

sorghum genotypes. Large genotypic variability existed for seedling emergence and seedling vigor of the sorghum genotypes infested with grain mold. Therefore, concerted efforts should be directed to eliminate the deteriorating effect of mold on sorghum grain quality during the growing period of the crop.

## GENERAL COMMENTS

The morphophysiological characteristics of different sorghum genotypes show considerable variations in seed size, shape and dimensions, surface orientation, seed structure, distribution pattern of corneous and floury endosperm, hardness, water uptake, seed viability, first leaf area and seedling dry weight. It is a fact that all the variations in these characters are statistically significant. An interesting fact is that most genotypes do not lose their viability even after presoaking for 40 hours when the radicles and plumules are advanced in growth and then transferred to the incubator for 15 days at 35°C (Moreno-Limón, 1988). Lines selected for resistance to presoaking and drying could be useful in an area where dry sowing is practiced. Different seed morphological traits were found to show relationships among themselves. They have shown relationships with some of the physiological functions, for example, seed size is related to grain hardness, total water uptake, first leaf area and seedling dry weight. Seed size is negatively correlated with percentage water uptake. Grain hardness is positively associated with the corneous endosperm content; the first leaf is positively correlated to seedling dry weight. These characteristics could be used as selection criteria for better seedling growth.

Sorghum grain attains germinability even before the attainment of physiological maturity. Some start germination at an early stage of grain development, others germinate at a later stage. In order to avoid grain weathering, we should look for genotypes that show no germinability at major stages of grain maturity. A number of lines have been selected at ICRISAT which show dormancy at a late stage of physiological maturity. Proper care needs to be taken not to use seeds affected with grain mold causing poor seedling vigor.



# GERMINATION AND SEEDLING ESTABLISHMENT

## INTRODUCTION

Germination, emergence and establishment of seedlings are vital to plant development. Many morphogenetic changes take place simultaneously before the establishment of a seedling. These processes involve complex serial, structural and metabolic transitions in possibly adverse situations under erratic environmental conditions. These processes are interrelated, and knowledge of the interactions among them help in the understanding of the plant's condition at each stage of development. The normal process of seedling development is largely controlled by environmental factors and influences the development of the adult plant. Seedling establishment is one of the major obstacles of crop production in the arid and semi-arid tropics (SAT) (Maiti, 1983, 1986). Despite adequate fertilizer use and irrigation, the yields are often low in some crops due to poor plant stands, which is a consequence of poor seedling emergence and establishment. Adverse conditions encountered in the SAT countries, like varying planting depths, limited moisture, high soil temperature, soil crushing, etc., affect seedling emergence. Therefore, improvement of seedling vigor and testing breeder's lines for crop establishment traits should be the major considerations in a breeding program. Investigations in this direction have clearly established that which is discussed herein.

Biological and environmental factors associated with screening for improved germination and establishment in different crop species have been reported by different workers (Kneebone, 1970; Wright, 1971; McKell, 1972). There has been a good deal of work relating seed characteristics with seedling vigor in different crops (Kneebone and Cremer, 1955; Isley, 1958; Kalton *et al.*, 1959; Christie and Kalton, 1960; Tossell 1960; Dhindsa and Slinkard, 1963; Lawrence, 1963; Maiti, 1981). Kneebone (1970) considered the seed size as the most promising selection criterion available to the breeder to improve seedling vigor. Seed size was related with early growth and grain yield in barley, and high protein content and seed size were related to good seedling vigor in wheat (Kaufmann and McFaden, 1963; Kaufmann and Guitard, 1967; Dasgupta and Austerson, 1973; Sterling *et al.*, 1977; Ries and Austerson, 1973). Seeds with high protein content in wheat produced more vigorous seedlings than those with low protein (Welch, 1977; Bullisani and Werner, 1980).

Ching (1973) reported that seed weight, adenosine triphosphate (ATP) and adenosine diphosphate (ADP) contents of the hydrated embryo were good vigor



predictors for high emergence rates in barley cultivars. Lawrence (1963) concluded that seed weight in rye grass was controlled to a large extent by the maternal parent, and that additive gene effects were responsible for explaining the genetic variation in the number of days to emergence. He found also a slight association between seedling growth and adult plant characteristics in Russian wild rye. This indicated that selection in the seedling stage could also have some bearing in breeding for higher yields. Lawrence (1963) suggested that breeding for improved seedling vigor in Russian wild ryegrass would be accomplished by selecting for large seed lines and then subjecting them to deep seedling in greenhouse or in the field. No such studies have been made on sorghum or millet.

Laboratory seed germination following ammonium chloride pretreatment is reported to be a useful technique for assessing seedling emergence in sorghum (Abdullahi and Vanderlip, 1972; Vanderlip *et al.*, 1973, and Yayock *et al.*, 1974). Vanderlip (1974) thought that the field establishment of pretreated seeds should show maximum efficiency in quick germination and rapid emergence. Arkin (1976) built up a simulation model for sorghum emergence.

Genetic variations for salt tolerance has been documented in different plants and crops such as corn (Schubert and Lauchli, 1986; Hajibagheri *et al.*, 1986), wheat (Gorham *et al.*, 1986), barley (Hurkman and Tanaka, 1987; Ramagosa *et al.*, 1988), sorghum (Weimberg *et al.*, 1984; Grieve and Maas, 1984; Boursier *et al.*, 1985) and Johnson grass (Yang *et al.*, 1989).

Sodium chloride salinity inhibited sorghum seedling growth and small seeds were most sensitive to salinity (Amthor, 1983). Grain sorghum is moderately tolerant to salinity, indicating that the yield reduction was due primarily to low weight per head, and vegetative growth was affected less than grain yield by salinity increase. Sorghum grain was more tolerant at germination than at later stages of growth (Francois *et al.*, 1984). Responses of sorghum to different concentrations of sodium and potassium salts were reported by Weimberg *et al.* (1984) who indicated that concentrations of inorganic phosphate, glucose, fructose, amino acids and malic acid fluctuated in both roots and leaves, in association with saline stress.

The degree of salinity tolerance of a species may depend on several complex mechanisms operating at anatomical, morphological, physiological, biochemical or gene expression levels (Flowers *et al.* 1977; Storey and Wyn Jones, 1981; Gorham *et al.* 1985; Munns and Termaat, 1986; Sachs and Ho, 1986; Thiel *et al.* 1988). Leaf extension is one of the most susceptible processes in plants sensitive to salinity stress (Munns and Termaat, 1986 and Aspinall, 1986). Salinity affects photosynthesis through the reduction in photosynthetic surface in *Beta vulgaris* (Papp *et al.*, 1983). Salinity was related to increased respiration rates (Schwarz and Gale, 1981). This was also observed in *Phaseolus*, *Xanthium* and *Atriplex* but not in *Zea*. Others have shown that salinity limited the assimilation of CO<sub>2</sub> in two ways: 1) the response of stomata to plant salinization, and 2) the capacity of plants to fix CO<sub>2</sub> (Longstreth *et al.*, 1984; Seeman and Crichley, 1985; Ball and Farquhar, 1984). Mechanisms of salinity tolerance in plants were reviewed by Cheeseman (1988) involving cellular and organismal metabolism relating to control and

integration of sodium ion acquisition and allocation, and those in readjustment of other aspects of metabolism, especially the carbon source. Osmotic adjustment and ion regulation in plant cells subjected to salinity are the best known model of the different mechanisms of plants to achieve salt tolerance (Flowers *et al.*, 1977; Greenway and Munns, 1980; Munns and Termaat, 1986; Binzel *et al.*, 1988). Glenn (1987) studied the role of cation accumulation and water content on the osmotic adjustment of several salt-tolerant grasses, reporting accumulation of Na<sup>+</sup> and lowering the water content as main strategy of osmotic adjustment.

## CROP ESTABLISHMENT IN SORGHUM

Crop establishment in sorghum is affected by a number of factors related to the seed and its environment (Table 3.1). Two important aspects of crop establishment are (Fig. 3.1): 1- events and conditions existing in the seed zone below ground from sowing to seedling emergence; 2- problems and factors affecting the seedlings from emergence to the final establishment above ground.

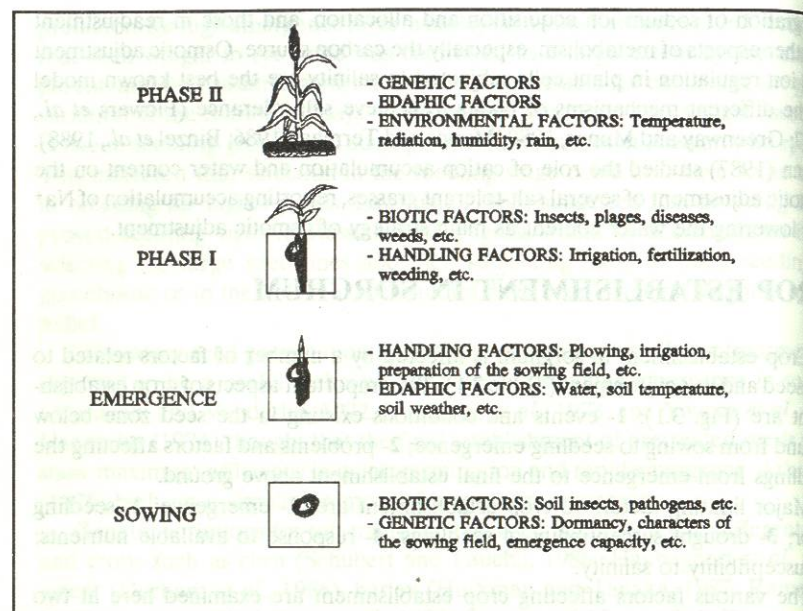
Major limiting factors to crop establishment are: 1- emergence; 2- seedling vigor; 3- drought susceptibility of seedlings; 4- response to available nutrients; 5- susceptibility to salinity.

The various factors affecting crop establishment are examined here at two distinct stages of plant development: 1- germination to emergence; 2- emergence to panicle initiation.

**Table 3.1** Factors affecting seedling emergence in sorghum.

A. SEED CHARACTERISTICS	B. ENVIRONMENTAL FACTORS
i) Seed management	i) Edaphic
a) seed storage	a) water
b) seed treatment	b) heat
ii) Physical characters of the seed	c) crusting and compaction
a) size	d) aeration
b) weight	e) soil reaction
c) moisture percentage	f) nutrients (pH and salt concentration)
d) density	
iii) Physiological characteristics of the seed	ii) Aerial
a) grain maturity	a) light
b) seed viability	b) heat
c) seed dormancy	c) humidity
C. MANAGEMENT	D. BIOLOGICAL
i) tillage	i) weed competition
ii) depth of sowing	ii) disease
	iii) pests.





**Figure 3.1** Factors that affect the establishment and productivity of crop.

### Germination

Germination begins with the imbibition of water by the seed and ends with the emergence of radicle from the testa. Mayer (1977) wrote that the two important processes involved in germination are: the physical process of water uptake and the initiation of the complex biochemical steps following rehydration. The activity of the embryo is maintained by its constant supply of nutrients, which in turn maintains the heterotrophic system until the seedlings are able to photosynthesize and become autotrophic. Crop seed germination was reviewed by Gelmond *et al.* (1978).

Germination involves three important steps (Mayer, 1977): 1- utilization of low molecular weight compounds with ATP synthesis; 2- selective breakdown of storage compounds with the reorganization of the mitochondrial membranes; and 3- breakdown of storage materials with the synthesis of new mitochondria.

In sorghum, sucrose is synthesized in the scutellum and is the primary sugar translocated to the growing shoots and roots. Sugar accumulation in sink regions were well correlated with their disappearance in the source tissue (endosperm). Endosperm hydrolysis does not occur readily during the early growth phases, and by the second day, the hydrolytic breakdown of insoluble carbohydrates in the endosperm exceeded the rate of use by the seedling until the 8th day (Newton *et al.*, 1980). Carboxylase activity increase at early stages of germination is important for seedling development (Perl, 1978). Root emergence and enzymatic activities in sorghum are directly correlated with field performance, while proteinase activity

is inversely correlated with seed vigor (Perl and Luria, 1978). Optimum moisture content for germination in sorghum was reported between 35 and 40%, while germination occurred between 15-30°C with an optimum at 22°C. Active germination and growth were assessed in terms of soluble carbohydrate and total starch in the seedling. Glucose and maltose are the main simple sugars of the soluble carbohydrate (Aisien and Ghosh, 1978). Sucrose and raffinose levels in the scutellum of the intact sorghum embryo declined sharply through germination, but increased at radicle emergence as the hexose sugars from the endosperm passed into the scutellum; maltose, maltotriose and glucose were the main products of enzymatic hydrolysis of the endosperm carbohydrates during seedling development (Aisien, 1982).

Standard germination percentage, as a measure of quality, is inadequate for seed vigor evaluation under the usual range of less than optimum field condition. Therefore, other tests should be used to provide more realistic information (Caldwell, 1960; Moore, 1964). Not only the germination test, but other supplemental tests, viz. accelerated aging, cold test, seedling growth rate, etc., which would ensure better assessment of seed vigor (Ahmed, 1977). Prolonged aging over 72 hours under 45°C and 100% R.H. is detrimental to sorghum seed.

### Dormancy

Research on seed dormancy in different crops is extensive, but few studies are available on sorghum. Grittons and Atkins (1963) reviewed dormancy in sorghum. Robbins and Porter (1946) reported that although some sorghum seeds germinate when their moisture content decreases to between 50-60 %, freshly harvested sorghum seeds were often dormant. Casey (1947) noted unusually high percentages of dormant seed in germination tests, observing that some varieties were more likely than others to exhibit dormancy; varieties which shed their glumes at threshing were not as dormant as were varieties with attached glumes. Brown *et al.* (1948) studied the effect of storage on viability of oats, barley and sorghum seeds, finding that sorghum seed was not dormant after the grains had been stored for two months at 40°C. Seed dormancy was more common in sorghum than in barley or oats.

Goodsell (1957) found that scarification of the seed with a small file was effective to break dormancy in sorghum. Mechanical devices for scarification of larger seed lots were effective in breaking dormancy, but excessive damage could hamper germination. Soaking the seed in water at 70°C for four minutes was effective in overcoming dormancy. Another method to overcome dormancy was by prechilling the seeds at 5°C for six days and by continuing the test at 20-30°C until all viable seeds had germinated (Robbins and Porter, 1946). Stanway (1958) suggested that freshly harvested or immature sorghum seed need to be prechilled before germination tests. She subsequently found that lower germination was obtained for prechilled as compared to unchilled seed lots. The commonly used procedure for laboratory germination of sorghum seed requires the alternation of temperatures of 20°C for about 16 days, and 30°C for about 8 hours. Alternating temperatures resulted in better germination of Johnson grass, *Sorghum halepense* than did constant temperature (Stanway, 1959). Tester and McCormik (1954) showed that freshly harvested Johnson grass seed gave higher germination



percentage when prechilled at 10°C as opposed to 5°C.

Weir (1959) reported that ungerminated seeds of *S. halepense* did eventually germinate if caryopses were maintained under favorable conditions. Germination was more rapid at 30-45°C than at 20-35°C. Barton (1939) suggested that low temperature pretreatment known as 'stratification' is effective in inducing germination of seeds with a dormant embryo. Seed scarification was most effective in overcoming dormancy. Grittons and Atkins (1963), working on a range of genotypes, reported that they differed significantly in the level of dormancy which germinated at intervals of two weeks and a month after harvest. Seed dormancy was of little consequence three months after harvest. Kersting *et al.* (1961) showed that sorghum seeds are capable of germinating as early as 12 days after flowering and seeds harvested 12, 15 and 18 days after flowering were slower to emerge and had less seedling vigor than older seeds. Maiti (1983) reported that some sorghum genotypes have the capacity to germinate even 10 days after anthesis, and genotypes showed genetic variability in pre- and postharvest physiology. Clark *et al.* (1967) reported that three mechanisms were found to operate in dormancy. The first was associated with initial seed moisture which functioned until it was reduced to 28% or less. The second mechanism was associated with the active seed growth and functioned until the maximum dry weight of the seeds was attained. The third mechanism functioned after the two others were no longer active and occurred in seeds which had attained maximum dry weight and in which the moisture content was less than 28%. These mechanisms work only in intact seeds since excised embryo from 15-30 day old seeds were not dormant.

#### WATER UPTAKE AND MOVEMENT IN THE SORGHUM GRAIN

Grosh and Miller (1959) and Jowett (1965) studied water uptake and movement in wheat and sorghum seeds. Glueck and Rooney (1978) attempted to follow the pathways by which water enters the sorghum kernel, finding that in the floury endosperm of sorghum the primary entry pathway for water was the disrupted connective tissue between the pericarp and rachis (Fig. 3.2). It then entered the cross and tube cells of the pericarp and rapidly moved around the seed. Concurrently, water appeared to move through the hilum (black layer) into the germ layer. After 30 minutes, water moved into the endosperm at the point where the endosperm, germ and pericarp meet. Some water also entered the kernel in the cross and tube cells. After about an hour, they found that water movement was maximum near the upper area of the scutellum. They suggested that water move via the scutellum vascular system into the endosperm, and this was more pronounced after 90 minutes. Once the water was in the endosperm, it moved readily through the less organized central floury endosperm.

#### Water uptake from soil

Due to erratic rainfall and high evaporation rates in the SAT countries, the moisture in the soil is often inadequate for germination and seedling establishment. Under inadequate soil moisture, a smaller seed-water contact area reduces the rate of water uptake causing delayed germination (Hadas and Russo, 1974). Seeds of maize and cotton differed in total amount of water absorbed (Stiles, 1948, 1949, cited by Mayer, 1977; Gelmond *et al.* 1978). Stiles (1949, cited by Mayer, 1977) thought that the seeds in xeric habitats would have low water requirements for

germination. Water uptake by seeds from soil is influenced by the differential of water potential between the soil and seed. The movement of water takes place of course from regions of higher concentration to those of lower potential (Fig. 3.2). See also Osmond *et al.* (1980). Thus, the occurrence and rate of germination in the soil are considerably influenced by soil moisture (matrix) potential and hydraulic conductivity (Collins-George and Hector, 1966; Sedgley, 1963). As the growing embryo is spatially separated from the storage endosperm in a cereal grain, there is at first a rapid water uptake by the embryo followed by uptake by other tissues (Milthorpe and Moorby, 1974).

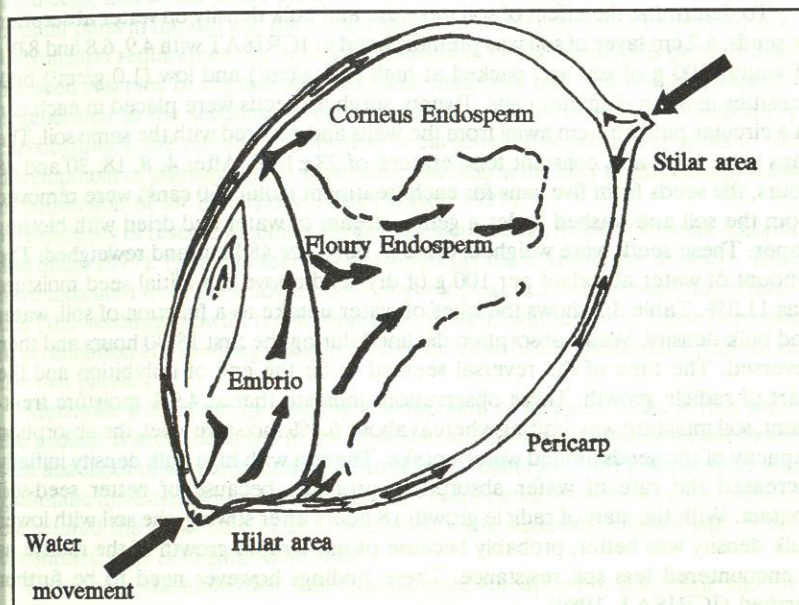


Figure 3.2 Water movement in sorghum grain (Glueck and Rooney, 1978).

Each seed has a specific hydration level below which germination will not occur. This hydration level is governed by the internal water potential for the seed. As the seed imbibes water during the early stage, its water potential increases, and during the later stages some internal metabolic changes occur (Hadas and Stibbe, 1973). When the seed attains the first critical hydration level, germination will occur. Mali *et al.* (1977) found that the critical seed hydration level in different sorghum varieties ranged from 21 to 34 % water; critical soil water potential ranged from -3 to -6 bar. Water absorption of 14 varieties of grain sorghum was studied at different moisture potentials (0.0, -0.3 and -4 bar). The seeds of all varieties did not require the same amount of water for germination. For a given time, the amount of water absorbed declined with a decrease in water potential. However, the total uptake increased with a corresponding lowering of the water



potential. The variation in absorption of water by the seeds might be attributed to the differences in the water requirement of embryo, the capacity and rate of water absorption by the endosperm, the hygroscopicity of the seed coats and the percentage of final germination. Mali *et al.* (1979) reported the seeds of CS3, SPV99, SPV302 and SPV370 probably exhibit adaptation to germination in arid lands which is indicated by their low optimal water requirement for germination. Soil moisture requirements for germination of sorghum, millet, tomato and Celery were studied by Fawusi and Agboola (1980). They showed that both sorghum and millet performed well at low moisture regime which explains their ability to survive in dry ecological zones in excess of 50% field capacity.

To determine the effect of soil moisture and bulk density on water absorption by seeds, a 2 cm layer of soil was premoistened at ICRISAT with 4.9, 6.8 and 8.9% of water/100 g of soil and packed at high (1.8 g/cm<sup>3</sup>) and low (1.0 g/cm<sup>3</sup>) bulk densities in 8 cm diameter cans. Twenty sorghum seeds were placed in each can in a circular pattern 1 cm away from the walls and covered with the same soil. The cans were kept at a constant temperature of 23±1°C. After 4, 8, 18, 30 and 48 hours, the seeds from five cans for each treatment (total 150 cans) were removed from the soil and washed under a gentle stream of water and dried with blotting paper. These seeds were weighed, dried at 60°C for 48 hours and reweighed. The amount of water absorbed per 100 g of dry seed above the initial seed moisture was 11.3%. Table 3.2 shows the rates of water uptake as a function of soil moisture and bulk density. Water absorption declined during the first 18-30 hours and then reversed. The time of the reversal seemed to be the end of imbibition and the start of radicle growth. These observations indicate that at 4.9% moisture treatment, soil moisture was limiting whereas above 6.8% moisture level, the absorption capacity of the seeds limited water uptake. The soil with high bulk density initially increased the rate of water absorption, probably because of better seed-soil contact. With the start of radicle growth 18 hours after sowing, the soil with low bulk density was better, probably because of more rapid growth of the radicle as it encountered less soil resistance. These findings however need to be further verified (ICRISAT, 1980).

**Table 3.2** Rates of water absorption by sorghum seeds as a function of soil moisture and bulk density.

Period after sowing (hr)	RATES OF WATER ABSORPTION (g/100 g per hour)					
	Soil water (g/100g)			Bulk density (g/cm <sup>3</sup> )		
	4.9	6.8	8.9	1.0	1.8	
0-4	4.6	5.6	5.6	5.0	5.4	
4-8	1.4	5.6	0.9	1.1	1.1	
8-18	0.5	0.4	0.4	0.5	0.4	
18-30	0.1	0.6	0.6	0.4	0.4	
30-48	1.4	2.4	3.3	2.5	2.2	

### SEEDLING ESTABLISHMENT

Osmond *et al.* (1980) stated that the transition of germinating seeds to the established seedling in the soil is the most profound phase in the life cycle of an individual plant. A close coordination of absorption function for nutrients in the root and synthetic function of photosynthesis in the shoot is needed to maintain this vital process. It is a complex process which involves water relations, nutrition and morphological changes during establishment (Osmond *et al.*, 1980). Water relation of seedlings during establishment in any crop involves: 1- the structural changes occurring in the seed during the transition from nonvacuolated to vacuolated cells, and 2- the water environments of the seedlings due to the relocation of plant parts in the soil and the rapid changes in water content in the soil surface.

Nutrition requirement for initial establishment of the seedling is derived from the seed reserves of organic and inorganic materials until autotrophic response is generated in the seedling. In cereals, where seed reserves are predominantly carbohydrates, the metabolic transition of carbohydrates principally leads to the development of photosynthetic apparatus, whereas in the fatty seeds, it is a process of conversion of fat to carbohydrates (Mayer, 1977).

Efficiency of reserve mobilization can be calculated as follows (Khanna-Chopra and Sinha 1977):  $\{[\text{Gain in seedling dry weight}]/[\text{Loss in kernel dry weight}]\}$ . They have indicated from the study of some physiological and biochemical characteristics (viz. seedling growth, respiration rate, protein synthesis, etc.) that heterosis in germination and seedling growth could be because of complementary traits from the two parents.

Metabolic studies during seedling development of sorghum indicate that while the protein content declined in the endosperm, an increase was observed in the root and shoot of sorghum seedlings (Afria and Mukherjee, 1981). Asparagine and glutamine increased with seedling growth. Phosphoenolpyruvate and pyruvic acid constituted the main bulk of keto acid pool, while succinate, malate and citrate constituted that of organic acid pool.

In sorghum, the embryonic axis - the plumule - is capped by coleoptile and the radicle by the coleorhiza. Within the seed, about five leaf primordia are often revealed on microscopic examination. As the seeds swell with the absorption of water, the seed coat breaks. At first, the radicle is covered with coleorhiza and then the small coleoptile emerges through scutellum at the hilar region. The radicle grows downwards geotropically with the production of minute root hairs to give rise to the primary seminal root for establishment of the seedling. With the extension of the radicle, the coleorhiza is seen at the base of the radicle. The coleoptile grows upwards and emerges above the ground after 3 or 4 days, depending on factors like soil density, temperature, moisture, variety, etc. In colder climates (13 to 20°C), the emergence may be prolonged up to 10 days (House, 1980).

After emergence of the coleoptile, the first leaf breaks through the scutellum. The young plant begins to grow with emergence of embryonic leaves, and then with the addition of more leaves. The coleoptile remains as a sheath at the base of the seedling. The seed remains at the place of sowing, the mesocotyl elongates and the first node is found at the base of the coleoptile just below ground level.



Secondary roots begin to develop from this node when the plant is three to seven days old. Gradually, the seedlings are fully established with the development of the primary root and shoot system.

The response of plumule elongation in sorghum to moisture tension is more than that of the radicle and the lowest water potential at which seeds tested germinate largely depends on temperature (El-Sharkawi and Springuel, 1977). Again, matric water potential strongly controls emergence at all temperatures except at 28°C. In this study, plumule elongation was strongly suppressed with decreasing water potential at all temperatures, but more pronounced in the optimal temperature range (28-34°C). The effect of salinity stress on the emergence of the radicle and the plumule of sorghum was studied by El-Sharkawi and Springuel (1979a). Radicle emergence in sorghum decreased at -5 bar ( $\Psi$ ) and plumule emergence at -7 bar ( $\Psi$ ). The interaction of salinity with temperature on plumule emergence was significant. It was also reported that indole-acetic acid (IAA) promotes radicle emergence at low  $\Psi$  levels (-13 bar) in sorghum by increasing the permeability of cells to salts and promoting water uptake at relatively high levels of stress (El-Sharkawi and Springuel, 1979b). Seedling establishment is influenced by factors affecting seedling emergence, and those affecting establishment of seedling after emergence (Fig. 3.1).

#### Factors affecting seedling emergence

There are several factors affecting seedling emergence of sorghum (Table 3.1). Sorghum grain attains germinability long before the attainment of physiological maturity, although genotypic variability is found to exist (Gritton and Atkin, 1966; Clark *et al.*, 1967; Maiti, 1977). The germinability reached before physiological maturity of seeds may decline at latter stages of development (Srivastava and Pinnell, 1963). With the attainment of physiological maturity, the seed becomes dormant.

Standard laboratory germination is the measure of viability (Pinthus and Rosenblum, 1961; Vanderlip *et al.*, 1973). Retention of viability in storage shows the usual pattern of decline with age, but seeds preserved in cold storage retain viability for a longer period.

Seeds of 3 sorghum varieties were soaked in water (40% water by volume) and the seeds started germinating, then they were removed and dried (to original level of moisture) under shade for 4 days; this seed-soaking treatment increased grain yield as compared to the controls (Parvatikar *et al.*, 1975).

Accelerated ageing of sorghum seeds was adopted by Gelmond *et al.* (1978) to allow them to imbibe moisture up to 17% at 20°C followed by additional storage in a closed container at 30°C. After various periods of ageing (0-48 days) seeds were tested for germinability at various time intervals. Percentage germination and field emergence percentage showed initial increment up to 16-20 hours and then declined sharply with time of ageing. Root emergence of sorghum seeds was found to be a function of time. All aged seeds maintained their original viability and none were killed.

Ageing brings about differences in seed viability (Gelmond *et al.*, 1978). There is a belief in practice that increasing seed water content before sowing improves emergence (Lyles and Fanning, 1964), but the potential advantage of water uptake

in corneous seeds which were more suitable for dry sowing than chalky seed, were highly affected by soaking and drying (Jowett, 1965). Raising seed water content in osmotic solutions which delay water uptake results in better subsequent performance (Heydecker, 1974).

Biochemical changes in sorghum seeds affected by accelerated ageing demonstrate that amylase, glutamic-pyruvic-transaminase, RNAase and glutamate decarboxylase follow the vigor profile with an increase after six days of ageing treatment followed by a decrease up to 48 days of ageing (Perl *et al.* 1978). There is an increase in proteolytic enzymes which may affect other enzyme concentration. It is concluded that the proteolytic enzymes may play an important role in sorghum seed deterioration during environmental ageing process. During ageing there were only small changes in the electrical conductivity of the seed leakage, and no significant differences in the rate of leakage of various compounds in the seeds as a result of internal concentration during imbibition rather than membrane deterioration. Therefore, the possible deterioration of the membrane during loss of vigor is overruled.

Sorghum seed can tolerate low water content, but rapid water uptake can do damage to the seedling (Nutile, 1964). Similarly, high temperature can damage seed in contrast to the deterioration of seed over long term storage (Ross and Webster, 1970). Maranville and Clegg (1976) have shown that high density improves emergence. Deterioration of seed quality not only reduces germination, but also may reduce vigor (Wilson and Eastin, 1982). In high altitudes, low temperature affects germination and emergence when there is substantial genetic variability (Miller, 1982). The optimum temperature for emergence was not examined by Evans and Stickler (1961), who found that shoot elongation was greater at 28°C than at 16°C. They report that genotypes varied in response to osmotic potential and temperature, and also according to the source of seed of each genotype. This was also affirmed by Wilson and Eastin (1982). Mali *et al.* (1979) have shown substantial differences between varieties in water uptake at the time of germination, and also differences within varieties in the rate of water uptake depending on water potentials of the soil. Stout *et al.* (1980) report delayed initiation, slow rate at low water availability in RS 610 where germination was reduced at -8 bars and fell to zero at -15 bars.

Evans and Stickler (1961) observed that between -8 and -14 bars, emergence rapidly declined from about 90% to zero. The time required for emergence ranged from 3 days to more than 10 days where temperature varied from 15.5°C to 22.2°C and moisture from field capacity to the wilting point.

Studies by Pathamanabhan and Sakharam Rao (1975) on salinity effects on seedling emergence indicate that seedling growth was much affected by salinity while the tolerant varieties exhibited better growth and tolerance. The reduction in dry matter was pronounced in all sorghum varieties. In another study, sorghum seeds were soaked in calcium chloride solution or distilled water for 24 hours. When the seeds were dried for four days in the open air until they regained their original weight. Seeds treated with calcium chloride gave higher yields than the control seeds (Naycem and Bapat 1976). Studies on germination of sorghum in 0 and 100 mM NaCl, NaHCO<sub>3</sub> and Na<sub>2</sub>SO<sub>4</sub> indicate that there is a drop in the



level of reducing sugars at every stage of germination due to salt stress (Narabau above the surface layer.

gauder *et al.*, 1979). Among the 3 salts used,  $\text{Na}_2\text{SO}_4$  was more effective. Ogra Baijal (1978) reported that the varieties differed significantly in their ability to grow under high salt conditions and the inhibition of growth was more pronounced beyond 8 mhos/cm EC. Salinity affects nutrient uptake of sorghum in tolerant susceptible lines; tolerant varieties had higher accumulation of sodium compared to the susceptible ones (Pathmanabhan and Saktharam Rao, 1977).

Therefore, seedling emergence is the outcome of a complex interaction between the seed-bed environment and the seed. The seed passes from a dehydrated state to attain critical hydration through imbibition, resulting in cell elongation of meristematic activity. The growth of the coleoptile through a covering soil requires varying amount of force and finally emerges from the soil surface which leads to the shift from an energy consuming process to an energy producing process. A critical factor affecting seedling emergence is the physical condition of seed-bed, its moisture supply, temperature and soil characteristics. The variability within a species for seed and seedling performance is of interest to crop scientists. Since the seed-bed environment is likely to be sub-optimal with receding moisture, the effects of moisture stress on the genotypes are related to a genotype performance over all seed-beds. At favorable temperatures, the rate of soil water uptake by imbibing seeds and the initiation of growth governs the germination process.

Depth of planting

Depth of sowing has profound effect on seedling emergence and the length of coleoptile and mesocotyl has been observed by Wanjari and Bhoyar (1980) and Maiti and Carrillo (1991). Deeper sowing is a normal practice in some African countries in zones of receding soil moisture. Irregular depth causes unevenness of seedling growth. The length of the coleoptile is considered an important attribute in determining the depth to which the seed could be sown in the soil (Banerjee, 1974). The length of the coleoptile is correlated to the culm length in wheat (Allan *et al.*, 1961). Attempts were made to select dwarf wheat with longer coleoptiles by hybridization (Chowdhury and Allan, 1963). Such studies need to be undertaken on sorghum. Maiti and Carrillo (1991) demonstrated that the sorghum genotypes showed great variability in elongation of mesocotyl under different planting depth and the emergence of seedlings is highly correlated to the mesocotyl elongation of the genotypes. They also showed that sorghum genotypes with longer mesocotyl showed higher seedling emergence, higher seedling vigor and seed viability, thus showing multiple stress resistance. An analysis of genetic parameters indicate that mesocotyl elongation is a reliable trait for its incorporation for stress resistance.

Effect of seed size on seedling emergence

Gelmond *et al.* (1976) state that germinability of seeds under optimal conditions in the laboratory is not always a reliable criterion for their field emergence. He has observed that the weight of 1000 seeds with high germinability was higher than in those with lower germinability. Light colored seeds were superior to dark ones in their percentage and rate of emergence and in 1000 seed weight. Large sorghum seeds have an advantage over small seeds in the rate of germination and emergence. There was no difference between hand threshed and combine-threshed seeds in their emergence ability under optimal conditions.

Seeds grouped into 3 size classes were sown in wooden flats for seedling emergence studies. It was observed that seed size had no effect on seedling emergence in the same genotype. Genotypes differing in seed size were found to show significant variation in seedling emergence. Similarly, seeds taken from different locations (base, middle and top) in the panicle showed a significant variation in their capacity to emerge (Maiti, 1986).

The effect of seed size on seed viability, seedling vigor and seedling emergence has been reported by several workers (Abdullahi and Vanderlip, 1972; Suh *et al.*, 1974).

Soil temperature

High soil surface temperature is one of the causes for poor emergence in the SAT. Each plant has a minimum and maximum temperature at which no seeds germinate, and an optimum temperature at which germination will be highest. Soil temperature has a direct effect on both germination and subsequent plumule extension, thereby resulting in poor seedling emergence. In the SAT, air temperature often exceeds  $40^\circ\text{C}$  (Peacock, 1982). The minimum temperature for sorghum germination is reported to be between  $7.2 - 10^\circ\text{C}$  and  $5.6^\circ\text{C}$  for subsequent growth (Quinby *et al.* 1973). At the soil surface, temperatures  $> 60^\circ\text{C}$  can be experienced by the emerging plumule (Peacock and Ntshole, 1976). Peacock

In one experiment by Maiti (1986) at ICRISAT, 10 genotypes were sown at depths of 20 mm, 30 mm, 40 mm and 50 mm, receiving a small shower soon upon sowing but none thereafter. Under the drying soil, seedling emerged from deeper depths. Seeds sown at 20 mm did not emerge, but with a first shower they started emerging; by this time, seedlings sown deeper were already established. This indicates that the seeds sown shallow did not lose viability, even when the germinating seedling were dried. The first shower was sufficient to complete the imbibition period, but it was not enough for the seedlings to emerge.