantly to increased seasonal dry matter accumulation.
 - Yield improvement in wheat and rice cultivars prior to 1970 has been a result, in part, of the shorter stature of newer cultivars and, consequently, less competition for DM between the stem and the grain (e.g., the 'green revolution' cultivars).

2. HI Model

2.1 Simple Approach

1. The relationship between yield (e.g seed DM) and total or aboveground DM is linear

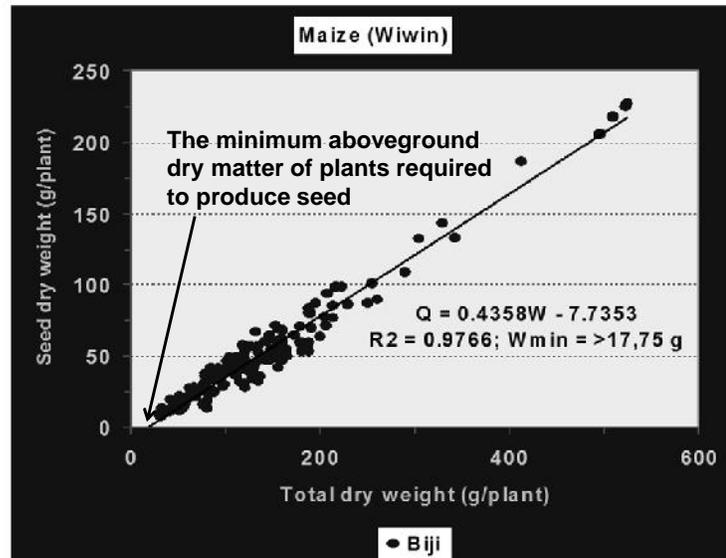
$$Q = aW + b$$
 where Q = yield, W = total DM, a & b = constants
2. The division of above equation with W results in

$$Q/W = a + b(1/W) \rightarrow HI = a + b(1/W)$$

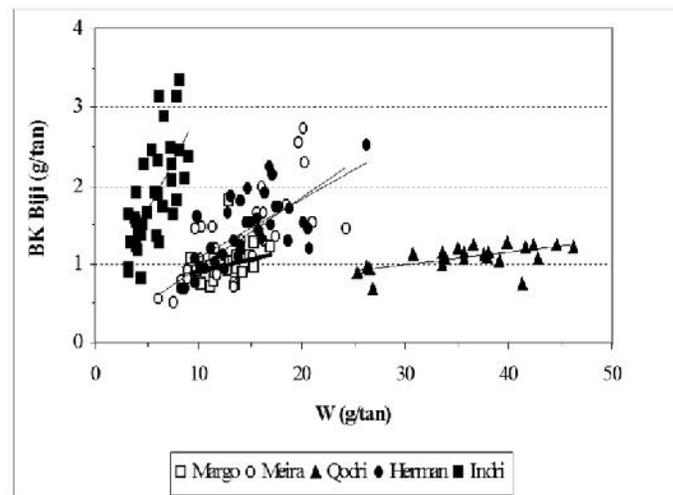
$$HI = a(1 + b/aW) \rightarrow HI = a(1 + k/W)$$
3. Results of an experiment in the field showed a close relationship between seed DM and aboveground DM in maize with a linear equation;

$$Q = 0.4358W - 7.7353 \rightarrow HI = 0.4358(1 - 17.7497/W)$$

Empirical Approach



$$W_0 = 17.74966$$



$$Q_1 = 0.027W_1 + 0.652; R^2 = 0.061$$

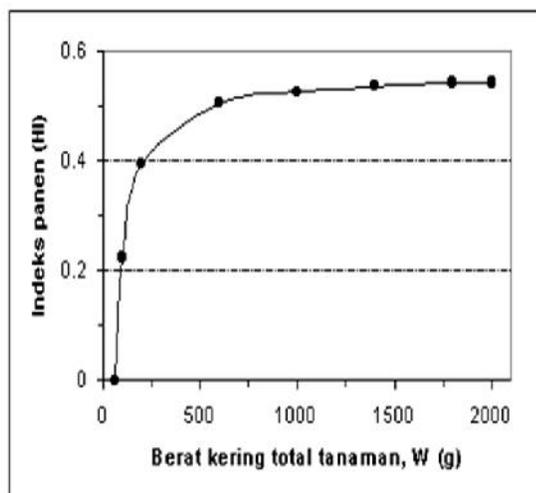
$$Q_2 = 0.088W_2 + 0.087; R^2 = 0.5183$$

$$Q_3 = 0.015W_3 + 0.540; R^2 = 0.3309$$

$$Q_4 = 0.075W_4 + 0.330; R^2 = 0.4487$$

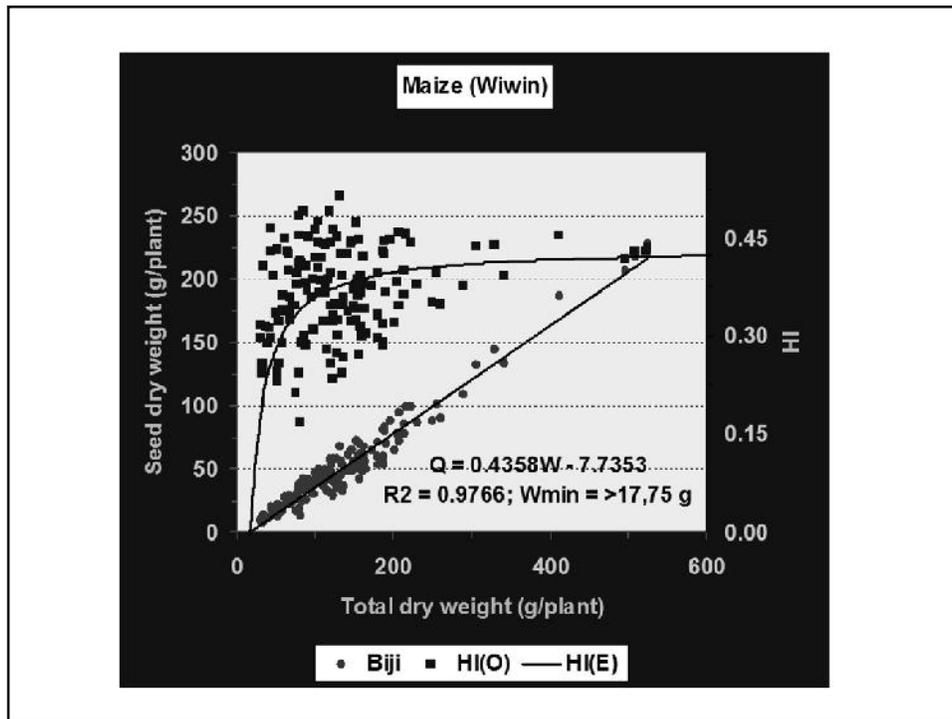
$$Q_5 = 0.250W_5 + 0.421; R^2 = 0.4599$$

Cassava: $HI = 0,56(1-60/W)$



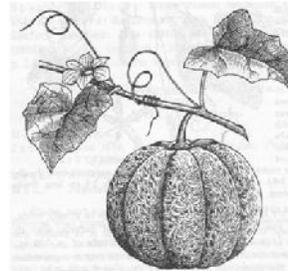
Harvest index (HI) of several crop species

Species	Varietas	W (Mg/ha)	HI	Age (days)
Lowland Rice	IR36	13,9	0,49	107
Upland Rice	IR36	14,3	0,33	118
Wheat	Acc. No. 4073	8,5	0,31	84
Maize	UPCA Var. 1	15,6	0,39	98
Sorghum	B8417	14,6	0,48	90
Soybean	Clark 63	6,4	0,47	84
Peanut	Moket	8,1	0,36	112
Sweet potato	Georgia Red	10,4	0,60	126

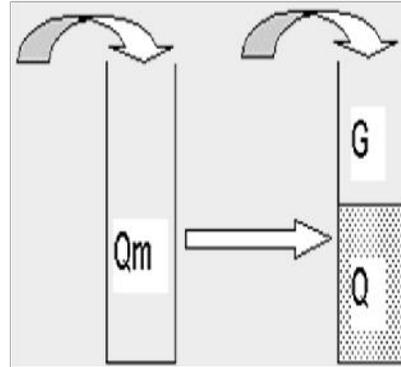


2.2 Sink Capacity Model

1. Would an increase in the production of biomass be followed by a continuous increase in the biomass of economic yield (seed biomass)?
2. The capacity of sinks (sink size) to accommodate photosynthate accumulation was not taken into consideration in the previous HI model.
3. The capacity of sinks is not unlimited and determined by plant genetics. For instance, the size of soybean seed is impossible to reach the size of hazelnut or rock melon.



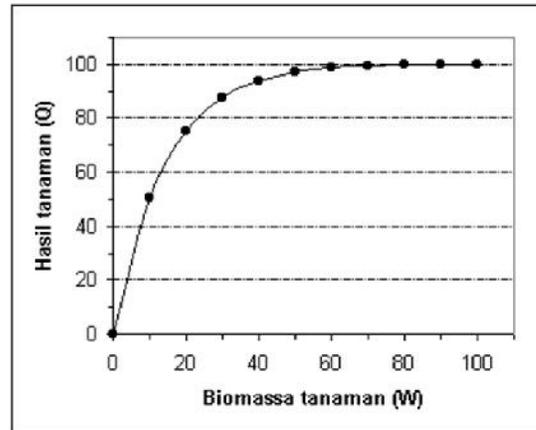
- If it is assumed that
- the maximum capacity of sink (e.g. seed) to accommodate photosynthate is Q_m , dan
 - some space of Q_m is filled by photosynthate after a particular time in the amount of Q ,
 - the capacity of seed available to accommodate additional photosynthate is $G = Q_m - Q$.



$$\frac{\delta Q}{\delta W} = k_f \cdot G \quad \frac{\delta Q}{\delta W} = k_f (Q_m - Q) \quad \frac{\delta Q}{(Q_m - Q)} = k_f \delta W$$

$$\int_{Q_0}^Q \frac{\delta Q}{(Q_m - Q)} = k_f \int_{W_0}^W \delta W \quad \rightarrow \quad Q = Q_m \left(1 - e^{-k_f W} \right)$$

- The above equation shows that an increase in the production of biomass is not followed by a continuously increase in seed biomass.
- The biomass of economic yield (seed) increases rapidly at the beginning, then slowly, and reaches a relatively constant level with an increase in the production of biomass.



$$Q = Q_m \left(1 - e^{-k_f W} \right)$$

