and have a distinct granular structure in contrast to the very uniform pattern of the wall deposits (Parry and Kelso, 1975).

Xylem parenchyma surrounding the metaxylem may be thick- or thin-walled. The xylem and phloem show a typical radial arrangement, protoxylem bundles present on the exterior of the metaxylem (exarch). The size, number and thickness of the metaxylem bundle varies according to cultivar. The pith is solid, with cells to elongated compactly arranged parenchyma cells. The size of pith varies in different cultivars (Fig. 6.9).

Root surface and root hairs of sorghum secrete 2 types of mucilage. The fibrillar layer exists on parts of the outer wall of epidermal cells and on root hairs. It consists of long fibrils parallel to the cell wall and connected by anastomoses. This layer can be colonized by bacteria and in thick layers, groups of bacteria were found. The mucilage is secreted from the endoplasmic reticulum, Golgi apparatus as well as mitochondria. The second type consists of small, heterogeneous and structureless drops on the distal part of the roots hairs (Werker and Kislev, 1978a,b).

Seedling root anatomy and *Striga* parasitization

Twenty-six sorghum cultivars representing a wide range of susceptible and resistant genotypes to *Striga asiatica* were studied for *Striga* parasitization and the role of root anatomy factors (Maiti *et al.*, 1984b).

Parasitisation on the susceptible sorghum root

Germination of *Striga* began with the radicle (or the haustorium) making its way out through the seed coat. The plumule grew very slowly at this stage and remained with the seed coat until the haustorium established vascular contact with the host root. The plumular axis was visible within the arch of the 2 cotyledonary leaves. The bulbous haustorium at the tip of the radicle made contact with the epidermis of the host and pressed against the cortical cells. These became distended and the haustorium came in contact with the endodermis. The outer tangential wall of the endodermis was disrupted, allowing the haustorium to penetrate to the stele, establishing a vascular connection with the host vascular bundle. In some cases, the presence of a substance which stained dark green with toluidine blue was noted when the haustorium was in contact with the endodermis. A chemical substance which softened or dissolved the cell walls of the host tissue was also produced by the advancing haustorial cells in *S.asiatica* (Saunders, 1933) and *S.gesperioides* (Okonkwo and Nwoko, 1978).

The invasion of the host stele was by the tracheids developed from the axis of the yound haustorium. These tracheids were characterized by the spiral thickening (Rogers and Nelson, 1962) and penetrated the xylem vessels either by dissolving cell walls or by mechanically disrupting them. This made the host parasite connections complete. At this stage, the haustorium was almost double the size of the host stele.

Development of the haustorium in the resistant cultivars

In resistant cultivars, the attachment to the root and the penetration of the cortex by the haustorium were similar to the process in the susceptible cultivars. However, in the resistant cultivars most of the haustoria failed to penetrate the endodermis in contrast to the susceptible cultivars in which most haustoria were

succesful in establishing vascular connections with the host root stele.

Many resistant cultivars were found to have thickening in the endodermal cell wall and the pericycle cells were also found to contain crystals. This can be observed in the resistant cultivar N13 (a local cultivar, Nandyal), in contrast to the susceptible CSH1 (an All India Coordinated Project hybrid). In another study, the course of development of thickenings was followed in these 2 cultivars in the absence of *Striga*. Cell wall thickenings in these 2 tissues as well as the presence of crystals was evident in N13 as early as 7 days after germination. In contrast, CSH1 had only negligible thickening in the endodermis and contained no crystals even 14 days after germination. By 28 days, there was only a small increase in thickening in the endodermis and pericycle of CSH1, whereas N13 accumulated considerable thickening materials, especially in the pericycle. In addition, several apparent responses to the invasion of the *Striga haustorium* were observed in certain cultivars. One of these appeared to be extra lignification in the pericycle cells at the point of contact of the haustorium with the endodermis in N13 and IS 4202. As a result, the haustorium appeared to become distorted and failed to penetrate the stele. In another resistant cultivar IS 8686 (SRN 4841), a few haustoria did penetrate the endodermis but on reaching the xylem, tyloses like occlusions from *Striga haustorium* were found in the xylem vessel.

Host root anatomy vs field resistance for Striga

Aspects of host root anatomy like thickness of the inner tangential wall of the endodermis, degree of lignification of the pericycle, and the frequency and size of crystals in the endodermal cells were studied in 26 selected cultivars. Generally, resistant cultivars showed a high degree of endodermal and pericyclic thickening and the presence of silica crystals, whereas susceptible ones showed less thickening and no crystals. Based on the overall score, all the cultivars in the resistant group had high or intermediate rating for all the 3 characteristics.

ESTABLISHMENT OF ROOT SYSTEM IN THE SOIL IN RELATION TO THEIR FUNCTIONS

Root system distribution in the soil is an indicator of the nutrient-uptake capability of a genotype. Sorghum roots are capable of penetrating the soil, 2 to 5 cm/day (Nakayama and van Bavel, 1963), reaching considerable depths quite early in the growing season. Kaigama *et al.* (1977) reported that sorghum roots of Pioneer 846 reached a maximum depth of 140 to 150 cm within 42 days after emergence. Myers (1980) found that the roots of both Pioneer 846 and RS 610 reached a depth of 135 cm by panicle initiation, 22 days after emergence. Both reports showed that a large part of the root mass was located within 15-20 cm of the soil surface.

Kaigama *et al.* (1977) showed that more than 90% of the total root weight was within 15 cm of the soil surface. Myers (1980) reported only 76-79% of the root mass in the 0-20 cm layer. It is practical, therefore, to restrict root sampling to the top 10-20 cm of the soil to get the real picture of root intensity of a genotype. Myers and Asher (1982) stated that sorghum roots remain active and capable of

nutrient absorption until very late in the growing season.

The plant root system plays an important role in determining the rate a amount of soil water available to the crop (Jordan and Sullivan, 1982). B (1974) stated that modification of the root system to extract greater quantities soil water or to regulate the rate of depletion play an important role in drought avoidance mechanism. There is genetic variablility for root characteris in sorghum (Jordan *et al.*, 1979 a,b; Blum *et al.*, 1977 a,b; Wright *et al.*, 1983; N and Weibel (1978); Bhan *et al.*, (1973); Jordan and Monk (1980), therefo scope for selection for better root systems exists. The genetic variability is gener expressed in the distribution of growth (dry matter) between the shoot and ro as well as behaviour of root axes and lateral branches. High root to shoot ra in young plants is found to be correlated with superior drought resitance (N and Weibel, 1978; Bhan *et al.*, 1973). Research needs to be directed to study value of specific root traits to drought resistance. Jordan and Sullivan (1982) stat that a choice of the root 'ideotype' should be based on a thorough understan of the seasonal pattern of water availability. Increased rooting depth tend increase water availability (Jordan and Miller, 1980). Increased rooting densit the deeper layers of the soil surface allows greater absorption of water in the s Water in the soil is depleted more slowly when there is a serious water defici deficits occur near anthesis, a sensitive growth phase, then deep rooting m contribute to yield maintenance, but a delay in water stress may avoid dama the crop provided water is available to complete grain development. Deep roo is considered to be an useful mechanism for crops grown on soils where de profile recharge occurs during the off-season (Jordan and Miller, 1980). Passio (1972) provided evidence that grain yield in wheat was highly correlated with water available at anthesis. Richards and Passioura (1981) showed genetic varia ity for xylem vessel diameter in wheat roots. Similar efforts need to be mad the case of sorghum (Jordan and Sullivan, 1982). Under drought conditions, soils in the shallow layers start drying from the surface, but the deep horizo the soil may have sufficient soil moisture. Therefore, deep rootedness is a feat that facilitates drought resistance. High root-shoot ratio is also considered adaptation for drought resistance in rice (Yoshida, 1981; Jordan and Miller, 19

WATER AND NUTRIENT UPTAKE BY ROOT SYSTE

The main function of the root system is to siphon water and nutrients from soil for the growth of the plant. Solar radiation, temperature and humidity important forces operating on the foliage and result in a constant demand water by the plant. In order to maintain the normal vital activity of the plant, cells in the tissues should be turgid. Plants give out excess water through stomata by a process known as transpiration. The growth of plant depends on h efficiently the root system of the plant taps available water in the soil. Un drought conditions, when the shallow layers are depleted of water, the pla should have a deep root system to tap water from deeper layers of the subs The rate of water absorption from a given soil volume should be proportional

the effective total length or intensity of the root system. The high rate of water absorption leads to a more rapid decrease in soil water in the shallow layers; more water is available to the roots deeper in the soil. Details of the water uptake process is explained in Chapter 8.

Along with water, plant roots absorb both macro- and micro-nutrients for normal growth. To optimize absorption of nutrients from the soil, an adequate concentration gradient should be maintained between the root surface and soil solution. The process of nutrient absorption consists of both active and passive ion absorption. The gradient of the mineral concentrations in the cell sap is maintained by the ascent of sap from the root to the foliage. Nutrient absorption by the root system depends on nutrient concentrations in soil water.

Nutrient content translocated through root is related to the photosynthetic activity of leaves because several essential nutrients are directly or indirectly related to photosynthesis and respiration. For example, nitrogen forms the main component of proteins which in turn is the main constituent of protoplasm, chloroplasts and mitochondria. Phosphorus is an energy-rich compound directly related to the metabolic processes. Similarly, potassium regulates the opening and closure of the stomata, promoting carbon dioxide diffusion in the green tissues. Nutrient deficiency disrupts the normal growth and development of the plant showing hunger signs such as yellowish leaves, a symptom of nitrogen deficiency, or a purplish pigmentation of the culm and leaves due to phosphate deficiency. Nutritional disorders of some elements causes visible symptoms in sorghum (Gallaher *et al.*, 1975; Kawasaki and Moritsugu, 1979; Clark, 1982). Aluminum toxicity reduces root growth (Clark, 1982). The mineral nutrition of sorghum was reviewed by Myers and Asher (1982).

Climatic factors play an important role in the uptake of nutrients. In a low rainfall area where crop population is sparse, the response to fertilizer is less. For crops grown predominantly on stored moisture, progressive drying of soil from the surface downwards starves the upper part of the soil of mineral nutrients (Myers and Asher, 1982).

Nitrogen Nutrition

Mirhadi and Kobayashi (1979) studied the effect of different levels of nitrogen application on growth, grain yield and chemical constituents of grain sorghum. Nitrogen content was highest in green leaf blades, followed by stems, roots, dead leaves and threshed head parts. This order was affected by nitrogen level in the medium. They found that nitrogen content in grain increased with an increase in nitrogen in the medium. They also observed that the amount of nitrogen required for the highest yields of crude protein in the grain was very high, suggesting the need for nitrogen fertilization. They also showed that the total nitrogen content per plant unit, dry weight of each plant part was remarkably higher at early growth stages, but decreased rapidly towards the soft dough stage. At this stage, there was no correlation between nitrogen content and the age of the plant. Nitrogen absorbed by the plant was distributed mainly in the stem and leaf blades during the vegetative stage, but was gradually translocated to the head for the development of grain. Nitrogen uptake of the plant was reported to be quite similar to that of fresh weight of plant; the total nitrogen in the plant was observed to be highest

at the hard dough stage. They found 2 peaks of absorption of nitrogen: at vege tive stage for the rapid development of plant parts and the reproductive stage, fo the development of grain.

Nitrogen and phosphorus uptake

Myers (1980) observed a relationship between root development and nutrie uptake in sorghum. Root development was rapid during the early crop growi cycle, reaching a peak dry weight at the mid-elongation phase, declining thereafte Nitrogen and phophorus levels were highest in roots when applied during the mi elongation phase, but declined at later stages.

Sometimes, even though the surface soil is nutrient rich, it is too dry for th roots to take up nutrient. Nutrient accumulation occurs at depth and it has bee reported by Lavy and Eastin (1969) that substantial amount of ^{32}P occurred depths of 30 and 60 cm. Smith and Myers (1978) found that much of the phospha rus and nitrogen uptake in water stressed dry land sorghum during grainfilling too place from the subsoil. This cautions the assessment of nutrient status of th sub-soil for a correct interpretation of the results of the field experiment. Mye and Asher (1982) and Cowie (1973) made a detailed study of the effect of N stre on N distribution in cultivar RS 610 in solution culture. They showed that und favorable growing conditions in the field, very little N remained within the root zone by anthesis when the fertilizer rate was (1/2 kg/ha). In the highest N trea ment (336 kg/N/ha), there was sufficient N in the soil during grainfilling. Significa net losses of N were observed from N-stressed sorghum after flowering.

ROOT SYSTEMS STUDY TECHNIQUES

Brick chamber technique

A brick chamber method was developed at ICRISAT (unpublished) to stu sorghum root development. The chamber (65 cm long, 50 cm wide, and 150 c deep) with 3 cemented sides, and a front made of brick and smeared with mu The chambers were gradually filled with soil (red or black) followed by continuo addition of water, and continuous packing of the soil with bamboo sticks for u form compaction. After filling with soil the brick chambers were exposed to t rains throughout the rainy season to ensure natural compaction before being use Once the desired amount of growth had occured, the bricks of the front wall we dismantled brick by brick from the top, and the roots were washed slowly w water by using a hose pipe. The whole root system can then be exposed, and t pattern of distribution of roots in different soil layers can be investigated.

Though the soil compaction in brick chambers did not simulate the bulk dens in the field, nevertheless a comparative study of the growth and development whole plant root system of different selected genotypes was possible in the chambers.

General patterns of root development (genotypic comparison)

Improvement in root development and function seems to be reflected in fi crop yields. Under periods of water stress, plants must proliferate roots i unexploited areas of the soil. The plant's ability to endure water stress is governe mainly by the rate of root proliferation and establishment during periods of

favorable moisture. Deep root systems also help in the efficient uptake of plant nutrients in the soil.

Laboratory study (Petri-plate culture)

It is important to know whether different genotypes show variations in the growth of radicle and plumule and how these variations are reflected in the final expression of the root systems. To obtain basic information about the growth of radicle and absorptive hair, different genotypes were grown in Petri dishes. Studies on CSH1, a non-heterotic hybrid, and 22E, a heterotic hybrid and their parents indicated that radicle and plumule lengths, and number of absorptive hairs were higher in 22E, a hybrid that showed heterosis in these parameters. A comparative study of radicle lengths of sorghum grown in Petri dishes for 5 days and in wooden trays indicated that a positive correlation existed between the 2 treatments.

Studies in pots and wooden trays

Studies on 36 genotypes in wooden trays for 20 days showed that the root system in different genotypes varied widely (range 0.044-0.15 gm/plant). Studies on the root system of another set of 48 genotypes on the 30th day indicate that there was much variation in their root systems, specially in total length, length of root canopy and average length of main adventitious roots. The total root length of the genotypes range between 106-191 cm, the majority of being between 104-174 cm. Thirty genotypes belonging to different taxonomic groups studied in pot culture also showed much variability in the components of their root system on the 30th day.

Root studies in polythene bags

To understand whether genotypic variability exists in the root system at the seedling stage, a set of 62 sorghum genotypes were grown in polythene bags (30 cm long and 10 cm diameter) in a greenhouse; 400 ml water were supplied in each bag containing 3 plants. Roots and shoots were washed 15 days after emergence. Genotypes showed significant variability for seedling vigor measured in terms of seedling height, seedling dry weight and also root dry weight.

CSH1, 22E and their parents (pot culture)

A comparative study on root systems of CSH1, 22E and their parents at 15, 30 and 45 days revealed that CSH1 showed much lower values compared to its parents in most major characteristics, but in total root length and dry weight of roots/shoot ratio, CSH1 exceeded its parents. In 22E, total root length and dry weight of root/shoot were much lower than those of its parents. The limitations of root studies in pot experiments are well known. Genotypic variability can, of course, be studied only between 15-30 days in the pot culture experiments.

Brick chamber method

The brick chamber method attempted to study root development of CSH1 and 22E, an unreleased hybrid. In 3 sets of different brick chambers, root and shoot samples were collected at 45, 60 and 75 days by dismantling the chambers. Measurements were made on the number, length and weight of roots and shoots. CSH1 and 22E were sown in brick chambers lined with polythene at different levels to observe the rate of root growth up to the stage of physiological maturity. The rate of root growth in 22E was higher than CSH1 in the early stages but at 75 days, CSH1 had more roots than 22E. It was also observed that the new flush

of roots coincided with the boot stage (60 days in 22E and 75 days in CS

At 60 days, the total number of main adventitious roots produced per pla greater in 22E than in CSH1 (37 and 27 respectively). At 75 days, they greater in CSH1 than in 22E (72 and 41 respectively). Similarly, at 60 da total root length of the main adventitious roots was higher than in CSH1 (79 545 cm respectively) but at 75 days, CSH1 exceeded 22E (1934 and 1420 c spectively). However, the average length of each main root at all stage greater in 22E than CSH1 (35 and 27 cm respectively at 75 days). The av dry weight of roots per plant at all stages was greater in 22E than in CSH and 25 g respectively at 75 days). Root/shoot ratio at all stages was greater i than in CSH1 (0.48 and 0.35 respectively at 75 days). At harvest, most o adventitious roots had decayed and only the top crown roots were present upper layer of the soil. A comparative study of the growth and develop the underground and above ground parts of the 2 hybrids (CSH1 and 22E their parents demonstrated that hybrids grew faster than their parents, bu showed a higher level of heterosis than its parents when compared to th CSH1 (ICRISAT, 1977).

Field study

CSH1, 22E and their parents were grown in alfisol during the postrainy s of 1976 under irrigated conditions in the field. Whole plants along with roots collected at different stages, i.e., panicle initiation, boot stage and flowering (50 X 50 cm²) were dug to a depth of 75 cm and filled with water, an overnight to soften the soil. On the next day, roots were washed carefu different layers of the soil.

It was observed in both cultivars that at panicle initiation under irrigated c tion new roots formed a spreading canopy horizontally in a network patter within 10 cm depth of the soil. At this stage some collar roots had also deve

At boot stage, the main adventitious roots grew laterally up to 25 cm, an duced a profuse network of lateral roots. In CSH1, the crown roots had pro lateral roots whereas in 22E they had sent out profuse lateral roots in a ne pattern. The main adventitious roots got distorted and some of the roots found dried out. In both cultivars the main adventitious roots which were d oped in the upper 10 cm layer at panicle initiation were found to decay or their activity as shown by the lack of root hair. The seminal roots were fou lose their root hair at this stage. In all the genotypes, a new flush of adven roots was found to develop at boot stage.

At the flowering stage, in 22E, the adventitious roots that were formed a stage were present, but some of these were inactive and dried up with the l root hair. CSH1, however had persistent profuse root systems when compar that in 22E. The zone of maximum root hair was limited within 45-50 cm in C and 35-40 cm in 22E. The crown roots that had already formed were fou produce extensive root hairs and played a predominant role in the root sy both in CSH1 and 22E. Maximum depth of root penetration was 70 cm in C and 50 cm in 22E.

Parents of CSH1 and 22E showed only slight deviation from their hybri general, the hybrids (CSH1 and 22E) produced a higher amount of root w

and root/shoot ratio when compared to their parents. Root/shoot ratio decreased from panicle initiation to boot and flowering stage. Under field conditions, the hybrid 22E was superior (heterosis) over its parents but this was not pronounced in CSH1 (Figs. 6.11-6.14).

Effect of soil types on root growth in brick chambers

Twelve chambers were filled with red soil and an equal number filled with black soil. Seeds were sown in 2 rows 30 cm apart with a space of 10 cm between plants. Ten days after emergence, the surface of the soil was covered with a 4 cm thick layer of fine sand which was then covered with a dark polythylene sheet layered with gravel to prevent evaporation losses from the soil surface. The plants were allowed to grow on the stored moisture. At 10 days intervals, two chambers of each soil type were dismanteled to study the root system from 30 days after emergence until maturity.

Developmental stages

Grain sorghum (CSH8) did not show significant difference in the attainment of different physiological stages in red and black soils (Table 6.1). In general, vegetative stages and early reproductive stages (1 to 5) were earlier in red soil than in black soil, but grain development stages were late only by 2 days. As the hybrid was grown in stored moisture and no further irrigation was provided, the physiological stages were somewhat delayed in red soil owing to water stress. The growth rate of the above ground parts in general was less in red soil compared to that in black soil (Figs. 6.15, 6.16). This observation was confirmed by measuring leaf water potential which was lower in red soils than in black soil (Fig. 6.17).

Measurements made were maximum root penetration in the soil, number of roots (and root dry weight) at different depths, the leaf area and length of stem. The tops were partitioned into leaves, stems and panicles, and were measured. The root biomass (Figs. 6.18 - 6.20) increased at a slow rate up to 30 days (early vegetative stage), but increased rapidly up to 60 days in black soil and 70 days in red soil, not increasing appreciably thereafter. By that time, CSH8 passed the half-bloom stage. The total dry matter at all stages though not significant, was less in black soil than in red soil.

Table 6.1 Physiological stages of development of grain sorghum in relation to date and days after emergence (in brick chamber).

Stage	No.Stages	Red soil (Days)	Black soil
0	Emergence	0	0
1	3 leaf	3	3
2	5 leaf	8	10
3	Growing point differentiation	-	-
4	Flag leaf visible	42	45
5	Boot stage	48	50
6	Half bloom	60	60
7	Soft dough	92	90
8	Hard dough	98	96
9	Physiological maturity	104	102

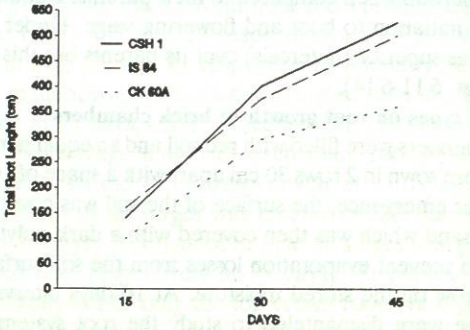

Fig. 6.11 Total root length in CSH1, an Indian hybrid and its parents at different stages.

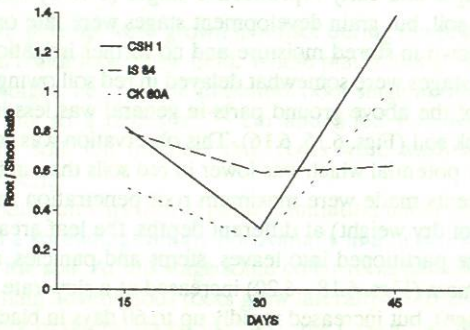

Fig. 6.12 Root/Shoot ratio in CSH 1 hybrid and its parents at different stages.

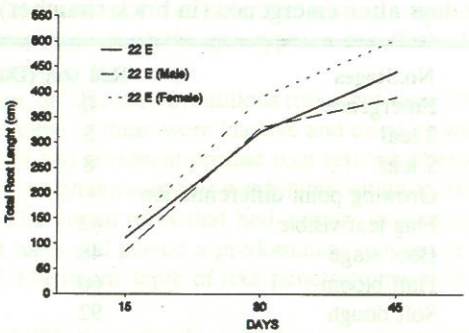

Fig. 6.13 Total root length in 22 E hybrid and its parents at different stages.

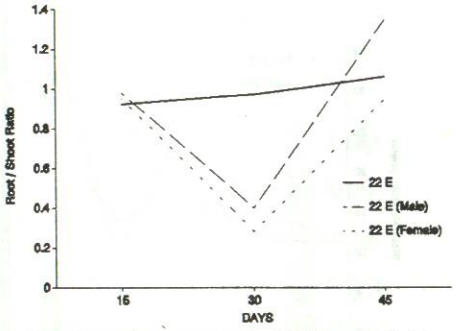

Fig. 6.14 Root/shoot ratio in 22 E, a hybrid and its parents at different stages.

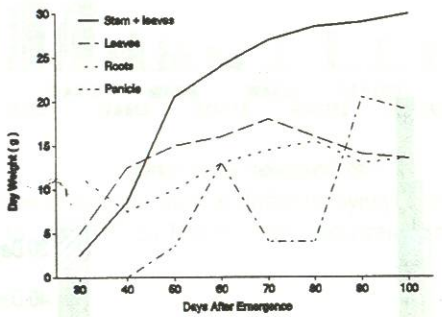

Fig. 6.15 Dry matter distribution at different stages of growth of CSH8 in red soil, post-rainy season, 1977.

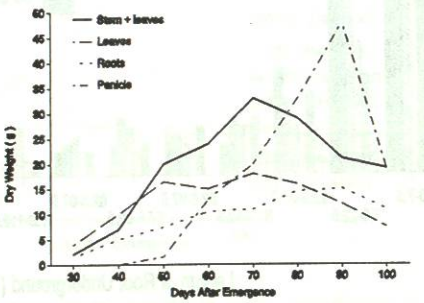

Fig. 6.16 Dry matter distribution at different stages of growth of CSH8 in red soil, post-rainy season, 1977.

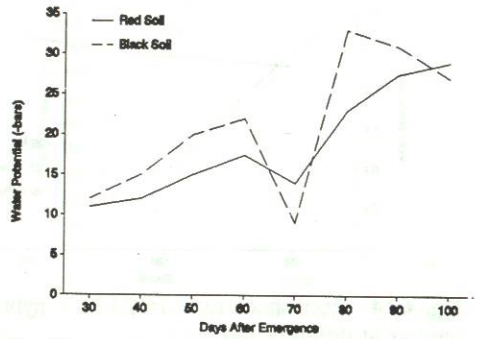

Fig. 6.17 Gradients of water potential of leaf in brick chambers in alfisol and vertisol at different stages of growth of CSH8, post-rainy season, 1977.

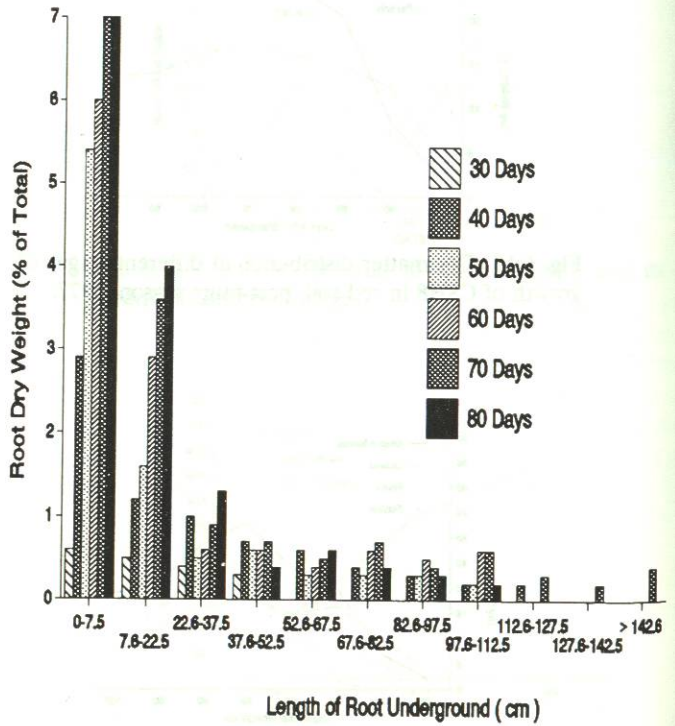

Fig. 6.18 Distribution of root bio-mass at different layers of black soil different stages of growth of CSH8, an Indian hybrid, 1977.

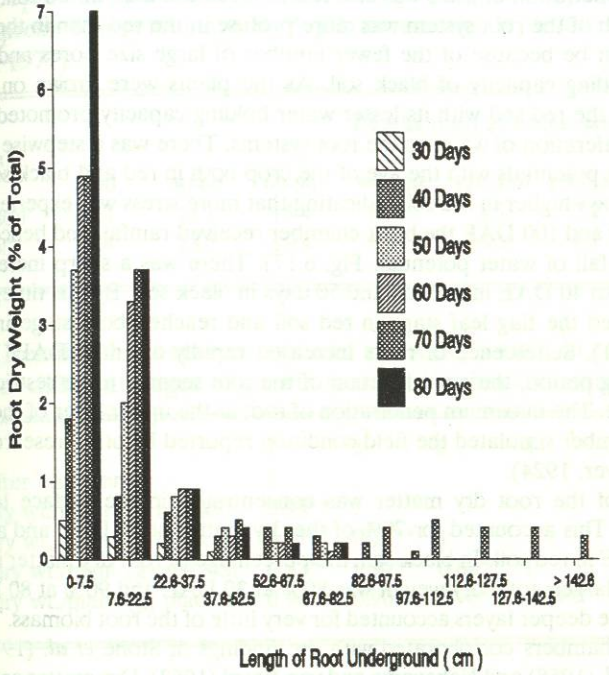

Fig. 6.19 Distribution of root bio-mass at different layers of red soil at different stages of growth of CSH8, an Indian hybrid, post-rainy season 1977.

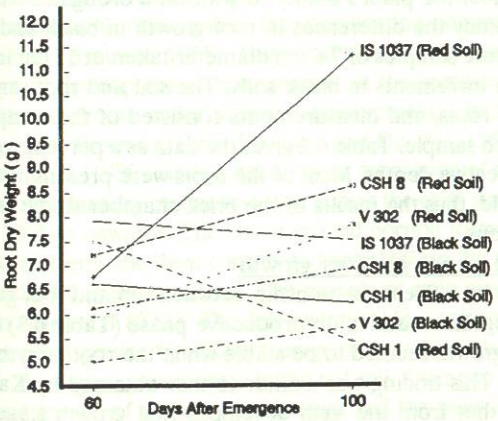

Fig. 6.20 Accumulation of dry weight in roots at different stages of growth in black and red soils.

The penetration of roots was also less in black soil than in red soil. Therefore the growth of the root system was more profuse in the red than in the black soil. This might be because of the fewer number of large size pores and the better water holding capacity of black soil. As the plants were grown on the stored moisture, the red soil with its lesser water holding capacity promoted the downward proliferation of water to the root systems. There was a stepwise increase in leaf water potentials with the age of the crop both in red and black soils, though it was always higher in red soil indicating that more stress was experienced in red soil (at 70 and 100 DAE the brick chamber received rainfall and hence there was a sudden fall of water potential; Fig. 6.17). There was a sharp increase in root depth up to 40 DAE in red soil and 50 days in black soil. By this time, the hybrid had crossed the flag leaf stage in red soil and reached boot stage in black soil (Table 6.1). Senescence of roots increased rapidly after 70 DAE. During the grainfilling period, the main function of the root seemed to be restricted to that of support. The maximum penetration of root at the upper layer of the soil in the brick chamber simulated the field condition reported by other researchers (Jeffrey and Weaver, 1924).

Most of the root dry matter was concentrated in the surface layers (0 to 22.5 cm). This accounted for 70% of the dry matter at 30 DAE and almost 85% at 80 DAE in red soil. In black soil, the percentage of root dry matter in this layer was even larger; total dry weight was 80% at 30 DAE and 90% at 80 DAE. The roots in the deeper layers accounted for very little of the root biomass. The findings in brick chambers corroborated with the findings of Stone *et al.* (1973), Blodgett *et al.* (1958) and Nakayama and van Bavel (1963). Dry matter accumulation followed a similar pattern in red and black soils. Root dry matter started declining after 80 DAE in red soil and 90 DAE in black soil (Fig. 6.20) by which time the hybrid had almost reached soft dough stage.

The depth to which the roots penetrate and their distribution in different horizons directly affect the plant's ability to withstand drought. Soil scientists at ICRISAT tried to study the differences in root growth in black and red soils by machine collected core samples of 7.6 cm diameter taken at 15 cm increments in red soils and 30 cm increments in black soils. The soil and root samples were washed to separate roots, and measurements consisted of the composite length of roots taken in each sample. Table 6.2 gives the data as a percentage of the total root lengths by respective depths. Most of the roots were present in the top layer of the soil in the field, thus the results of the brick chamber studies seem to tally with field observations.

Coordination of top growth and root growth

There seemed to be a linear relationship between top and root growth (Pearsell, 1927) during vegetative and midreproductive phase (Table 6.3) but between 60-70 days the top growth seemed to be stable while the root growth declined as the roots senesced. This finding was similar to that obtained by Kaigama *et al.* (1977), who found that from the sixth developmental growth stage, the above ground growth was stable, while root depth was stable in the field from stage 5 to stage 6. Thereafter, there was senescence in the root system which was not taken into account by the coring technique (Kaigama *et al.* 1977). The extraction

Table 6.2 Depth and distribution of roots of sorghum grown on black and red soils-expressed in percentage by depth increments, Hyderabad 1975 (ICRISAT, 1977).

Soil were taken	Depths (cm) at which samples 0-30	30-60	60-90	90-120	120-150	150-180
Black soil	49.4	18.1	15.4	11.4	3.5	2.2
Red soil	35.4	13.5	19.4	15.9	14.1	1.7

Table 6.3 Relationship between root and shoot dry weight in red and black soils at different stages of growth (correlation, brick chamber).

	1	2	3	4	5
1 Days after emergence	1				
2 Root dry wt./plant (g) red soil	0.93**	1			
3 Root dry wt./plant (g) black soil	0.72**	0.76**	1		
4 Shoot dry wt./plant (g) red soil	0.92**	0.90**	0.82**	1	
5 Shoot dry wt./plant (g) black soil	0.94**	0.90**	0.90**	0.94**	1

of roots from the soil included both live and senesced roots. As a result, there was downward trend of root depth during the late grainfilling phase. Therefore, while shoot dry weight increased, the death of older roots might not be fully compensated by new growth. High yielding cereals have been reported to be accompanied by a progressive decrease in the weight of roots (Evans and Dunstone, 1970). To maintain the source-sink relationship, the coordination between root and shoot growth is essential (Brouwer, 1965). This relationship is reported to alter during the later stages of development due to changes in the partitioning of dry matter between roots and shoots under different environmental factors (Nielsen and Cunningham, 1964; Brouwer, 1965; Brouwer and De Wit, 1969; Russell, 1977). González-Rodríguez (1989) made a quantitative estimation of root development.

The increase in plant dry matter was slow during the early stages and increased rapidly from 30 days onwards. The above ground portion formed the bulk of the dry weight. At maturity, the stem contributed only 16% to the total dry weight in the red soil and 10% in the black soil. The root-shoot ratio was higher in red soil (0.19) than in black soil (0.11). The low water holding capacity of the red soil enables better plant growth by efficient usage of stored moisture. This might be the reason for the higher growth rates in the red soil. Owing to some stress in red soil, the normal growth of panicle was checked and the panicle was malformed. Leaf area index (LAI) increased rapidly to a maximum at 50 DAE in both red and black soil. Thus, maximum photosynthetic efficiency is reached around boot stage. In the black soil, CSH8 attained a maximum of 5.3 LAI compared 4.9 LAI

in the red soil.

The study clearly shows that both shoot and root dry weight correlate positive with the age of the crop. Root and shoot also showed significant positive associations between themselves in both soils (Table 6.3). Root dry weight increased significantly with the age of the crop and was much larger in red soil. Significant positive correlations were observed between root an shoot dry weights and age of the crop for both soils, although the relationship of root dry weight was higher than shoot dry weight. Shoot dry weight also showed a strong positive correlation with root weight in red soil and black soil.

Responses of some cultivars showing different levels of drought tolerance in red and black soils

Four sorghum cultivars IS 1037 (drought-tolerant type), CSH8 (avoidant), CSH1 (intermediate), and V302 (susceptible) were grown in brick chambers under irrigated conditions to find out differences in root growth. The brick chambers were dismantled at 2 stages, 65 DAE and 95 DAE. The root biomass is given in Table 6.4.

Table 6.4 Dry weight of roots (g) in plant of some sorghum cultivars in black and red soils.

	Black soil		Red soil	
Genotype	**65 days**	**95 days**	**65 days**	**95 days**
IS 1037	6.88	11.41	7.95	7.62
CSH8	7.36	8.58	5.99	6.90
CSH1	7.47	5.39	6.65	6.15
V302	5.90	7.76	5.10	5.73

It is possible to differentiate the genotypes with respect to root growth with the use of the brick chamber technique. In red soil, IS 1037 and CSH8 which showed drought resistance under field conditions also showed maximum root biomass. Under irrigated condition, higher water holding capacity in the black soil with less water holding capacity of the red soil might have encouraged the root growth in the deeper layers. Thus, the hypothesis that the roots of drought-resistant cultivars are longer than the more susceptible ones could be confirmed using the brick chamber technique.

Usefulness of the brick chamber technique

Despite its drawbacks, the brick chamber technique may be used for the following specific studies:

1. Development of the root system, the growth pattern and proliferation of individual roots with the age of the crop and their distribution of different levels of the soil.
2. Correlation of root and shoot growth to assess the stage at which the root system (a) shows maximum efficiency and (b) starts to senescence.

3. Finding genotypic differences in root growth for subsequent correlation with drought and yield responses.
4. Root competition in intercropping and to suggest ideal crop mix for diverse environments.
5. Nodulation of pigeonpea intercropped with sorghum.
6. Finding out the responses of cultivars to different levels and methods of applying fertilisers.
7. Finding differences in root growth of cultivars induced by changes in soil texture, moisture and fertility.

GENERAL COMMENTS

Although attempts have been made to study the root systems in sorghum, very little progress has been made. The main reason for this is that efficient techniques to study root systems in the field are not available. Another is that roots -unlike other plant parts- are inaccesible to direct observation without elaborate excavation. Much of our knowledge of root development is based upon laboratory cultured seedlings in rhizotron. As roots play an important role in the uptake of water and nutrients, crop productivity is largely dependent on an efficient root system. Due to the limitation in conducting root studies, it is difficult to correlate crop productivity with the efficiency of root systems. The adaptability of a crop cannot be judged in proper perspective if we neglect the performance of its root system. Root estimation with the help of soil cores cannot give a clear picture of the entire root system in the field, and some simple techniques need to be developed to study them. Genetic variability in the root system, which is an essential prerequisite for genetic improvement, has been reported by different researchers. Studies also report a relationship between root depth and drought resistance. These need to be confirmed by further research.

As a number of research studies indicated that more than 80% of the total root mass was located in the upper 20-30 cm soil layer, techniques need to be developed to assess root mass from the upper layer of soil to enable the categorization of sorghum genotypes on the basis of this trait. We also need to identify genotypes which have greater root mass in the upper layer and which also have a large number of roots at a deeper soil level. The genotype with this "root ideotype" may be adaptable to adverse soil conditions. We need to study whether seedling root system is in any way related to the performance of the adult system. Therefore, genotypes need to be evaluated for efficient root systems at the seedling stage both
under normal and stress situations (water/nutrient). The hope is to correlate the resistance at the seedling stage with resistance at the adult stage. This may be assessed in a long glass tube, a PVC cylinder or a brick chamber, and may help us to compare the total root system of different genotypes.

Root studies in brick chambers have shown good correlation with that in the field in terms of pattern of root distribution in the soil as well as the drought resistant nature of some sorghum genotypes. Root elongation in tube culture or