(1982) stated that optimum germination occurs when soil temperature is bet
21 to 35°C and the lethal temperature for germination of sorghum ranges
40 - 48°C.

Sorghum seeds were observed to germinate at 40°C but not at 47°C. M
(1982) reported that the minimum temperature may vary within species fro
to 16.5°C. With an optimum temperature between 25 and 30°C, Singh
Dhaliwal (1972) obtained maximum germination at 25°C, but no germin
between 5 and 10°C. The optimum temperature for radicle growth is near
same as for germination. Andrews *et al.* (1981) reported that 55% of the sorg
lines tested under simulated soil moisture conditions showed emergence at
seed zone temperature, while only 36% emerged at 48°C. Adams (1965), B
et al. (1971) and Unger (1978) found that surface residues influence soil tem
ture.

In a study at ICRISAT (1980), seedling emergence was noted with a set
genotypes in a wide range of soil surface temperatures. Charcoal, light ka
heavy kaolin and bare soil were used as surface covers to modify tempera
(42°C and 65°C at 14:00 hours). In the charcoal treatment, where temper
reached 65°C at 0.5 cm depth, there was no emergence, but most seeds
germinated. The seedlings which failed to emerge did not show any sign of
deficiency, and they appeared turgid. In the higher soil temperatures, the le
had emerged out of the coleoptile and unfolded slightly while still in the
(ICRISAT, 1980). Details of the technique are described in Appendix-1. W
et al. (1982) demonstrated that delayed and poor emergence were associated
high soil surface temperature. They observed that the plumule of the suscep
genotypes bent laterally after reaching high soil surface temperatures in
charcoal while the coleoptile of the tolerant genotypes could emerge.

In another study, the author tested 50 sorghum lines at ICRISAT in Indi
their emergence ability over a wide range of temperatures by planting on diffe
dates between October 1980 and April 1981. Two different soil temper
profiles were obtained at each planting by using kaolin and charcoal as sur
covers (Fig. 3.3). It was found that emergence was significantly affected by: 1-
of planting (environment), 2- surface treatment (kaolin and charcoal cover)
3- genotype, and significant genotype X treatment (2+3) interactions were ob
ed. This indicated that genotypes behave differently in different treatments

It was evident that with the increase in temperature from January to Ap
ICRISAT, there was decrease in emergence in the charcoal treatment. In
kaolin treatment, the emergence was relatively higher. During winter mo
emergence took a longer time in kaolin than in charcoal due to the prevailing
temperature in the former (ICRISAT, 1980). In these studies, emergence
seedlings showed significant negative association with temperature (r^2= 0.
both soil surface and seed level (Maiti, 1986).

A set of 102 genotypes were again tested by the author with charcoal and ka
3 times - in November 1982, January and February 1983, and similar results
obtained. The date of planting (environment), surface temperature, genotype
their interactions had a significant effect on emergence. Both, low tempera
in January planting and high temperature in May affected seedling emerge

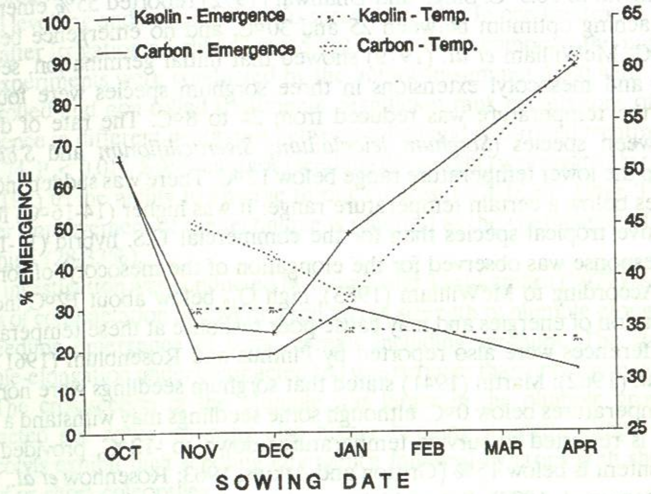

Figure 3.3 Effect of seasonal temperature on the emergence of seedlings in charcoal and kaolin.

Some genotypes were selected showing good emergence in low and high temperatures.

A technique was developed at ICRISAT in 1982 to study seedling emergence response to high soil temperature with no drought stress. Long clay pots (30 cm) filled with sieved alfisol (red soil) were kept in a water tank. Seeds were sown 50 mm deep in each pot. The soil was heated with a bank of infrared lamps fitted on a frame above the water tank. Temperature of 35 to 50°C at 20 mm depth could be maintained by varying the height of the lamps. Temperature was recorded at 6 hr intervals with a thermocouple, and the soil was heated until seedling emergence stopped 6 to 7 days after sowing. Sufficient moisture remained as water was supplied through capillary movement through the walls of the earthen pot. The test temperature was kept at 45°C. The maximum soil surface temperature in the field trials was reached on most days between 14:00 and 15:00 hrs. Using this technique, genotypic differences in emergence were most evident at 45°C. The effects of temperature, genotype and temperature X genotype interactions were highly significant. By simulating soil temperatures in the field, the technique can be used to screen genotypes to emerge through specified soil temperature under no drought situation (ICRISAT, 1982).

The effect of low temperature on germination and establishment of sorghum has been reported by several soil scientists and discussed further by Peacock (1982). Quinby *et al.* (1958, cited by Peacock, 1982) reported that the minimum temperature for germination is between 7.2°C and 10°C. Pinthus and Rosenblum (1961) quoted a range of 8-10°C. Both these groups indicated that a higher temperature of 15.6°C was required for subsequent emergence. Accordin Thomas and Miller (1979), the minimum germination temperature varies wi species from 4.6 to 16.5°C. Singh and Dhaliwal (1972) reported 55% emerge at 15°C reaching optimum between 25 and 30°C, and no emergence betw 5 and -10°C. McWilliam *et al.* (1979) showed that initial germination, seed respiration and mesocotyl extensions in three sorghum species were found decline as the temperature was reduced from 24 to 8°C. The rate of dec varied between species (*Sorghum leiocladum*; *S.verticiliflorum* and *S.bico* especially in the lower temperature range below 12°C. There was sudden incre in Q_{10} values below a certain temperature range. It was higher (14-16°C) for more sensitive tropical species than for the commercial U.S. hybrid (11-12 A similar response was observed for the elongation of the mesocotyl of sorgh seedlings. According to McWilliam (1983), high Q_{10} below about 12°C indic a high activation of energies and may cause poor response at these temperatu Genetic differences were also reported by Pinthus and Rosenblum (1961), Stickler *et al.* (1962). Martin (1941) stated that sorghum seedlings were norm killed at temperatures below 0°C, although some seedlings may withstand a sl frost. Seed is reported to survive temperatures down to -12°C, provided s moisture content is below 15% (Gritton and Atkins, 1963; Rosenhow *et al.*, 19 Bass and Stanwood, 1978), but at higher moisture levels (30-35%) subsequ germination was markedly affected (Carlson and Atkins 1960; Rosenhow *et* 1962; Kantor and Webster, 1967).

Effect of soil crust on emergence

After sowing, soil crusting and compaction are important problems in semia tropics (Miller and Gifford, 1980) where rain showers are often followed by su days. The surface crust creates impedance for the emergence of seedlings different crops. Soil particles are rearranged to form a compact zone at the s surface resulting in higher bulk density, less macroporosity and higher mechani strength than the underlying soil (Lemos and Lutz, 1957; Tackett and Pears 1965). The sequence of events leading to crust is explained clearly by Richa (1953). Soil structure and texture greatly influences the strength of the cr (Mathers *et al.*, 1966).

Crusting has a direct effect on plant growth and an indirect effect on t desirable soil processes. The direct effect on plant growth includes mechani obstruction to the emergence of germinating seedlings and damage to roots by t formation of warps and cracks in the drying crust. The indirect effect of crust soil includes water percolation rate, increase in runoff and inhibition of microb activity. Besides soil crust per se, bulk density of the soil was shown to aff seedling emergence in sorghum (Mali *et al.*, 1977). Some measures have bee suggested to prevent crust formation. Of these, the use of mulches, chemicals a tillage are important (Mehta and Prihar, 1973; Chowdhury and Prihar, 1976; Khe *et al.*, 1976; Agrawal, 1980).

Different techniques were adopted to study the genotypic variability of sorghu for emergence ability through crust in the field and in brick flats. The results a few experiments conducted at ICRISAT, Patancheru are described here (Ag wal *et al.*, 1986).

A technique for investigating emergence through simulated crust was developed and tested in the field. The technique involves preparing the land to a fine tilth, careful levelling and controlled perfo-spray irrigation. In one treatment, about six hours after irrigation a light roller (15 kg) was used to compress the upper layer. Two experiments were conducted by the author in summer 1980 with 100 lines, using rolled and non-rolled treatments. Significant rank correlations of seedling emergence in different genotypes between rolled and non-rolled treatments exist ($r = 0.74$, $P < 0.01$). Seedling vigor (seedling dry weight) was positively correlated ($P < 0.01$) to the ability to emerge through a crust (ICRISAT, 1980; Table 3.2). Further improvement of the technique is required as the coefficients of variation were high (28-33%).

An investigation was conducted by Inouye and Tanakamaru (1977) to study the effects of compactation of covering soil on the strength of plumule elongation and the seedling emergence of some cereals including sorghum. The strength of plumule-elongation under compacted soil was stronger than under non-compacted soil. The crosssection of the plumule was larger in the plumule grown under compacted soil cover, showing also higher bending strength. Crops with long mesocotyls exhibit high seedling emergence followed by crops with short mesocotyles or short coleoptiles.

The emergence of sorghum genotypes under crust conditions in the arid soils at Hissar, India was compared with that in the alfisols at Patancheru, ICRISAT (Tables 3.3 - 3.7). The main objective was to establish whether genetic variability existed and to identify genotypes which emerge well through soil crusts in both soil types (Agrawal *et al.*, 1986; for details of the technique, see Appendix 1). Significant treatment X genotype interaction was obtained, indicating that genotypes behaved differently; some lines showed better emergence in all crust situations. Crust strength in the alfisol field increased 4 to 6 kg/cm² during the period of seedling emergence, while in the brick containers it was only 2 kg/cm². The higher crust strength in alfisol could be associated with subsoil compaction in the field situation whereas in the brick container, the crust is thin (2 - 3 mm thick) and weak. As expected, there was gradual depletion of soil moisture with time, accompanied by a small increase in soil temperature. This brought about a marked

Table 3.3 Effect of crust on the emergence of seedlings (means of % emergence, significant $P < 0.01\%$).

	Exp. 1	Exp. 2	Exp. 3
Mean of treatments with crust	32.4	19.8	38.4
Mean of treatments without crust	52.4	42.0	54.6
LSD at 5% of genotypes	4.0	1.3	21.8
LSD at 5% of treatments	11.6	9.9	11.0

* Experiments: 1- 31 genotypes at Hissar, 2- 45 genotypes at Hissar, 3- 101 genotypes at Hissar. (LSD= least significan difference).

increase in crust strength in the field and in the brick containers, mean percenta emergence was higher in the field than in at the brick containers at ICRISA though the crust strength was higher in the field. This appeared to be due to th emergence of seedlings through several cracks in the field, which did not occ in fine grained soils in the brick container.

Moisture content of the soil (Carnes, 1934; Sharma and Agrawal, 1978) a also structure and texture (Mathers *et al.*, 1966) are known to greatly influen the strength of the crust. The two test sites, Hissar and ICRISAT, have simil bulk density, but differ in other physical characteristics, consequently, the natu of the crust was different at the two locations. The aridosols at Hissar were lo in organic matter and susceptible to surface crusting, and a thin layer of surfa crust, 2 mm thick, was formed. The alfisols at ICRISAT, in addition to surfa crusting, appeared to be prone to soil hardening while drying. The crust streng recorded by the penetrometer on the day of emergence was much higher in th alfisol where only surface crusting was involved. This explains the lower emergen in the crusted alfisols than in the aridosols, although the difference was very sma (4%).

The percentage emergence on the first day showed a significant positive correl tion with final percentage emergence in all experiments (r = 0.59, 0.75 and 0. in experiment nos. 1, 2 and 3 respectively; $P < 0.01$); similarly, the final percen age emergence showed a significant positive correlation with the emergence ind (r = 0.56, 0.56, 0.66 in experiment nos. 1, 2 and 3 respectively; $P < 0.01$; Tab 3.4). Also the rank correlation between emergence on the first and final day ov all experiments was significant (r = 0.70; $P < 0.01$). Thus, as expected, th emergence on the first day may give an indication of the emergence on the fin day. The lines that emerged earlier, often emerged better in the crusted soils. Th the genotypes which emerge faster are better suited for crusting soils. Therefo rapid emergence could be used as a preselection criterion for better genotyp under crust situations.

Since crust strength increased over time, the higher emergence in genotyp which emerged earlier may be ascribed to their emergence through a weaker cru Thus the better emergence of these lines may be attributed to 'crust avoidanc The faster rate of coleoptile growth and seed vigor could help these genotyp to emerge through crusts.

Analysis of data from all 3 experiments indicated that genotype, experime

Table 3.4 Means and ranges of final seedling emergence % and eme gence index in all experiments (Mean [range]).

Expt.No.	Seedling emergence % Crusted soil	Seedling emergence % Uncrusted soil	Emergence index Crusted soil
1	40 [1-66]	65 [11-88]	50 [15-58]
2	36 [7-68]		7 [3- 9]
3	26 [1-71]		11 [0-15]

nd genotype X experiment interaction had a significant effect on percentage mergence and the emergence index. Genotypes behaved significantly different different crust situations, however, some genotypes emerged well (more than % emergence) in all the three crust situations (Table 3.5 & 3.6).

able 3.5 Percent emergence of seedlings of some sorghum genotypes.

Genotype	% Seedling Emergence Crusted	% Seedling Emergence Uncrusted	Crusted/ Uncrusted
IS-4474	67	69	0.96
IS-684	52	63	0.83
IS-155	60	69	0.82
IS-3510	59	73	0.80
IS-8962	13	59	0.23
IS-4542	11	49	0.22
IS-4663	7	77	0.09
IS-923	3	40	0.07

able 3.6 Mean emergence % of some lines showing better emergence different soil environments.

GENOTYPE	Alfisol field, Patancheru	Aridosol flats, Hissar flats	Alfisol flats Patancheru
IS-923	87.5	82.0	63.0
CSV-5	84.5	89.5	92.5
IS-5140	78.5	70.0	73.0
IS-4667	100.0	84.0	66.0
IS-8962	84.5	80.0	66.0
IS-2314	82.0	86.5	87.5
CSH5	82.0	100.0	92.5
IS-2482	97.5	100.0	77.5
IS 5567	75.5	64.0	77.5
GPR-148	63.0	84.0	87.5
IS-5109	97.5	62.0	92.5
IS-4664	73.5	89.5	99.5
IS-5067	91.0	95.0	96.5
IS-4663	68.0	70.0	63.0
IS-15632	100.0	99.0	96.5
M35-1	89.0	97.5	100.0

The seedlings that emerged on the first day encountered a crust which hardened pidly. After the first day, the increase in crust strength was less. Hence, the seedlings that emerged subsequently were subjected to higher crust strength. Si ficant genotypic variability was found in emergence percentage based on the n ber of seeds that did not emerge on the first day. Even after removing the e emerging lines which avoided crust, the remaining genotypes also showed sig cant variability in emergence through soils prone to crusting. Genotypes show good emergence ability at Patancheru and Hissar were IS 4349, IS 5977, IS 2 IS 1072, IS 10022, Nagawhite and IS 5642. At Hissar, some lines emerged we the presence of soil crust, while others failed miserably (ICRISAT, 1980).

Although good management practices like use of mulches, chemicals and till suggested by some authors (Bansal *et al.*, 1971; Mehta and Prihar, 1973) co improve emergence in an adverse soil environments, selection of lines with be ability to emerge under such situations would be advantageous. It is now impor to establish the morphological and physiological characteristics of genotypes wh are responsible for the large variation in their ability to emerge through a cr Thus, genetic improvement for emergence through crust along with impro agronomic practices to reduce crust strength should improve stand establishm in soils prone to crusting. Efforts are required to further simplify methods develop techniques which would enable the screening of a large number of li at one time in the field for better emergence under crusting.

Effect of crust strength on radicle and plumule length and percentage emerge of post rainy season sorghum

A tractor mounted planter with a 20 mm chisel furrow-opener was used w the covering wheels. CSH-5, an Indian hybrid was planted at 5 cm depth in m soil at 14 seeds/m. To induce crust formation, water was applied by a trac mounted sprayer two days after sowing. There was no difference in radicle len for the crust and no crust treatments. Plumule length were also similar until start of emergence when the soil crust arrested the rate of plumule elongatio crust treatment (Table 3.7). The penetrometer used to measure crust stren indicated that the lower plumule length and percentage emergence were con quences of the crust since there was no differences in the soil moisture in 0-5 layer. Management practices such as mulching and tillage would bring down crust strength and inherent genetic improvement would further aid in better sta establishment in a crusting soil.

Effect of tillage and genotype on seedling emergence and establishment

Six genotypes showing a range of seedling vigor, 2 each for high, intermedi and poor vigor, were included (Nagawhite, IS 1096, IS 881, CSV5, IS 914 a Swarna). Different tillage treatments were applied to prepare the seed bed black soil, Patancheru (ICRISAT) and seeds were sown at 40 mm depth in ea treatment. Different tillage treatments have a significant effect on seedling em gence and early seedling vigor. High seedling vigor lines have shown their superi ity in seedling vigor over other lines in all tillage treatments (Maiti and Awadw - unpublished; Table 3.8).

Effects of methods of providing seed-soil contact on crop establishment

(N.K. Awadwal - personal communication)

Providing good seed-soil contact accelerates seedling emergence. The meth for providing seed soil contact is to cover the seed in the furrow with loose s

Table 3.7 Shoot and root growth in crusted and uncrusted fields at Hissar (mean of 26 genotypes).

	Crusted		Uncrusted	
After	**20 days**	**25 days**	**20 days**	**25 days**
Main root length (cm)	11.3	9.4	12.6	12.0
Shoot length (cm)	13.1	11.5	17.3	14.8
Dry weight (g)	0.12	0.11	0.15	0.14

Table 3.8 Effect of tillage and genotype on seedling emergence and establishment in alfisol. (NS- not significant; * P > 0.05; ** P > 0.01; LSD- least significant difference).

		F - values (Variables)		
Source of variation	**df**	**% First emergence**	**% Final emergence**	**Plant height 10 days after planting**
Replications	1	1.439 NS	0.109 NS	0.16 NS
Tillage	5	8.124 *	7.428 *	0.249 NS
Genotypes	5	42.628 **	49.782 **	6.132 **
Interaction	25	2.703 **	2.669 **	0.676 **
LSD at 5%				
Tillage	7.84	8.5	0.92	0.71
Genotype	5.81	5.65	0.48	0.94
Within tillage	14.2	13.8	1.17	2.30
Between tillage	15.1	15.1	1.4	2.21

3 levels of pressure). The experiment was done in alfisol with one genotypes, CSH-8, an All India Coordinated Project hybrid. Methods of providing seed soil contact have significant effects on seedling emergence, and also on seedling vigor.

Effect of soaking and drying on seed viability

Moreno-L.(1988) demonstrated that some sorghum genotypes had capacity to emerge even after 40 hours soaking in water and drying in the incubator at 35 °C for 15 days. These lines could be adapted in dry sowing conditions in semi-arid tropics (Maiti, 1986; Moreno-L., 1988). Later studies have shown that lines resistant to this stress factors contain specific protein of molecular weight of 33.5 kda which is absent or negligible in susceptible lines (Maiti, 1990, unpublished). It was also reported that resistant lines can incorporate higher amounts of amino acids compared to susceptible ones (Sharon *et al.*, 1988). Future studies are needed to confirm whether the specific protein of 33.5 kda is related to resistance under dry sowing.

POST-EMERGENCE GROWTH (SEEDLING VIGOR)

Seedling vigor traits such as dry weight of seed, dry weight of new g (radicle and plumule), length of radicle and plumule, dry weight of root and first leaf area and total leaf area of seedling, showed variation over a wide Different parameters were measured to indicate **1**- the proportion of seed re mobilized = [Dry weight of seed lost during germination]/[Initial dry wei seed]; **2**- the proportion of mobilized reserves utilized for new growth = weight of new growth (radicle + plumule)]/[Initial dry weight of seeds 5 day germination]; **3**- the proportion of original seed reserve to new growth = weight of new growth]/[Initial seed weight].

Different seedling vigor traits showed significant associations among them (Tables 3.9 - 3.10). Genotypes which had more initial seed weight consu lower proportion of its mobilized food reserve for new growth, while the gen which had less initial seed weight (small seeds) consumed relatively higher p of its mobilized food reserve for new growth. Therefore, the absolute wei seed reserve mobilized for new growth during germination and seedling st 5, 20 and 30 days increases with the increase in seed size. However, the as tions between seed size and seedling size at 20 and 30 days after emer although significant, are not very strong. In general, big seedlings at 15 and 3 are produced from big seeds, but not all big seeds produce big seedlings. T because the photosynthetic area and efficiency of seedlings after emergenc influences the seedling growth rate. Seedling size (seedling dry weight) corr significantly with seed size (r^2= 0.61; Maiti- unpublished).

Table 3.9 Associations among different seedling vigor criteria genotypes). (** P > 0.01).

Traits	1	2	3	4
1-Seed weight (25), g	1			
2-Dry weight of seed lost, g	0.74**	1		
3-Dry weight of new growth, g	0.56**	0.78**	1	
4-New growth/seed lost	-0.38**	-0.42**	0.16	1

Endosperm-dependent seedling growth

In order to assess the effect of endosperm content on seedling growth, sorghum genotypes (IS 7755, IS 7999, IS 11150, IS 4310, IS 3921 and IS 127 selected for a study. The endosperm was carefully cut to 3/4, 1/2 and 1/4 sharp blade without injuring the embryo. Thirty seeds from each treatment weighed and put for germination testing in petri dishes lined with wet filter p together with a control (whole seeds). Germination counts were taken aft hours and dry weight of seedlings was recorded after 5 days. There we differences among the genotypes, but the endosperm treatment (size) signific affected seedling size (P < 0.01). However, both genotype and endosperm ment were found to be significantly for dry weight of seedlings at 5 days.

Table 3.10 Correlations (r) among seedling traits (4) (36 genotypes, in wooden flats). (** P > 0.01).

Traits	1	2	3	4
1-Dry wt. of shoot/plant, g	1			
2-Dry wt. of root/plant, g	0.76 **	1		
3-Total dry weight, g	0.93 **	0.86 **	1	
4-First leaf area, cm²	0.48 **	0.48 **	0.57 **	1
5-Total leaf area, cm²	0.79 **	0.64 **	0.84 **	0.46**

Relationship between protein content and seedling size

In wheat, high seedling vigor is related to seed protein content vigor (Welch, 1977; Bullisani and Warner (1980). Similar findings were obtained by the author for sorghum (Table 3.11).

Table 3.11 Relationship between protein content and seedling size. (* P < 0.05; ** P < 0.01).

	1	2	3	4	5	6
1-UIR, %	1.00					
2-Protein, %	0.87**	1.00				
3-Seed weight (30), g	-0.48*	-0.61**	1.00			
4-Seedling wt. (30) 5 d.	0.15	0.27	0.08	1.00		
5-Seedling wt./plant, 15 day, g	-0.12	-0.46**	0.63**	0.09	1.00	
6-Total protein content	0.45	0.51	0.35	0.46*	0.11	1.00

Seedling vigor in laboratory and field tests

The dry weight of seedlings sown in the laboratory showed significant positive correlation with dry weight of seedlings sown in the field. To standardize a laboratory test that may be used as a preliminary indication for the evaluation of seedling vigor, regression analyses were attempted for the dry weight of seedlings grown in the laboratory and in the field. The analysis established a significant relationship between the dry weight of field shoot at 30 or 20 day and dry weight of new growth on the fifth day in the laboratory. These results indicate that laboratory tests may help as a preliminary screening method for the evaluation of seedling vigor under field conditions.

Evaluation of seedling vigor

There are 2 important aspects of seedling vigor in sorghum: **1**- the ability to establish a satisfactory stand under a variety of conditions, and **2**- the ability to produce rapidly growing seedlings. Work done in this area has largely concent on stand establishment and relationship of seed characteristics, seed so laboratory tests for vigor, and to field establishment. Initial work on seedling by the author at ICRISAT concentrated more on the seedling size/growth aspects of vigor. This was partly in response to the large variation in see growth rates that were evident in the breeding materials and germplasm co tions. It was also based on the assumption that large, vigorous seedlings perform better over a wide range of seed-bed and environmental conditions need to be researched for genetic improvement for sorghum crop adaptati

Seedling size or growth rate is best assessed by direct measurement of weight and leaf area. For evaluation of seedling vigor, direct measurem approximately 15 days after emergence are used in genotype comparison. H ever, this is a laborious and time-consuming process when a large number of are involved. The present study was undertaken to evaluate how effective si visual scoring for seedling size is, and how closely visual scores are relate measured seedling dry weights and leaf areas (Maiti, 1981). Seedling size variety is largely determined by edaphic conditions and soil fertility. There to evaluate seedling vigor of a set of genotypes, we need to grow these seed in a precision field with uniform fertility. This simple non-destructive techn could be used in the evaluation and improvement of seedling vigor in segreg generations in a breeding program.

Sorghum lines with improved seedling growth rate have been shown to be m competitive with weeds (Guneyli *et al.*, 1969). No study directly links seedling to final crop performance in sorghum, although seedling size/dry weight has b reported to be positively correlated to grain yield in oats (Bain *et al.*, 1969) barley (Singh *et al.*, 1975). Lawrence (1963) has standardized different met for evaluation of Russian wild rye grass for seedling vigor. He suggested selecting large-seeded lines and selecting them for deep seeding is a suit method of incorporating seedling vigor in a breeding program.

Visual rating of seedling vigor

A wide range of seedling vigor has been reported in sorghum (Maiti, 19 Differences in height, leaf breadth, leaf number and pseudostem thickness w evident in sorghum germplasm belonging to different taxonomic groups. Vi scores were compared to measured dry weight per seedling for their abilit distinguish among genotypes by computing ANOVA tables for genotypes u visual score at 7 and 11 days, and dry weight at 15 days. Research at ICRIS has shown that 15 days after emergence, genotypes are generally variable in t expression of seedling vigor (Maiti, 1981).

Relationship of visual score to dry weight and leaf area

The relationship of the visual score to actual seedling growth and leaf area examined in a set of 50 genotypes. All correlation coefficients were highly sig cant (at 1% probability). Leaf area and dry weight were also very closely linearly related in these lines (Tables 3.12 - 3.13). To understand if the relation between visual score and seedling dry weight is a result of interaction of genot differences for height and maturity, 22 dwarf germplasms belonging more or to the same maturity group were evaluated. It was found that visual scores sho

ignificant relationship with seedling dry weight ($r^2 = 0.92$).

Table 3.12 Comparison of visual scoring to dry weight determination for seedling vigor assessment (512 genotypes; Maiti, 1981).

Traits	F ratio	CV	LSD 5%	Range	Mean
Visual score 7 days	2.93 **	14%	1.2	1-5	3.2
Visual score 14 days	2.03 **	18%	1.5	1-5	3.0
Dry weight per plant (g) 15 days	1.76 **	27%	0.4	0.14-1.24	0.46
[** $P < 0.01$]					

Table 3.13 Correlations among seedling vigor estimates (50 genotypes; Maiti, 1981). All coefficients significant, $P < 0.01$.

Traits	1	2	3	4
1-Visual score 7 days	1.00			
2-Visual score 14 days	0.84	1.00		
3-Dry weight 15 days	-0.76	-0.82	1.00	
4-Leaf area 15 days	-0.81	-0.87	-0.90	1.00

Comparison of criteria for estimating seedling vigor

The visual score was compared to measured dry weight per seedling (at 14 and 15 days) for its ability to distinguish among genotypes. F ratios for genotypes were not different for visual score and dry weight, but the coefficient of variation for the visual score (14 and 18%) was lower than that for the measured dry weight (27%). Similarly, the ratio of the range of the measured variable to the LSD was better in the case of visual score (4.2 and 3.3) than in the case of the actual seedling dry weight (2.8) (Maiti and Bidinger, 1979; Maiti, 1981).

The visual scores should be effective in distinguishing genetic differences in seedling vigor in sorghum. For routine breeding work however, scoring should be quite efficient, specially in that the range of scores is approximately three times the LSD. Visual scores are well correlated to the direct measures of seedling vigor and are effective tools for distinguishing genetic differences among a large number of entries. A large number of lines can be scored easily and rapidly by using this technique which suggests that this could be routinely incorporated into a breeding program where seedling vigor is an important attribute. Studies at ICRISAT have indicated that seedling vigor is correlated to its emergence ability through crust and drought resistance at the seedling stage (ICRISAT, 1980). Therefore, the performance of high seedling vigor lines under adverse conditions needs to be tested.

The only limitation of the visual scoring method is that direct comparis between experiments, generations, etc., may not be possible, although r comparisons could be made. But this should not be considered a serious limita as the main objective of the breeding program is usually the selection of the b individuals from a group of entries handled and tested as a unit (Maiti, 198

Crosses (F3 population) between seedling vigor source and a range of pare (Maiti - unpublished)

It is interesting to study how seedling vigor behaves in parents and their pro nies. Sixty-six crosses were made at Patancheru, ICRISAT, between Nagaw (with extraordinary early seedling vigor) and a range of parents from NP, WA and bulk Y were evaluated in the field.

Similar type of associations were observed as in the previous studies. The weight of seedling at emergence showed significant positive correlation with dry weight of seedling at 15 days. On the basis of this study, 28/66 entries, w found to be superior to Nagawhite at emergence and at 15 days after emerge At 15 days after emergence, entries with seed size less than that of Nagaw were all inferior in performance. Using the measurement made on the 66 cro between Nagawhite and a range of parents from NP, WABC and bulk appears that the evaluation and selection for good seedling growth (regardles yield) could be based on: 1- dry weight measurement at 7 or 15 day stage to m sure that vigor is not ephemeral, while taking into consideration differences in area and or photosynthetic efficiency of leaves; 2- seed size having selected genotypes based on seedling size, these may be grouped into: a) genotypes seedling size and seed size equal or greater than the check, and b) same as but the seed size smaller than the check.

Relationship between seedling vigor with the total biological yield

The yield components of 66 crosses and Nagawhite (high seedling vigor and CSH-1, an Indian hybrid, were taken in separate experiments. Seedling weight at 15 day (seedling vigor) was found to correlate with the final plant he (r= 0.4, P => 0.01), total dry weight (r= 0.4, P => 0.01) and weight of seed the seedling vigor materials (r = 0.4, P < 0.1) but not with grain weight panicle. Plant height again was found to be associated with grain weight (r= P > 0.01). In this experiment (F3 progenies of Nagawhite X, Bulk Y and WAB seedling vigor was found to be associated with their good performance in resp of yield components and yield. The study indicated that the bigger the seed size (at 15 days after emergence), the higher the total (biological) yield, altho this may not apply to all big seedlings. However, higher seedling growth may necessarily lead to higher economic yield, because the characteristic determin seed number have to make a complementary contribution if rapid and hig growth rate during seedling development stage is to result in increased y (Maiti, unpublished).

The higher the leaf area at emergence, the bigger the seedlings at 15-20 d after emergence. Furthermore, as soon as the seedling becomes autotrophic total and leaf growth rates depend on the photosynthetic efficiency of its lea which at emergence, are larger in the large seeded genotypes. Therefore, seed from a genotype whose initial seed weight is less than the check could parti

compensate for the disadvantage in seed size, although this may not happen. The selected genotypes have also been tested for yield. The material with vigor greater than the original parent crossed to Nagawhite indicated that enough improvement was achieved both in seedling growth and yield. The materials with yield lower than the original parents crossed to Nagawhite obviously had significantly reduced seedling vigor, but they may be maintained as a source material for further use in population or crosses. It is assumed that this may be put together in a population which included the early seedling vigor, a GS2 with a partitioning of the photosynthates and the nutrients which favored the developing panicle and plants with a GS3 having a longer than usual duration of grain-filling coupled with a higher rate of filling. We might get a recombination from such a population which would show improved yield. Research effort needs to focus in this direction.

Factors controlling seedling vigor in sorghum

Where seedling vigor is a breeding objective, evaluation of seedling vigor in a crop must be done under constraints other than those that affect the evaluation of vigor in commercial seed lots. A breeding line is often represented by a few panicles, a single panicle, or even a plant. Successive generations may be produced under very different environmental conditions, particularly where off-season nurseries are employed. With certain crops, only selected portions of the reproductive structure(s) may be harvested for generation advance. How these constraints affect the results of seedling vigor evaluations - or if they are important at all-is largely a matter of conjecture.

All these constraints exist for sorghum (*Sorghum bicolor* L. Moench). Head to row selection is the common practice in both pedigree breeding and in male-sterile-based population breeding systems. Two generations per year are grown in programs where alternate locations (temperate zones) or irrigation facilities (tropical zones) are available. Finally, it is a common practice to remove the frequency of outcrossing when the panicle is not bagged.

The existing literature on seedling vigor in sorghum deals mainly with the role of seed size in germination, field establishment and seedling size. Seed-lot comparisons have demonstrated that larger seeds generally have a superior germination than standard germination (Abdullahi and Vanderlip, 1972; Maranville and Clegg, 1977). However, field establishment is not always superior in larger sized seeds (Abdullahi and Vanderlip, 1972; Suh *et al.*, 1974; Maranville and Clegg, 1976). Similarly, seedling size (or growth rate) was not related to seed size (Suh *et al.* 1974). Similar results have been reported from comparisons among cultivars (Swanson and Hunter, 1936), and for comparisons of different seed lots of the same cultivar (Abdullahi and Vanderlip, 1972). In neither case were demonstrable differences among cultivars/seed lots related to seed size differences. Maiti and Carrillo (1991) reported that sorghum genotypes showed variability in seedling emergence from deeper planting depth, and the capacity of emergence from deeper planting is associated with the capacity of elongation of mesocotyl from deep planting.

The objective of these studies were to: 1- evaluate the effects of the constraints on seedling vigor evaluation on the results of vigor evaluation tests, and 2- to test the effects of seed size differences in seedling vigor in these comparisons.