temperature was large (Quinby *et al.*, 1973); Wade, unpublished). Research at ICRISAT (Peacock, 1982) has shown that the rate of leaf extension is marked reduced above 34°C. The base temperature for high leaf extension is around 15.5°C. Water stress and high temperature had a drastic effect on the rate of extension.

Peacock (1982) reviewed the effect of environment on leaf growth. McCree and Davis (1974) reported that dry matter production is highly affected by leaf area especially during Growth Stage 1 (GS1), when the canopy is developing. In Poaceae, the components affecting leaf area development are time for panicle initiations (through its leaf number), rate of leaf appearance, leaf expansion and leaf senescence, the absence of water and nutrient stress and are largely governed by temperatures (for maize, Watts, 1974; for temperate grasses, Peacock 1975 and 1976; for temperate cereals, Gallagher, 1979; for sorghum, Troughton *et al.* 1974, and McCree and Davis, 1974). Johnson (1967) showed that leaf extension was closely related to air temperatures, particularly at night.

Leaf area, which is the basis of growth and yield, depends on the number of leaves, rates of expansion, eventual size of the leaves and senescence. The physiology of leaves, with special reference to radiation, interception and photosynthetic conversion, depends on the number and arrangement of the leaves; it also depends on panicle initiation where large genetic variations exist. Differences in the number of leaves produced, the rate of leaf production and panicle initiation depend on cultivar, temperature and photoperiod (Quinby *et al.*, 1973). Eastin (1972a) and Brown (1978) state that much of the leaf expansion occurs concurrently with panicle development during GS2 and that the 2 processes are competitive for substrate.

Importance of leaf area development

The importance of leaf area in determining canopy photosynthesis and water used by a crop is well recognized. Formation and maintenance of active leaf area is essential for continued production of photosynthate to maintain carbon and energy flow to both developing grain and plant tissues (Jordan *et al.*, 1983). Measurement of the light photosynthetically active radiation (PAR at 400 – 700 nm wavelength intercepted by the crop canopy) has become a very useful tool in such studies. The net PAR for a plant can be determined once the total canopy leaf area of the plant affecting leaf area development is calculated (Chapter 6).

The information on leaf area is needed for calculating transpiration when the plant canopy provides only a partial ground cover. In the dynamic sorghum model of Arkin *et al.* (1976), the leaf area development was modelled from inputs of number of leaves produced by the hybrids plants and the maximum area of each leaf. The rate of leaf expansion out of the whorl was related to the mean daily temperature when the plants were adequately watered. Arkin *et al.* (1976) developed a mathematical model for computing light interception in a grain sorghum plant canopy. Sound data base between measured and computed dry matter accumulation in the study by Arkin *et al.* (1976) indicated that the model was responsive to morphological differences in different genotypes.

About one-third of total leaf area was fully developed at the time of panicle initiation. One to 3 lower leaves may also have senesced by that time. Following

panicle initiation, the remaining leaves expanded in succession. Simultaneously, the lower leaves continued to senesce. By soft dough stage 8 to 12 functional leaves were present, at hard dough stage, additional leaves were lost. By the time the grains attained physiological maturity, the remaining functional leaves turned yellowish brown or attained senescence (Arkin *et al.* 1976).

The leaf growth of a sorghum crop can be measured in terms of dry weight of leaves and leaf area of whole plant per unit ground area. As leaves intercept solar radiation, leaf area index (LAI) is used by crop physiologists for crop photosynthesis and growth analysis (Yoshida, 1972): LAI = [(Sum of leaf area of all leaves, cm²) / (ground area of field where the leaves have been collected, cm²)].

In sorghum all the exposed green leaves are measured for LAI. This indicates the magnitude of leaf area relative to the ground. For example, if LAI=3, the crop has a leaf area thrice as large as the ground area. LAI greater than 1 is needed to cover the ground surface because all the leaves are brighter, flat and not in the same plane to cover the ground surface. LAI increases with the age of the crop and reaches its peak around flowering. After heading with the senescence of leaves, LAI declines.

Leaf area of the sorghum crop could be measured with the help of an automatic leaf area meter but the leaf area of a individual leaf could be measured in the following way (Ajmad, 1975):

Leaf area (cm²) = length (cm) x breadth (cm) x 0.74.

The product of leaf length (L) and maximum width (W) is highly correlated with the actual area (A) of fully developed leaves. The formula A = L X W X 0.75 estimate the area of most individual leaves with reasonable accuracy but tends to overestimate the area of small leaves (Bueno and Atkins, 1981). Fourth leaf from the top shows good correlation with total leaves, but no single leaf accurately reflects the leaf area which is influenced by genetic and environmental factors (Bueno and Atkins, 1981).

A study on 4 sorghum genotypes during the rainy season of 1981 showed that there was a gradual increase in leaf area from 15-30 days after emergence, but a sharp rise from 30 - 45 days. From 45-60 days, leaf area showed slight decline later, followed by a sharp one due to senescence of leaves (unpublished, Fig. 4.23).

Water stress effects on leaf growth

Several reports show that water stress affects leaf growth considerably. Sivakumar *et al.* (1981) reported the LAI differences in sorghum in an alfisol and vertisol, and also under irrigated and nonirrigated conditions. Under irrigated conditions LAI increased up to 3.5 in vertisol, but reached nearer to 4.0 in alfisol under nonirrigated conditions. LAI did not show any difference in alfisol and vertisol. This shows that leaf area development is directly affected by water stress.

Slatyer (1973) stated that the growth of a plant organ depends on cell division followed by expansion and differentiation of individual cells. Uptake of water and nutrients, synthesis of structural materials and metabolites and transfer of substances between cells, are all related events. One of the most commonly observed effects of water deficits on plants is a reduction in growth with the effect being most pronounced in organs that are actively growing at the onset of water stress. Both cell division and cell expansion are known to be very sensitive to water
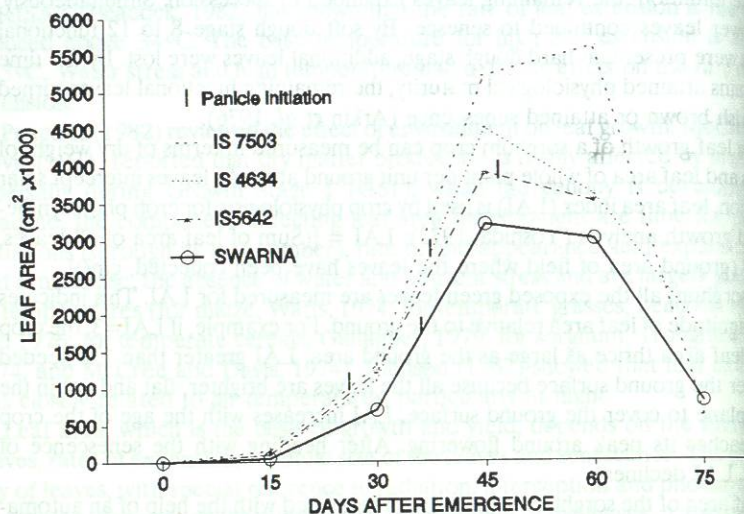
Figure 4.23 Development of leaf area in leaves of glossy and nonglossy lines of sorghum (unpublished).

deficits as measured by a decrease in plant cell number and their size (Boyer, 1968, 1970; Acevedo et al., 1971; Clough and Milthorpe, 1975). Hsiao (1973) suggested that the rate of cell division may decrease as a result of decreased cell expansion. With regard to plant adaptation to limited water supply, the turgor pressure acts as the physical force for cell enlargement. The driving force for the stretching and yielding of the cell wall is the turgor pressure (Lockhart, 1965a). Therefore, to maintain a steady growth rate, the rate of water uptake must equal to the rate of cell wall formation. Before either of these events can take place, turgor pressure should drop inside the cell. If there are no volume changes, this drop in turgor must be brought by a decrease of stress in the cell wall which is a phenomenon of stress relaxation (Yamamoto et al., 1974). Stress relaxation seems to be the primary event in cell enlargement, while uptake of water and cell extension occurs only afterwards. If the threshold turgor is relatively high, a small drop in turgor may reduce the rate of cell enlargement. For cell elongation to be irreversible, synthesis and deposition of new cell wall material must occur. In addition, the initial growth of the cell wall appears to be under metabolic and hormonal control (Yamamoto et al., 1974; Green and Cummins, 1974). Subcellular changes that occured in sorghum leaves during increasing water stress and subsequent rewatering are described by Giles et al. (1976). Stomata closed, abscisic acid levels were elevated as well as the amount of starch in the bundle sheath. Chloroplasts were reduced by decrease in water potential. Swelling of the outer chloroplast membrane and reorganization of the tonoplast to form mall vesicles from the large central vacuole occured under decreasing water potential. On rewatering

large amounts of starch reappeared.

Effect of water stress on leaf extension

Leaf extension patterns for grain sorghum were studied by Johnson (1967), who reported that LER of irrigated plants was low during night, reached mid-point around 8:00 to 9:00 am and attained its maximum between noon and 16:00 hours. The temperature varied between 15 to 18°C at night and 30 to 35°C at midday. Leaf extension is reduced little by water stress (ICRISAT, 1982; Seetharama et al., 1980, 1982). Sánchez-Díaz et al. (1971, 1973) showed that there was no difference in leaf elongation between sorghum and corn under severe moisture stress.

Diurnal evaluation of leaf water potential (Ψ) of sorghum was studied in detail by Elias (1976) and was found to be related to changes in incoming solar radiation. With surface and an increase in energy flux, the rate of transpiration also increased and leaf water potential started to decrease. The incoming energy flux was highest around midday when transpiration was maximum and leaf water potential minimum; late in the afternoon, as the solar radiation decreased, Ψ increased. Elias (1976) showed that contrary to normal finding, the rate of leaf elongation under field condition was high when Ψ was low and vice versa. He found that the growth rate in sorghum was low at sunrise, increased between noon and 14:00, and decreased as the night approached. Turgor pressure (ΨP) decreased early in the morning but later increased, reaching its maximum midafternoon. This was the reason why rates of leaf extension at midday were extremely high. Elias (1976) interpreted that the osmotic adjustment played an important role through turgor in the high growth rates was observed. Other authors (e.g., Boyer, 1968) also reported that ΨP does not necessarily decrease with decreasing Ψ. Elias clearly demonstrated that the pattern of leaf extension is determined by the interaction of temperature and water status. When day temperatures were high, leaf elongation rate was reduced by a decrease in ΨP. The ΨP values measured from noon to 14:00 were usually high, and so were the rates of leaf elongation during these hours. Subsequently, he found that ΨP correlated well with leaf elongation rate under controlled conditions. Elias found the relationship between ΨP and LER positive. He found that high LER were associated with high ΨP and low LER correlated well with low value of ΨP. Elias (1976) also showed that within a sorghum crop canopy, the amount of transpiration declined from the top of the canopy to the ground, because of light interception by leaves. Hence, one would expect the upper leaves to transpire more actively and to have lower Ψ than the lower leaves. Leaf Ψ decreased with height up to the flag leaf during morning hours; in the afternoon, the flag leaf showed higher values than the leaf immediately below it. The causes for improvement in water status of the flag leaf in the afternoon were apparently related to stomatal operation. In most cases, the decrease in Ψ in different leaves was directly related to solar radiation. Fully exposed leaves had lower Ψ than those in the shade. It was indicated that leaf Ψ decreased due to osmoregulation, a drought avoidance mechanisms resulting in formation of more osmotically active cellular solutes (Stout et al., 1978). Greater leaf senescence of nonirrigated crop is another drought avoidance mechanism to reduce transpiration requirements (Stout and Simpson, 1978).

Water stress extended the period of leaf and stem growth and inflorescen[ce] development, and led to decreased vegetative and reproductive growth in sorgh[um] (Stout *el al.*, 1978).

The difference in stomatal conductance in sorghum under water stress was d[ue] to differences in osmoregulation rather than leaf tissue elasticity. A concep[tual] model of osmotic adjustment to a crop with increasing water deficit was develop[ed] (Wright, 1981).

CULM

The vegetative shoot apex consists of a single tunica and a massive corpus (L[ee,] 1974). The ultrastructure of the tunica and corpus and the young stem are diff[er]ent from the outer corpus with respect to the morphology of the plastids and [the] development of vacuoles. Plastids in the tunica and outer corpus are small a[nd] the thylakoids are poorly developed. Protein and starch granules are usu[ally] accumulated inside the leucoplast in the inner corpus and underlying stem reg[ion.] Starch granules are deposited in the stroma, while the proteinaceous granules a[re] bound by membranes inside the plastid. The thylakoids of the plastid tend [to] aggregate together in the inner corpus and the young stem region. Endoplas[mic] reticulum plays an important role in the formation of vacuoles. Development [of] vacuoles take place by dilation of the cisternae of endoplasmic reticulum. La[rge] vacuoles, presence of ergastic substace in the plastids, differentiation of p[ro]plastids into leucoplasts are considered as important morphological expressi[on] of cell differentiation. Tunica and corpus region are regarded as promerist[em] (Lee, 1974). Therefore, the stem apex consists of a superficial primordium form[ing] the apical dome which is enclosed by ensheathing leaf primordia and develop[ing] leaves. Leaves are derived as lateral primordia from the base of the apical m[eristem] stem.

The culm or stem is made up of a series of alternating nodes and interno[des] encircled by leaf sheaths. The stem is slender to stout with length varying fr[om] 0.5 to 5.00 cm, is broader at the base and narrower at the upper end. The n[ode] is enveloped by the leaf sheath and appears as a ring at the base of the l[eaf] sheath. A bud is present at each node, except at the flag leaf and sprouts [on] alternate sides of the stem. Sometimes these buds may develop into axillary till[ers.] Basal tillers are formed at the first node (House, 1980).

Stem anatomy

Stem anatomy in sorghum is typical to that of grasses. In a transverse sect[ion,] the epidermis consists of cubical to boat-shaped epidermal cells with a thicke[ned] outer wall. The ground tissue consists of thinwalled parenchyma. The vascu[lar] bundles are joint collaterally and scattered in the ground tissue. Just below [the] epidermis, there is a continuous layer of sclerenchyma. The number of cell lay[ers] in the sclerenchyma band and thickness of cell wall show variation in differe[nt] genotypes. In some genotypes, the hypodermal bands of sclerenchyma are conne[ct]ed to the sclerenchyma bundle sheath of the subtendending vascular bundl[e.] There are alternate bands of large and small vascular bundles below the hypo[der-]

[der]mal sclerenchyma band. The vascular bundles towards the center are larger in size. Mechanical tissues in the outer vascular bundles are extensive, particularly in the peripheral region. The genotypes show much variation in internal structure which includes intensity of mechanical tissues, intensity and size of vascular bundles, etc. (Figs. 4.20-4.21). The various types of vascular bundles were described in detail by Patel *et al.* (1981) in sorghum (*Sorghum vulgare*). Mesocotyl shows a cylindrical vascular tissue with 4 to 6 collateral, endarch vascular strands and presence of large metaxylem vessels between the 2 adjacent collateral bundles.

Three layers of vascular bundles are recognized in the internode at the periphery to the central part. The outermost layer comprises a variety of bundles, the central layer of middlesized, elongated fibrovascular strands and the innermost layer of small bundles.

In the stem, different types of vascular bundles are noticed: 1- large bundle ensheathed by sclerenchymatous mass on lateral and xylary polar ends and a voluminous phloic cap of sclerenchyma just beneath the epidermal layer, 2- similar to the first but without epidermal sclerenchyma sheath, 3- comparatively small with smaller xylary fibrous strands and the phloic cap equal in volume to that of the xylic sclernchyma strand, and 4- smallest vascular bundles intermingles between the above 3 types with absence of phloic elements.

Nodal vasculature is most complex. Some bundles in the node lack sclerenchyma sheath. The structure of the inflorescence internode is different. The most stricking feature is the absence of the subepidermal masses of very large fibrous strands, and shape and size of vascular bundles differ in internodal vascular
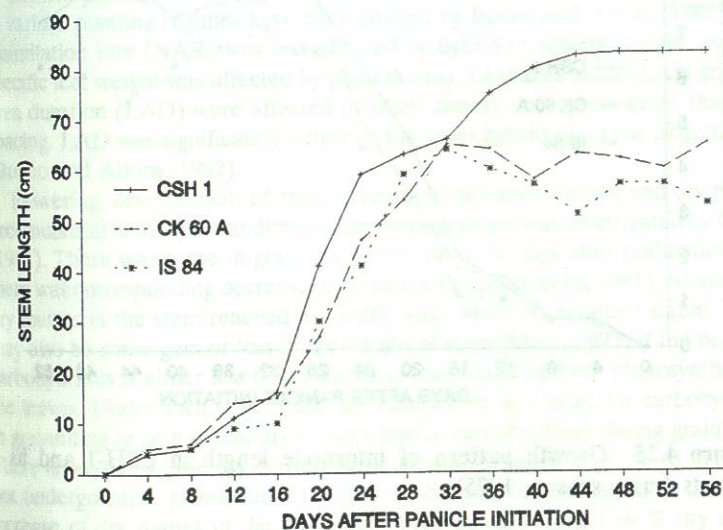

Figure 4.24 Stem elongation of CSH-1, and Indian hybrid, and its parents at different stages (rainy season, 1975).

bundle. Plants resistant to lodging had generally larger vascular bundles than the lodging-susceptible types. The former were also more resistant to senescence in all tissues after freezing. This is associated with the number of total nonstructural carbohydrate in the resistant types. The lodging-resistant lines, which are generally perennial in nature than the susceptible types, showed higher dry matter value than the later at all growth stages. There was an association between lodging susceptibility and higher potassium and stalk protein (Esechie, 1975). Attempt could be made to correlate the intensity of mechanical tissue in the stem with lodging resistance.

Stem elongation

Elongation of the stem internodes begins shortly after panicle initiation and increases rapidly, starting with the short basal internodes, followed by the longer upper internodes and finally the peduncle. This produces the common sigmoid pattern of stem elongation with the rate of elongation at its peak at the flag leaf stage. There may be further increase in stem length following flowering in some cultivars due to continued elongation of terminal internode - the peduncle (Maiti, 1977; Figs. 4.24-4.25). As both leaves and stem contribute to the production of dry matter, the partitioning of dry matter in different plant parts will be discussed next.
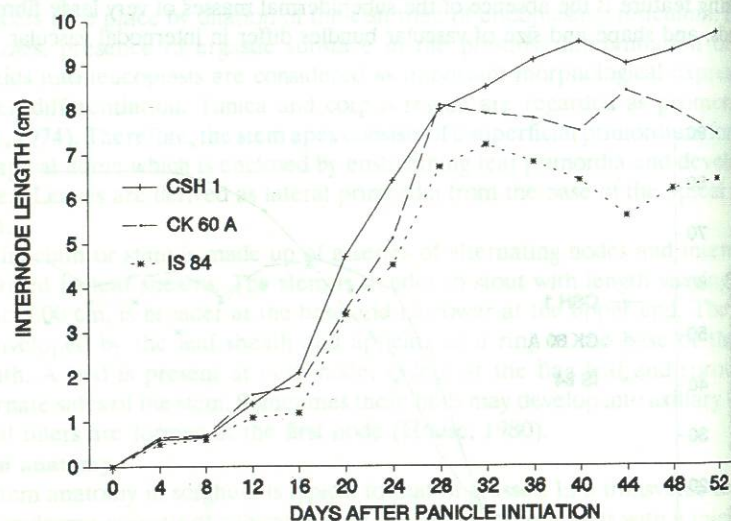

Figure 4.25 Growth pattern of internode length in CSH-1 and its parents (rainy season, 1975).

DRY MATTER DISTRIBUTION IN DIFFERENT PLANT ORGANS

Sorghum grain that shows a C4 dicarboxylic acid pathway of photosynthesis, which is believed to be an adaptation for efficient carbon fixation in environments where water limits growth. Arkin *et al.* (1976) formulated a dynamic growth model for sorghum. They concluded that at panicle initiation, all the remaining leaf primordia are laid and stem elongation takes place along with the extension and expansion of new leaves. This leads to a quick increase in leaf and stem dry weight.

The maximum dry weight of leaves was reached at the time of half bloom (stage 6) and of the culm between growth stages 6 and 7 (soft dough) or at full bloom. At the time of maximum culm weight, the plant had accumulated one half of its dry weight which then decreased until the grain was at hard dough-stage 6. After that, a gradual increase in culm weight occured. Of the total dry matter, leaves contribute 20%, culms 20% and heads and grain 60% (Reeves, 1971, cited by Vanderlip *et al.*, 1973).

Studies on growth and nutrient accumulation in grain sorghum by Jacques *et al.*, (1975) indicate that nutrient concentration (Zn, Cu, Fe, Mn) in blade, sheath, culm and head tissues generally decreased until maximum dry weight was reached, and then stabilized or decreased only slightly and gradually as grain developed. Whole plant nutrient concentrations decreased through most of plant growth (Jacques *et al.*, 1975).

Growth parameters throughout development for a range of sorghum hybrids in various planting regimes have been studied by Bueno and Atkins (1982). Net assimilation rate (NAR) was less affected by hybrid or sowing regime, average specific leaf weight was affected by plant density. Leaf area index (LAI) and leaf area duration (LAD) were affected by plant density and hybrid more than row spacing. LAD was significantly longer in the taller hybrid of a near isogenic line (Bueno and Atkins, 1982).

Flowering, development of grain, changes in moisture content and dry matter accumulation in the grain at different developing stages was investigated by Chang (1981). There was a rise in grain dry weight up to 40 days after pollination, and there was corresponding decrease in percent moisture (Chang, 1981). At anthesis, dry matter in the stem reached its zenith, after which it remained stable. There may also be some gain or loss in dry weight of stem (Maiti, 1977) if the need for carbohydrates is either less or greater than that available from photosynthesis in the leaves. Under such conditions, the stem serves as a store for carbohydrates in grainfilling or as a repositary to store excess carbohydrates during grainfilling. There is relatively little dry matter distribution to the panicle as the panicle does not undergo rapid growth until the end of this period. During GS-3, the major increase of dry matter in the plant was in the panicle. About 50 % dry matter accumulated in the head, 25 % in the stem, and about 10 % in the leaf at the final stage. Dry weight of the stressed plants was about 75 % that of unstressed plant at maturity (Arkin *et al.*, 1976). Partitioning of dry matter to different plant parts

and its proportion varied in different genotypes (Maiti, 1986; Fig. 4.26). Carbohydrate content in sorghum culm changes with age of the crop. Total structural carbohydrate content showed increase the prebooting stage to anthesis (40%) in one sorghum cultivar, with much increase in succesive fractions. Diurnal variation, reaching maximum at late afternoon, were most apparent at the prebooting stage. Glucose content in the upper culm declined, and sucrose increased at anthesis (McBee and Miller, 1982). Sorghum genotypes show variation in biochemical components (carbohydrate, wax, chlorophyll and HCN) at different growth stages (García-Mendoza, 1986).
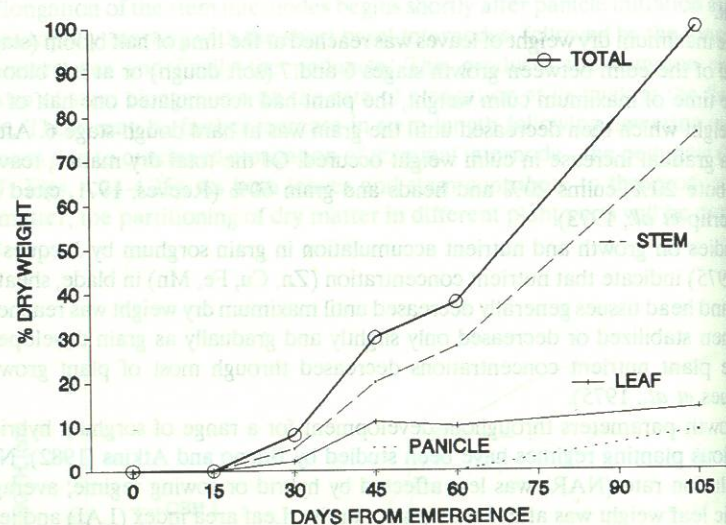

Figure 4.26 Partitioning of dry matter in different plant parts in IS-4634 in rainy season.

COMPARATIVE LOOK ON STEM AND HEAD GROWTH IN DIFFERENT SEASONS

Maiti (1977) observed that the stems of all cultivars continue to increase in weight after ceasing to gain height, attaining the maximum weight before the peak grain growth rate is reached. In postrainy season, maximum stem weights were reached in 28 to 36 days after panicle initiation, but in late postrainy season the period extended from 44 to 52 days. Comparative growth studies of head and stem in 3 seasons, rainy, postrainy, and late postrainy showed that dry matter production in stem and panicle was much lower in the postrainy season than in the rainy season. A further decrease was registered in the late postrainy season. Cultivar

22E was the only one that needed to draw translocates substantially on sources of assimilates to support grain growth which was most rapid in this cultivar. In rainy and postrainy seasons, stem dry weight tended to be lower at anthesis; the loss was more after anthesis, but there was a sharp rise in panicle dry weight. This might indicate the mobilization of stem reserve to the developing grain in the head, as observed in the case of wheat (Rawson and Evans (1971) and Austin et al. (1977) and in barley (Gallagher et al. 1975). In late postrainy season, there was considerable increase in stem dry weight and a negligible increase in panicle dry weight, indicating less translocation of assimilates. The favourable climatic condition prevailing in post-January caused considerable decrease in stem dry weight and negligible mobilization of stem reserves. As sink size and number were limited in late postrainy season, the lesser demand in the panicles led to the intensification of photosynthesis in the stem. During postrainy and rainy seasons, the sink size was high. This demanded more translocates and favoured mobilization of stem reserve to the sink (Maiti, 1986).

A comparative study on anatomy, morphology and growth characteristics of sorghum genotypes showed that the genotypes showed variation in morpho-anatomical characters in different growth stages, e.g. stomatal and epidermal cell frequency and correlations among these (Villanueva et al., 1988).

GENERAL COMMENTS

From this comparative study of leaf and stem growth in sorghum we can deduce that the growth of these 2 plant parts - as in any other cereal - involves several dynamic growth processes. The initiation and early development of leaves of any taxon raise important and complex questions concerning the regulation of development processes in plants. It is difficult to interpret the developmental processes of leaf which leads us to some pertinent questions raised by Steeves and Sussex (1972):

1- Why does the peripheral region of the shoot give rise to outgrowth ?
2- What mechanism regulates the placement of the outgrowth in the meristem ?
3- What influences the outgrowth in such a way to cause them to be leaves ?
4- What is the nature of the response to these influences that result in leaf development ?

Several theories have been postulated to seek answers to these questions. However, the formation of leaf primordia is a major activity of the shoot lateral meristem. The change in growth pattern of a particular group of cells results in the formation of a distinctive organ - the leaf. The leaf has a definite developmental destiny characterized by its bilateral symmetry and elaborate structural specialization.

Leaf extension and the growth of sorghum leaves takes place due to active cell division and expansion of the leaf meristem located at the base of the leaf sheath. The growth of the stem is dormant until the transformation of vegetative meristem to reproductive meristem and the formation of all the leaf primordia. The initiation of the panicle meristem accelerates the growth of the stem. At this point,

several dynamic forces lead to the elongation of the panicle internode, growth of the stem and expansive growth of the leaf. Vertical growth is controlled by the intercalary meristem. Along with lateral expansive growth of the leaf, the panicle component also grows simultaneously. All these processes are coordinated by a hormone-controlled system of organogenesis. Therefore, it is appropriate to conclude that any adverse climatic conditions prevailing during the dynamic growth process will directly affect crop growth as a whole and consequently, its yield. Among the mineral elements, nitrogen in particular influences the cell expansion process. High nitrogen supply will lead to large leaves. The potential of leaf development is influenced by nutrient supply, light and temperature (Milthorpe and Moorby, 1976). Water stress has a direct effect on cell division and cell expansion (Boyer, 1968, 1970; Lockhart, 1965 a,b). Cell division of plants appears to be less affected than expansion in the higher level of water content but does not cease at lower levels (Milthorpe and Moorby, 1976). There is an immediate effect on cell expansion rate due to inadequate turgor pressure required for the maintenance of cell wall growth (Lockhart, 1965 a,b). Hence, prolonged drought directly affects the crop with reduced photosynthesis, reduced mineral nutrient supply, protein synthesis and other aspects of metabolism, as all these adverse conditions affect leaf area development, stem elongation, panicle growth and partitioning of dry matter in plant parts. It is well established that a very strong relationship exists between the temperature and the water status of the plant. Nevertheless, we also know that for all practical purposes, both these factors cannot be separated. Therefore, a more comprehensive approach would be to study other environmental factors affecting leaf growth. Leaf growth and canopy development are of great interest to the crop physiologist. Efficiency of the crop with respect to leaf and canopy development for light penetration would offer suitable recombination of desirable characteristics in cultivars. A dwarf cultivar with few leaves, greater efficiency of these 2 components in tapping solar energy to a large productive head would offer an ideal plant type to the breeder. Therefore, the challenge to the crop physiologist is to come up with an ideal plant type that combines these desirable characteristics.

5

PANICLE DEVELOP-MENT AND PRODUC-TIVITY

INTRODUCTION

To understand the physiology of crop growth and yield, a thorough knowledge of the developmental processes is essential. In cereals, panicle development and productivity are the principal factors governing yield potential. Productivity of cereals thus depends on how efficient crops are in the biological conversion of radiation into economic yield at the physiologically critical phase of panicle initiation and development and ultimately, in the partitioning of photosynthates into grains. In sorghum, unfavorable conditions affecting the normal developmental process are reflected in the initiation of the reproductive apex and the formation of florets.

At this juncture, crop physiologists are trying to understand panicle development under stress and optimal conditions during rainy and postrainy seasons, and to relate these to economic yield. This aspect is going to be discussed for different crops before focusing on sorghum.

Production of dry matter, its partitioning between grain and straw, and efficient translocation of dry matter and nutrients to the developing grains is the principal contributing factor for productivity in rice (Sircar, 1977). Some genotypes may have higher photosynthesis, but because the sink number, size and storage capacity is limited, the yield may be less. Sircar (1977) stated that the yield of photosensitive winter rice in India is higher in dry postrainy season than in wet rainy season because of higher solar energy incident on the leaf surface.

The physiological bases of growth and yield in wheat and barley have been studied in some detail. Porter et al. (1950) demonstrated that carbohydrates in the grain are derived mainly from photosynthesis in wheat. Barnel (1938) and Stoy (1965) found that wheat and other cereals contain considerable amounts of soluble carbohydrates at anthesis in the stem, but at maturity, these carbohydrates virtually disappear. In wheat, there is substantial loss in the dry weight of the stem during the most rapid period of grain filling, but stem weight rises again (Evans and Wardlaw, 1976; Austin et al., 1977). That this loss was accounted for partly by the stem may be a reflection of the balance between the demand exerted by the grain and the supply from the assimilatory organs. To overcome this problem, a reduction in accumulation of stem reserves and a progressive increase in the proportion of assimilates accumulated in grains is desirable (Evans and Wardlaw, 1976). Sink limitation is as equally important as source limitation in determining grain yield (Evans and Rawson, 1970; Bremner and Rawson, 1972). It was observed in wheat