**Physiology of grain yield in cereals**

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**Origin and adaptation**

The cereals are originally domesticated at tropical or low latitudes, but their most conspicuous agronomic development has been at higher latitudes, under longer days and cooler temperatures.

**Reproductive development:**

Control of the reproductive cycle by day length or temperatures is an important component of the adaptation of wild plants to their environments. The length of the vegetative phase depends on whether or not there is a juvenile stage and on the extent to which floral induction is delayed by photoperiod or vernalization.

**ROOT GROWTH**

**ROOT FUNCTION AND GROWTH PATTERNS:**

At lower temperatures, assimilates from the leaves are more uniformly distributed along wheat roots, which may be associated with more sustained ion uptake by the older parts. Primarily root number in rice correlates with the number of secondary roots, total length, total dry weight, and whole surface area. Constant relationship between the total number of roots, their surface area, volume, and dry weight of the different members, and suggested that any one of these features could be used to express the absorbing activity of the root system.

**ROOT FUNCTION AND GROWTH PATTERNS**

**GENETIC VARIATION:** Winter cereals tend to develop a greater root system than spring types, presumably because of a longer growth period, longer the vegetative period the greater is root development.

**ENVIRONMENTAL CONTROL OF ROOTING PATTERNS:**

Drying in the upper layers of soil can increase the growth of roots and uptake of water from the lower layers. The level of nutrition can affect the growth of roots and shoots differentially, root growth generally being reduced under high levels of nutrition. The partitioning of dry material into the root relative to the shoot is high in the seedling stages of growth and steadily declines throughout development. Greatest total length of root occurs under the lowest nutrient status, this is due to greater branching rather than to increased extension rate.

**ROOT FUNCTION AND GROWTH PATTERNS**

Root growth is generally enhanced by a deficiency of nitrogen and phosphorus but not by a lack of potassium. Optimum temperature for root growth, in isolation, is probably very similar to that for the shoot in most plants. Temperature may also influence the angle of root growth and hence penetration. High root/shoot ratios are generally associated with high light intensities. Roots are poor competitors for a limi9ted supply of carbohydrate. Growth in root weight is more sensitive to reduced light than is shoot growth of barley; root length may be less affected than weight.

**NUTRIENT UPTAKE**

The uptake of nutrients by roots is a metabolic process and as such is sensitive to temperature. Nutrient uptake is dependent on a supply of carbohydrate from the shoot to the roots, and is enhanced under high light. Movement of ions from the roots to the shoot is influenced by the transpiration rate and by water flow through the xylem. The time course for uptake of K may differ from that of other major nutrients in that uptake ceases earlier and K may actually be lost toward maturity. Differences in the uptake of nutrients by roots which, appear to be morphological and anatomical differences rather than to variation in ion transport mechanisms.

**CANOPY GROWTH**

Early growth of cereal canopies is approximately sigmoid both accumulated dry weight and leaf area index. The increase in LAI is closely paralleled by the increase in canopy photosynthesis. Early increase in LAI depends on light and temperature conditions. It increases with increased application of nitrogenous fertilizers, and particularly with increased sowing density. Grain yield, on the other hand, increase with increase in maximum LAI only up to a point. It may plateau at still higher LAI values. Grain yield may fall when very high maximum LAI values are attained. An optimum LAI at anthesis of 8-10 is also evident in the grain yields summarized. Another difference among the cereals appears to be the timing of anthesis in relation to when they usually reach maximum LAI and canopy development. Wheat, in which maximum LAI is reached well before anthesis, LAI may fall rapidly during early grain filling. Under such conditions, common to many wheat growing areas, grain growth takes place during a period of no root growth. Water stress is less marked and temperatures are cooler. Photosynthesis provides most of the increase in crop dry weight as well as the metabolic energy required for crop development. Early life of cereal crops the leaf blades are the main photosynthetic organs and crop growth rate depends on both the rate of expansion of leaf area and the rate of photosynthesis per unit leaf area. Once the leaf canopy has closed, leaf photosynthetic rate becomes the more important determinant, depending not only on weather conditions but also on the geometry of the canopy. End of the life cycle photosynthesis by the stems, leaf sheaths, and inflorescences tends to become increasingly important as the leaves sense, especially in temperate small grain crops.

**DIFFERENCES BETWEEN C3 and C4**

•Whereas in maize, finger millet, and probably pearl millet C4 pathway low CO2 compensation or the lack of enhancement of the photosynthetic rate at low oxygen concentrations.

•Kranz anatomy of the leaves and closer spacing of the veins which may influence translocation as well as photosynthesis. Smaller resistance offered by membrane of the leaves of C4 compared with C3, in dry matter production per unit of water transpired. Photosynthesis by single leaves of the C3 cereals tends to reach light saturation at 3 to 5% of full sunlight.

•The maximum photosynthetic rates achieved. The greater rates of photosynthesis in C4 plants, associated with their reduced photo respiratory losses.

•Greater photosynthetic rate may be of advantage at high light intensities, especially in view of their more efficient use of water, at low light intensities-in overcast weather or for leaves deep in the canopy- their photosynthetic rate may be less than that of C3 plants.

•Poor photosynthetic performance of the tropical (C4) grasses at cool temperatures, relative to temperate (C3) grasses and cereals.

•At high temp, on the other hand, photosynthesis by C3 cereals falls off rapidly >300C as in wheat. Whereas, photosynthesis by the C4 cereals may reach its peak at temp of 30-40 ºC.

**CULTIVER DIFFERENCES**

Substantial differences in photosynthetic rate per unit leaf area have been found in wheat. The highest rates have been found in the primitive and wild diploid wheat. With a progressive fall in the course of evolution both between species and among modern cultivars the relations between maximum photosynthetic rate and leaf area is negative. Photorespiration was proportional to photosynthetic rate across many lines and the latter was negatively correlated with mesophyll cell size, but only inconsistently with specific leaf weight.

**CANOPY PHOTOSYNTHESIS**

In the early stages of crop growth, the main determinant of its photosynthesis is the extent of leaf area development. As the LAI increase, so does the extent of light interception, which exceeds 95% for most cereal crops with an LAI of about 4. Once the canopy is closed in this way, further increase in LAI has little effect on crop photosynthesis, which is then most influenced by the incident radiation and the structure of the canopy. Light interception by cereal crops is low during early establishment but then increases rapidly as the larger upper leaves expand and tillers develop. Earlier closure of the can be effected by increase in sowing density. This increases the early crop growth rate, in proportion to the increase in light interception; it may have little effect on subsequent crop growth rate and an adverse effect on grain yield.

**CANOPY ARCHITECTURE**

Individual plants of many C4 cereals are much larger than those of the C3 cereals. Height, leaf size and the vertical separation of leaves is greater in the C4 cereals, features that affect not only light penetration into the crop, but also its ventilation with CO2. Canopy structure in maize can be controlled by the density of planting far more than the C3 cereals. C3 cereals, therefore, more upright leaves may be advantageous to both photosynthesis and yield in high density crops. In maize horizontal leaves may have an advantage at LAI values less than 3, more erect leaves could result in up to a 2fold increase in photosynthesis at high LAI, greater light interception with less erect leaves but little effect on yield. Small yield advantage with more upright leaves at high LAI. Leaf inclination has a greater influence on yield in the C3 cereals than it has in maize and other C4 cereals.

**PHOTOSYNTHESIS BY STEM AND EARS**

Stems and leaf sheaths to account for 39-44% of canopy photosynthesis in wheat. Net photosynthesis by the awned was rather less, but increased in relative importance as the elevation of the sun declined. In barley, ear photosynthesis may comprise one quarter to one half of total crop photosynthesis, and contributes 24-84% of grain growth. Cereal awns are not only active in photosynthesis, but may also increase the efficiency of water use by the crop, modify the energy balance and turbulence above the crop and may increase the movement of cytokinins to the grains. The large, terminal inflorescences of sorghum can intercept 25-40% of incoming radiation. Their net photosynthesis is rather low.

**Respiratory losses**

Difference among the cereals in their photorespiration as a result of the oxygenase activity of carboxy dismutase. Respiratory losses represent a substantial fraction of the CO2 fixed in crop photosynthesis. Its values for Maize are 20% and for Rice it is 34-57%. Crop respiration is approximately proportional to photosynthesis. The distinction between these is operational rather than biochemical. Growth of respiration represents the metabolic cost of converting the translocated products of photosynthesis to structural, cytoplasmic, or storage compound. The rate of maintenance respiration depends on temperature and on other conditions. For Maize theses ranges from 0.0080.002 g g-1d-1, Sorghum 0.0068 g g-1d-1 at 20 ºC and 0.011 g g1d-1 at 30 ºC. Thus, the cereals appear to have rather low rates of maintenance respiration compared with other crops like sunflower or cotton.

**Translocation**

Limitation to yield in cereals have often been considered in terms of the relative importance of the source and sink, with little or no account being taken of the system transporting assimilates from source to sink. The capacity of this system could limit grain growth however, and changes in the transport and partitioning of assimilates are likely to have been a major component in the evolution of the cereals.

**A. Loading and export**

•The distance between the parallel veins in leaves of C4 graminae is only half or less that in the C3 species and the distance traversed from the site of fixation to the phloem is correspondingly smaller.

•C4 Species are faster in export of assimilates. Initial export is more rapid and it is more complete, what is not exported immediately stored in as starch in the bundle sheath chloroplasts by day and almost entirely mobilized and exported during the following night.

•In the C3 grasses and cereals on the other hand, a greater proportion of assimilates is accumulated in the leaves and these are exported more gradually.

•Loading of the assimilated into the phloem by active process in C3 plants which, requires metabolic energy and accompanied by the hydrolysis and resynthesis of sucrose, usually associated with movement against a concentration gradient.

•Initial export of assimilates were adversely effected by low light intensity in the C4 grasses. The high sugar content of the bundle sheath cells may be associated with their greater resistance to injury by water stress.

**B. Phloem capacity and speed of movement**

•A many fold increase in the need by ears to import assimilates through the peduncle has occurred in the course of evolution in cereals.

•In Wheat, this increased need has been matched by a comparable increase in the area of phloem in the peduncle, with the result that the rate of transfer per unit cross sectional area of phloem has not changed.

•Leaves of C4 graminae maintain specific mass transfer rates 3-4 times higher than those in C3.

**C. Unloading of assimilates**

•The pattern of demand have a predominant influence on the distribution of assimilates, through modified to some extent by vascular pattern.

•Sucrose hydrolysis and resynthesis is a prerequisite to the transfer of assimilates to the endosperm, which could imply loading against a concentration gradient.

•Assimilates presumably diffuse through the pigment strand cells in the gap of the seed coat to the nuclear projection and from there to the nearby aleuron layer cells.

•Rate of growth per kernel can be up to 5 times higher in maize than in the temperate cereals. The arrangements for unloading and transfer of assimilates within the caryopsis of C4 cereals may be much more efficient than those in the C3.

**D. Distribution of assimilates**

•The pattern of distribution depends to a considerable extent on environmental conditions. Drought stress and low temperatures is favor root to relative shoot growth. Root growth is also relatively more important in the early stages of crop development.

•Older leaves export predominately downward to roots and tillers. Even after anthesis the lower leaves of the main stem may continue to export much of their assimilates to the tillers.

•Selection for greater yield has resulted in the flag leaf and the leaves below it playing a greater role in the supply of assimilates for grain growth.

•The flag leaf, stem and ear are the organs closest to the grains are the main source of carbohydrates for grain growth.

**E. Role of reserves**

•Carbohydrate reserves accumulated by cereals before anthesis were previously assumed to play a major role in grain growth. C4 cereals there are a rapid initial export from leaves of more than half of assimilates and nearly all the reminder is exported during the following night.

•Starch can accumulate to quite high levels in the leaf blades up to 45% of dry weight in wheat.

•Assimilates from the lower leaves and earlier photosynthesis tend to be stored in the lower internodes of wheat, whereas assimilates from the flag leaves after anthesis tends to be stored in the upper nodes and peduncle. As a result of this storage, stem weight may continue to increase after its elongation has ceased and then fall during grain growth.

•Pre-anthesis assimilates accounted for 12% of final grain weight in sorghum. Carbohydrate reserves in cereals can make a major contribution to grain yield in most crops under stress condition, but where nutrition and water supply are favorable the reserves are often drawn on to only a limited extent.

**Grain growth**

There is a linear increase in the dry weight of kernel throughout most of the period of their growth. The period of linear increase is proceeded by an initial lag after anthesis and may be terminated quite suddenly. Cessation of grain growth in maize is indicated by formation of a black closing layer in the placental region.

**Rate of grain growth**

The rate of growth per kernel increases with temperature in rice. The effect of light intensity on the grain growth is more complex. Only at very low light intensities, combined with high temperatures did an increase in intensity results in faster grain growth in some wheat cultivars.

**Protein storage**

Major yield advances in some cereals has been associate with a progressive fall in % protein as in triticale and sorghum. Selection for high % protein may reduce yield. Low light intensity during grain development may affect the storage of starch more than that of protein, leading to reduce grain yield, but a higher percentage protein. Protein content in enhanced relative to starch content at high temperatures in rice. • Drought stress also enhances the relative protein content. However, it is much influenced by the adequacy of nitrogen nutrition during grain development. Nitrogen uptake is continuous during the grain filling; both the protein and starch content of the grains may increase linearly until near maturity. Under these conditions the % protein in the grain need not fall, and may even rise, as storage proceeds.

**Limiting stages in the life cycle**

•Roots and leaf growth dominate the vegetative stage together with tillering, the extent of which depends on assimilate supply within the plant.

•In the second stage (reproductive stage) ushered in by inflorescence imitation, the rapidly elongation stems and the differentiating inflorescence are the main competitors for assimilates, although root growth continues and expansion of the upper leaves is completed.

•Stem growth ceases soon after anthesis, and the developing grains then become the dominant sink for assimilates ion the final stage of the life cycle, although root growth and tillering may be renewed if conditions are favorable.

•Sink and storage capacity for assimilates at this late stage is to a large degree determined by the extent of photosynthesis earlier in the life cycle, especially during the reproductive stage of the crop.

•Surplus storage capacity is suggested by the formation of far tillers than eventually bear ears, more spikelets than bear grains in maize and barley and more florets than filled grains in wheat and rice.

•Similarly leaf area reduction or shading treatments late in the life cycle may reduce crop growth without reducing grain yield.

**A) Duration of life cycle stages**

The relative duration of the various stages and their optimum balance obviously depend to a very great degree on seasonal conditions under which the crop is grown. Higher yields were associated with shorter times in the vegetative stage and longer times in the grain filling stage. The environment determines the, which stage of the life cycle it is more important to extent. An adequately long vegetative stage is required to establish the root system and leaf canopy as a basis for later crop growth. It is needed to establish the tillers and potential spikelets sites which contribute to eventual grain storage capacity, particularly in the temperate cereals in which tillering is more important and primordial accumulate eat the shoot apex before inflorescence initiation occurs. Greater fertilizer use and denser plating all permit a shortening of the vegetative phase. LAI vales above 4 have little effect on crop photosynthesis in spite of their large effect on estimates of leaf area duration. Yield in cereals often a close relation to LAI at anthesis, in wheat, maize and rice. Yield is largely determined by yield capacity which is in turn determined by the extent of canopy growth or nitrogen uptake, often related to the maximum LAI attained.

**Photosynthetic limitations to yield at the various stages**

Shading and reduced photosynthesis has effect on yield when given during the vegetative stage, and most effect during the reproductive stage, with the grain filling stage also being sensitive. Yield being most affected by shading during the reproductive stage and least during the vegetative stage. CO2 enrichment before anthesis causes a greater increase in yield of rice under tropical conditions, through effects on both grain number and kernel weight. Early thinning of wheat crops led to an increase in ear number per plant, later per-anthesis thing increased kernel weight. The increased in kernel weight from crop thinning at anthesis ranged from 6- 14% being greater at higher temperatures. In rice Crops at high altitudes grain yield may be positively related to temperature and radiation levels during grain filling, but negatively related at lower latitudes. Spikelets number in rice is related positively to solar radiation but negatively to temperature during the reproductive growth. Cereals grain yield may be positively associated with both temperature and incident radiation in the lower part of their range

**Yield components**

Tillers may be accounted for 30% of the total grain yield in a dense stand of wheat (300 plants m-2) about half of the plants producing only the main stem ear, at half that plants density 50-60% of the yield may come from tillers and third of the plants may have as many as four ears. Increase in grain number per ear and kernel weight may also help components for low stand densities. The physiological basis of crop growth was given by Watson (1952).

Three stages of cereals grain ripening are recognized:

1. The milking stage

2. The dough stage

3. The flint stages

Yield attributes:

1. Number of plants per sq. metre

2. Number of effective tillers per plant

3. Grains per earhead

4. Test weight

**Contribution of plant parts to the grain yield**

100% Grain yield=Other leaves, stem etc.- 60%, Flag leaf- 35%, Awns- 5%

**Grain growth**

It depends upon the reproductive phase of crop plants. Longer the reproductive phase longer will be grain filling stage. Grain growth takes place mainly during milking stage and after this.

Grain growth and length depend upon the following factors:

1.Leaf photosynthesis

2.Leaf age

3.Canopy photosynthesis

4.Translocation of photosynthate

Net Photosynthesis = Gross Photosynthesis - respiration

Other factors:

•Genetic make-up of variety

•Cultural practices

•Environment

**Summary**

•We can increase grain yield by reducing respiration losses

•Proper cultural practices

•Selection of efficient plant varieties