EMERGENCE, SEEDLING VIGOR, AND STAND ESTABLISHMENT OF PEARL MILLET AS AFFECTED BY MESOCOTYL ELONGATION AND OTHER SEED AND SEEDLING TRAITS

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX TABLES

INTRODUCTION

Pearl millet [*Pennisetum americanum* (L.) Leeke] is the most important of the millets in the arid and semiarid regions of Asia and Africa. Sprague (1981) reported that pearl millet is grown where rainfall and soil fertilty limit sorghum [*Sorghum bicolor* (L.) Moench] production. In Africa and Asia, millet is grown primarily for human consumption due to its high nutritional value. It is valuable as a fodder crop due to its high albuminoid and fat contents, in addition to the absence of HCN which makes sorghum dangerous to grazing livestock (Gupta and Sehgal, 1971). Pearl millet stalks are used for home and fence construction in most African countries. In Sudan, pearl millet is grown mainly in the western regions where rainfall is a limiting factor for sorghum production. In the eastern part of the country, farmers grow sorghum mainly, but due to the high infestation of witchweed [*Striga hermonthica* (Del.) Benth.] and shortage of rainfall, they have started growing millet.

Poor stand establishment resulting from low seed quality and low seedling vigor is a major problem facing millet growers in the less developed countries. Therefore, research on the crop should be directed toward improvement of establishment capacity. Coleoptile and mesocotyl lengths have been shown to affect seedling emergence in intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv.](Hunt and Miller, 1965), rice (*Oryza sativa* L.) (Turner et al., 1982), and corn (*Zea mays* L.) (Wilson and Loomis, 1967). Available literature, however, contain no reports on relationships of mesocotyl and coleoptile length, to emergence, seedling vigor, and stand establishment in pearl millet. Objectives of this study were : (1) to investigate the effects of seed weight and lengths of radicle, mesocotyl, and coleoptile on emergence, seedling vigor, and establishment of pearl millet and (2) to study relationships among the foregoing characters.

LITERATURE REVIEW

Seed Weight and Size

Pearl millet is characterized by small seeds that limit amounts of mineral and carbohydrate available for seedling growth. Seed size and density influence seedling emergence, early seedling vigor, and stand establishment of the crop (Gardner, 1980; Lawan et al., 1985). Okonkwo and Vanderlip (1985) considered seed size and seed weight to be among the factors determining seed quality in pearl millet. On sandy soil, seedling height of Baladi' pearl millet increased with an increase in seed weight (Vanderlip et al., 1985).

A positive correlation between seed weight and emergence from deep planting has been demonstrated in intermediate wheatgrass (Rogler, 1954). Berdahl and Baker (1984) showed that emergence and coleoptile length of Russian wildrye [Elymus junceus Fisch.] increased with increased seed weight but that this relationship diminished at weights exceeding 3.0 mg /seed. Gaspar et al., (1981) found that, in several forage species germination increased with seed weight, but this relationship became less pronounced at high weights. With witchweed, [Striga asiatica (L.) Kunize], larger and heavier seeds had greater seed viability and germination capacity than smaller and lighter seeds (Bebawi et al., 1984). Seedling vigor in soybean [Glycine max (L) Merr.] was related more to seed size than to standard germination (Hoy and Gamble, 1985), and seed weight of that species could be used as a criterion for selecting for improved seedling vigor (Berdahl and Baker, 1984; Boyd et al., 1971).

Germination Germination Index and Stand Establishment

In general, poor germination results in poor stand establishment, which leads to low yield. Better stand establishment probably could be achieved if cultivars with greater emergence potential were developed. According to Copeland (1976), the major events in seed germination are imbibition of water, enzyme activity, initiation of embryo growth, rupture of the seed coat, and emergence of the seedling. Germinaton of the seed and establishment of the seedling are critical stages in the life cycle of most crops, especially small-seeded species. Blacklow (1972) defined germination as growth of the embryo and emergence of the radicle. Maguire (1962) used a germination score weighted in favor of early germination to select and evaluate seedling emergence and vigor in Kentucky bluegrass (Poa pratensis L.). Lawan et al., (1985) reported that a similar index was affected by both seed size and seed density in pearl millet. According to Thomson (1979), establishment of the seedling begins with the end of germination and ends when the seedling is independent of the accumulated food in the seed. Hukkeri and Shukla (1983) defined stand establishment in sorghum as the period from 0 to 30 days after seeding.

Seedling Vigor

Heydecker (1960) defined seedling vigor as the ability of a plant to extrude its aerial parts from the soil (or water) in a suboptimal environment. Several traits have been used as criteria of seedling vigor. Among these are time to emergence, emergence index, abililty to emerge from inordinate depths, visual scoring, seedling height, and seedling dry weight.

Time to Emergence:

This trait was used by McKenzie et al., (1980) as a criterion of seedling vigor in rice plants. They reported that mean days to emergence increased with a decrease in soil temperature. Warrington and Kanemasu (1983) reported that corn seedling emergence is very slow at (16/6^{o}C) compared to (30/30^{o}C).

Emergence Index:

The germination index described by Magurie (1962) could be modified to serve as an emergence index.

Visual Appearence:

Visual scoring has been used for evaluating seedling vigor and stand establishment in sorghum (Maiti et al., 1981), and pearl millet (Anonymous, 1977-78). Visual scores were correlated with seedling dry weight in pearl millet (Anonymous, 1977-78) and sorghum (Maiti et al., 1981).

Seedling Height and Dry Weight:

Seedling height and seedling dry weight were used as criteria of stand establishment and seedling vigor in pearl millet (Mwageni, 1978; Lawan et al., 1985) and sorghum (Maiti et al., 1981).

Radicle Mesocotyl and Coleoptile Length

In cereal seedlings, the root and the shoot are very important for water and nutrient uptake during establishment (Abbass Al-ani and Hay, 1983). Increases in soil temperature up to 25°C increase extension of the root system of pearl millet (Abbass Al-ani and Hay, 1983). The radicle is the basal end of the embryonic axis, which grows into the primary root (Wilson and Loomis, 1967). Radicle length is independent of shoot length, but radicle removal reduces shoot growth. The rate of radicle and shoot (mesocotyl and coleoptile) elongation of corn is greatest between 30 and 40°C and ceases below 9°C (Blacklow, 1972). Tischler and Monk (1980), reported reduction of stand establishment in kleingrass (*Panicum coloratum* L.) due to an inadequate root system. The mesocotyl is the internode below the coleoptilar node. It elongates by cell division in the absence of light (Turner et al., 1982; Avery, 1930). Mesocotyl elongation has been shown to be important in emergence of the corn seedling. When corn seed is planted too deeply and growing conditions are not favorable, mesocotyl elongation may cease before emergence (Wilson and Loomis, 1967). Short mesocotyls result in poor emergence from 10 cm in rice (Turner et al., 1982). Internode length is a major factor differentiating dwarf and tall plants of millet and is controlled by the so-called "d" loci (Burton and Fortson, 1966). Whether those loci also control mesocotyl length has not been reported, although Burton et al.(1969) observed no effect of the d2 gene on rate of emergence or early seedling growth.

The coleoptile is the sheath which protects the plumule of the grass seedling during its emergence from the soil (Turner et al., 1982). When the seedling is exposed to light, the coleoptile ruptures, the plumule emerges, and mesocoyl elongation ceases (Wilson and Loomis, 1967; Turner et al., 1982). Burleigh et al., (1965) reported that wheat cultivars with longer coleoptiles emerged more rapildy than those with shorter ones.

Mesocotyl and coleoptile (shoot) contributions to emergence are influenced by planting depth (Turner et al., 1982). Corn seedlings can emerge from 15 cm by mesocotyl and coleoptile elongation (Grant and Buckle, 1977). Some rice seedlings can emerge from a depth of 10 cm by mesocotyl elongation, others emerge by mesocotyl and coleoptile elongation (Turner et al., 1982).

MATERIALS AND METHODS

Seed Sources

Twenty-five seedlots representing different genotypes of pearl millet were obtained from the Fort Hays Branch Experiment Station, Hays, Kansas. Seventeen of the seedlots represented dwarf genotypes (dwarf seedlots) while eight represented normal genotypes (tall seedlots), (Appendix table 1).

Laboratory Determinations

Seed Weight:

One-hundred seeds of each lot were weighed. Measurements were replicated three times and results were adjusted to weight per 1000 seeds.

Germination and Germination Index:

Chlorox (sodium hypochlorite) solution (0.26%) was used to moisten filter papers. Twenty-five seeds selected randomly from each lot were arranged on a double layer of moist filter paper in a 9-cm Petri dish. Petri dishes were randomized and placed in the dark in a germinator at 30°C for 5 days. Germinated seeds were counted daily and discarded. Seeds were considered germinated when they had produced both a plumule and a radicle. No germination was observed on the first day. The procedure was replicated three times. Germination was the total number of seeds germinated after 5 days, calculated as a percentage of 25. Maguire's (1962) formula was applied to daily germination counts to provide a germination index. Thus:

$$\text{Germination index} = \frac{\text{No. of seeds germinated on first day}}{\text{Days to first count}} + \ldots + \frac{\text{No. of seeds germinated on last day}}{\text{Days to final count}}$$

Seedling Measurements:

Twenty-five seeds selected randomly from each lot were arranged in a line across the middle of a double thickness of paper towels that had been soaked in a Chlorox solution (0.26%). Towels were rolled at right angles to the lines of seeds, and rolls were placed upright in beakers. Beakers then were placed in the dark in a germinator at 30°C for 5 days. Rolled towels then were removed from the germinator and soaked in water to facilitate removal of germinated seeds.

The following measurements were made (Fig. 1) for each of three replications.

Mesocotyl Length:

This was measured as the distance from the seed to the

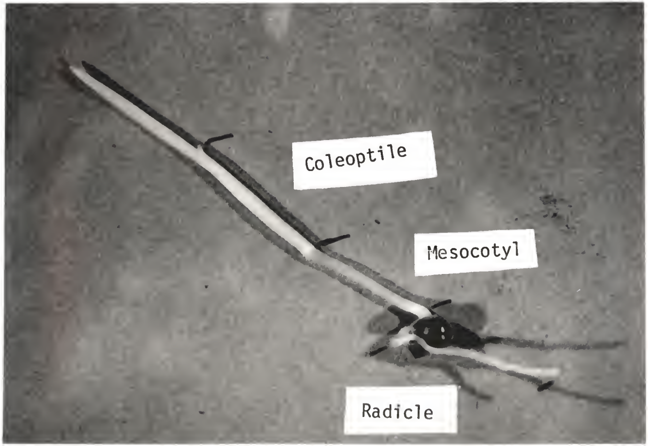

Fig. 1. Seedling Measurments in the Laboratory.

coleoptilar node.

Coleoptile Length:

This was the length of the protective sheath enclosing the plumule in the early stages of seedling development.

Shoot Length:

This was computed as the sum of the mesocotyl and coleoptile lengths.

Radicle Length:

This was the length of the primary root.

Field Study

Site, Soil and Meterological Conditions:

A field study was conducted on Unit 1 of the Ashland Research Farm of the Kansas Agriculture Experiment Station, Manhattan. The soil at the experimental site is a Haynie very fine sandy loam (coarse-silty, mixed, mesic, Mollic Udifluvent). The monthly rainfall was 14.0, and 2.7 cm for June, and July, respectively. The mean monthly temperature was 24 and 26^{o}C for June and July, respectively.

Seeding and Statistical Design.

On Julian day 156 (5 June), 1984, seed from each lot was planted at two depths. Design of the planting was a split plot in which seedlots were main plots and planting depths were subplots. Main plots were arranged in a randomized complete block with three replications. Each subplot consisted of a single 5-m row. Row spacing was 0.75 m. Seeding was by a two-row vacuum planter with one drill set to plant deeply (5.4 cm) and the other set to plant at a shallow depth (3.2 cm). Ninety seeds were planted in each subplot. Furadan (2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl methyl-carbamate) was applied with the seeds to control chinchbugs (*Blssus leucopterus* Say). Propazine [2-chloro-4, 6-bis(isopropylamino)-s-triazine] for weed control was applied at 2.24 kg A.I./ha to the soil surface after seeding. Weeds occurring after emergence were controlled by hand hoeing.

Determinations:

Field determinations were as follows:

Establishment:

Established seedlings were counted on Julian day 170, 1984 (14 days after planting). Seedlings were counted along a 4.5 -m rod for each subplot (row).

Apparent Seedling Vigor (Visual Appearance):

On Julian day 170, 1984, subplots were rated visually on a scale of 0-5. Zero represented no emergence. One represented the least vigorous and 5 the most vigorous seedlings.

Seedling Height:

On Julian day 176 (20 days after planting), seedling height was measured from the surface of the soil to the top of the extended leaves. Measurements were made on five seedlings, or fewer if five did not emerge, selected randomly from each subplot. Measurements for each subplot were averaged to give a single value.

Seedling Dry Weight:

On Julian day 185 (29 days after planting), above-ground parts of five randomly selected seedlings were harvested from each subplot. They were dried in an oven at 52^{o}C for 3 days and

Fig. 2. Visual Appearance (Rating).

weighed. An average seedling weight was calculated for the five seedlings.

Mature Plant Height:

Five plants were randomly selected from each subplot at maturity for measurement of final plant height. Each plant was measured from the ground to the top of the highest panicle, and the five measurements for each subplot were averaged.

Greenhouse Study

On Julian days 82 and 83, 1985, 25 seeds of each lot were planted in plastic pots in the greenhouse at depths of 4, 8, and 12 cm. Pots were 20 cm in diameter and 20 cm deep. Seeds were placed on clay loam in the bottom of the pots and covered with 4, 8, or 12 cm of sand to provide the desired depth of planting. Clay loam and sand were autoclaved for 2 hours before placement in the pots. The experiment was a split plot with planting depths as main plots and seedlots as subplots (individual pots). Main plots were arranged in a randomized complete block with two replications. Pots were watered with tap water at planting and as necessary thereafter. Greenhouse temperature was maintained at 29 and 21°C during day and night, respectively. The following determinations were made.

Time to Emergence:

Time from planting until 20% of the seeds planted had emerged was reported in days as indicated by Gubbles (1975). Time was reported as 14 when no seedlings emerged by the 14th day, and as 10 when emergence by the 14th day was 1 through 19% .

Emergence:

Number of seedlings emerged was counted daily for 6 days after planting, and the total was reported as a percentage of the number of seeds planted.

Emergence Index:

Daily emergence counts were used to compute an emergence index as indicated by Maguire (1962).

Visual Appearance:

The procedure was the same as that used in the field for apparent seedling vigor. Ratings were made 14 days after planting.

Establishment:

On Julian days 96 and 97 (14 days after planting), the number of established (surviving) seedlings in each subplot was counted and reported as a percentage of the number of seeds planted.

Seedling Height:

Seedling height was measured 20 days after planting (Julian days 101 and 102). The procedure was the same as that used in the field.

Seedling Dry Weight:

On Julian days 101 and 102, 15 seedlings were selected randomly from each subplot. They were dried in an oven at 65°C for 3 days and weighed. Weight was expressed as an average per seedling for each subplot (pot).

RESULTS AND DISCUSSION

Laboratory Study

Analysis of variance results are shown in Table 1. Mean separations are shown in Tables 2 and 3.

The tendency of radicles to become attached to paper towels resulted in frequent radicle breakage during measurement and probably contributed to the high CV (26.23%) in radicle length, even though an attempt was made to remove and measure all parts of broken radicles. Coleoptiles continued to elongate after they were removed from the germinator before measurements were completed. Elongation during measurement contributed to error and may have been responsible for the high CV (25.22%) in coleoptile length (Table 1).

Significant differences occurred among dwarf seedlots in all laboratory variables and among tall in all except radicle and coleoptile lengths (Tables 1, 3). High CVs in those variables may have obscured real but small differences among tall seedlots. Overall dwarf and tall means differed significantly in radicle length and seed weight, where dwarf means exceeded tall, and in germination index where the tall mean was greater (Table 2). These results agreed with findings of an earlier study of pearl millet by Lawan et al. (1985), who reported that standard germination index and seed weight were significantly affected by seedlots. Also, Mwageni (1978) reported that standard germination differed significantly among seedlots. Absence of a significant dwarf-tall difference in mesocotyl length indicates that that variable is controlled by loci other than those determining

Table 1. Analyses of Variance for laboratory variables.

Sources	DF	Radicle Length	Mesocotyl Length	Coleoptile Length	Shoot Length	Germination	Germination Index	Seed Weight
		Mean Squares						
		(cm)	(cm)	(cm)	(cm)	(%)		(g/1000 seeds)
Total	74							
Rep	2	7.20	5.26	0.11	4.84	96.64	5.35	0.15
Seedlots								
Among dwarf	16	2.53**	0.49**	0.20*	0.54**	220.51**	3.62**	15.56**
Among tall	7	0.68	0.80**	0.09	1.04**	156.86**	2.63**	13.33**
Dwarf vs tall	1	2.50*	0.01	0.06	0.05	157.63	5.39*	3.41**
Error	48	0.41	0.08	0.09	0.17	39.08	0.85	0.30
CV (%)		26.23	14.98	25.22	13.60	7.00	9.73	4.42

* Significant at 0.05.
** Significant at 0.01.

Table 2. Overall dwarf and tall seedlot means for laboratory variables.

Variables	Dwarf	Tall	LSD (0.05)
Radicle length (cm)	2.58	2.19	0.32
Mesocotyl length (cm)	1.86	1.87	n.s
Coleoptile length (cm)	1.22	1.16	n.s
Shoot length (cm)	3.08	3.02	n.s
Germination (%)	90.27	87.17	n.s
Germination index	9.29	9.86	0.46
Seed weight (g/1000 seeds)	12.58	12.13	0.27

dwarf-tall height differences. Higher average seed weight of dwarf seedlots may have reflected the fact that pedigrees of most dwarf entries contained the large-seeded PI 185642 from the Gold Coast (Stegmeier, 1985).

Table 3. Dwarf and tall seedlot means for laboratory variables.

Seedlot	Radicle	Mesocotyl	Coleoptile	Shoot	Germination	Germination index	Seed weight
				Dwarf			
	(cm)	(cm)	(cm)	(cm)	(%)		(g/1000)
7	3.09	2.12	1.02	3.13	97.0	10.28	12.17
10	1.86	1.99	0.96	2.95	95.0	9.41	8.33
11	1.54	1.55	0.99	2.54	83.0	8.20	9.57
12	2.16	1.72	1.29	3.01	88.0	9.46	12.83
13	2.31	2.00	1.17	3.17	99.0	10.99	11.33
14	5.14	2.79	1.07	3.86	99.0	9.94	11.83
15	3.34	1.71	2.05	3.76	100.0	10.97	13.17
16	2.10	2.22	1.18	3.40	88.0	9.50	12.33
17	1.99	1.82	1.05	2.87	85.0	7.97	10.33
18	1.52	1.44	1.18	2.62	65.0	6.45	13.00
19	2.75	1.41	1.36	2.77	93.0	9.10	15.83
20	2.13	1.16	1.25	2.41	92.0	9.47	15.66
21	3.48	1.83	1.44	3.27	90.0	9.14	15.17
22	1.74	1.49	1.13	2.63	80.0	8.29	13.50
23	3.32	2.42	1.22	3.64	95.0	9.46	11.83
24	2.32	2.05	0.99	3.04	91.0	9.40	10.50
25	3.04	1.94	1.31	3.25	95.0	9.72	16.50
				Tall			
1	2.09	1.17	0.95	2.12	97.0	11.06	13.00
2	2.38	2.84	1.33	4.18	96.0	11.22	9.83
3	3.22	1.60	1.40	3.00	87.0	10.00	13.83
4	1.61	1.55	1.14	2.69	77.0	8.45	10.17
5	2.08	1.81	0.99	2.80	88.0	10.00	10.33
6	1.89	1.91	1.11	3.02	78.0	9.08	12.00
8	1.99	2.35	1.01	3.36	84.0	9.50	11.83
9	2.23	1.71	1.31	3.02	89.0	9.56	16.00
LSD (0.05)	1.05	0.46	0.49	0.67	10.21	1.51	0.89

Field Study

Rainfall in June 1984 was 15 cm, of which 70% was received in the first 8 days after planting. This heavy rain together with high temperatures during that period resulted in soil crusting and heavy weed infestation in parts of the field, leading to variable stands. Stand variability probably contributed to the high CV's for the determinations and may have obscured real effects in some of the variables (Table 4).

Mature plant height was the only significant variable among dwarf seedlots, but tall seedlots differed significantly in establishment, seedling dry weight, and mature plant height (Tables 4 and 6). Tall seedlings were significantly taller than dwarf seedlings even though measurements were made before stem elongation. Tall plants were significantly taller than dwarf plants at maturity (Table 5). Planting depth did not affect any of the variables, and there were no seedlot x depth interactions (Table 4). Both seeding depths were relatively shallow (3.2 and 5.4 cm) and may not have been sufficiently different to elicit detectable depth effects.

Table 4. Analyses of variance for field study.

Source	DF	Visual appea-rance	Establ-ishment	Seedling height	Seedling dry weight	Mature plant height
			Mean squares			
		(cm)	(#)	(cm)	(g)	(cm)
Total	149					
Rep	2	2.34	143.17	110.75	21.57	892.63
Seedlot						
Among dwarf (DW)	16	1.69	64.31	86.54	17.34	1267.03**
Among tall (T)	7	2.19	103.37*	135.22	34.05*	8329.90**
Dwarf vs Tall (DT)	1	2.29	26.41	369.08*	41.89	78582.10**
Error (a)	48	1.55	42.39	78.22	12.04	456.30
Depth (D)	1	2.16	9.13	3.28	5.81	316.91
Seedlot* depth						
DW * D	16	0.40	12.60	38.23	4.93	106.04
T * D	7	0.67	18.51	9.29	6.15	99.04
DT * D	1	0.08	3.45	8.48	3.41	436.20
Error (b)	50	0.51	17.26	29.53	6.00	176.02
CV (error a)		37.50	37.96	26.12	53.00	15.79
CV (error b)		21.50	24.22	16.06	37.11	9.08

* Significant at 0.05.
** Significant at 0.01.
\# Seedlings per 4.5 m of row.

Table 5. Overall dwarf and tall seedlot means for field variables.

Variables	Dwarf	Tall	LSD (.05)
Visual appearance	3.24	3.50	n.s
Establishment (#)	17.44	16.54	n.s
Seedling height (cm)	32.77	36.13	3.10
Seedling dry weight (g/seedling)	6.24	7.37	n.s
Mature plant height (cm)	111.70	185.42	7.48

Seedlings per 4.5 m of row.

Table 6. Tall seedlot means for stand establishment, and seedling dry weight in field study.

Seedlot	Establishment	Seedling dry weight
	(#)	(g/seedling)
1	13.17	5.76
2	14.17	4.32
3	13.50	5.04
4	15.00	6.40
5	18.17	9.27
6	13.33	5.64
8	20.50	8.89
9	24.50	11.80
LSD (.05)	7.52	4.01

Seedling per 4.5 m of row.

Greenhouse Study

Analyses of variance for greenhouse results are summarized in Table 7. Significant mean differences are shown in Tables 9 through 11.

Time to 20% Emergence:

Time to 20% emergence was significantly affected by all sources of variation (Table 7). Time generally increased with planting depth, but the effect was more pronounced with some seedlots than with others, resulting in significant among-dwarf x depth and among-tall x depth interactions (Tables 7, 9, and 10). The significant dwarf vs. tall x depth interaction reflected the fact that dwarf entries required more time than tall to reach 20% emergence at the 12-cm depth of planting but not at the 4- or 8-cm depths (Table 8 and Fig. 3).

Emergence Percent:

Seedling emergence was significantly affected by all sources of variation except the dwarf x depth interaction (Table 7). The significant dwarf vs. tall x depth interaction reflected the fact that tall seedlots showed significantly higher emergence than dwarf at the 12-cm depth of planting but not at the 4- or 8-cm depths (Table 8 and Fig. 4). Emergence generally declined as planting depth increased and was sharply reduced at 12 cm (Table 8). The high CV for emergence may have obscured other real effects in this variable (Table 7).

Emergence Index:

Analyses of variance for emergence index differed from that for emergence percent mainly in lack of significance for the

Table 7. Analyses of variance for greenhouse study.

Sources	DF	Time to 20% Emerg-	Emerg- ence percent	Emerg- ence index	Visual appear- ance	Estab- lishm- ent	Seedl- ing height	Seedl- ing dry weight
		Mean squares						
		(days)	(%)			(%)	(cm)	(mg)
Total	149							
Rep.	1	0.54	89.70	0.01	0.80	34.56	34.56	564.40
Depth (D)	2	285.30*	48956.50*	141.33*	96.50**	33164.90**	2680.50**	6648.00*
Error (a)	2	3.92	642.00	3.74	0.20	283.98	5.40	131.28
Seedlots								
Among Dwarf (DW)	16	4.51**	579.41**	1.63**	1.77**	777.31**	59.58**	341.49**
Among Tall (T)	7	6.02**	716.00**	1.98**	1.00	646.67**	24.47	143.57
Dwarf vs Tall (DT)	1	7.88*	911.40*	1.96	2.37*	966.00*	149.95**	645.90*
DW*D	32	2.83*	250.84	0.69	0.69	333.80*	22.48	141.04
T*D	14	4.84**	647.00**	1.43*	0.81	760.35**	15.75	150.20
DT*D	2	15.88**	1073.78**	2.22**	1.06	952.58**	35.61	109.00
Error (b)	72	1.63	224.14	0.66	0.55	181.17	14.00	126.35
CV (Error a)		31.12	55.60	83.00	11.58	32.66	16.10	36.99
CV (Error b)		20.20	32.85	35.19	22.84	23.15	22.71	36.14

* Significant at .05.
** Significant at .01.

dwarf vs. tall effect (Table 7). The dwarf vs. tall effect was significant only at the 12-cm depth of planting in both variables (Table 8).

Visual Appearance:

Visual appearance was significantly affected by planting depth, among-dwarf differences, and the dwarf vs. tall effect (Table 7). The rating tended to decline as planting depth increased (Table 8 and Fig. 5). There was no dwarf vs. tall x depth interaction although the significant differences between tall and dwarf means occurred mainly at the 12-cm depth of planting.

Establishment:

Establishment was significantly affected by all sources of variation (Table 7). Number of emerged seedlings declined as planting depth increased, but the effect was more pronounced with some seedlots than with others, giving rise to significant among-dwarf x depth and among-tall x depth interactions (Tables 9 and 10 and Fig. 6). At the 12-cm depth, establishment was more reduced with dwarf seedlots than with tall, producing a significant dwarf vs. tall x depth interaction (Table 8 and Fig. 4).

Table 8. Overall dwarf and tall means for greenhouse variables at three greenhouse planting depths

Variables	Planting depths						LSD (.05)@
	4cm		8-cm		12-cm		
	Dwarf	Tall	Dwarf	Tall	Dwarf	Tall	
Time to 20% emergence	4.50	4.50	5.29	5.68	9.62	7.75	0.77
Emergence (%)	70.12	70.75	56.47	55.00	5.09	21.75	9.03
Emergence index	3.76	3.75	2.69	2.67	0.22	0.98	0.49
Visual appearance	4.50	4.56	3.38	3.50	1.56	2.19	n.s
Establishment (%)	75.77	78.50	69.76	67.50	23.65	39.50	8.12
Seedling height (cm)	24.03	24.43	15.06	17.06	8.29	12.31	n.s
Seedling dry weight (mg)	43.17	44.18	27.40	32.56	18.38	25.63	n.s

@ for comparing dwarf and tall means at the same planting depth.

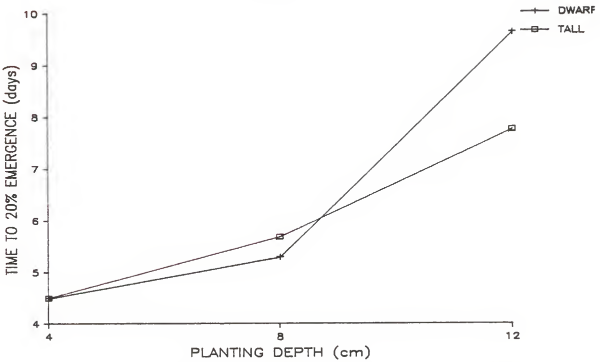

Fig. 3. Dwarf vs. tall x depth relationship. Greenhouse time to 20% emergence at three planting depths.

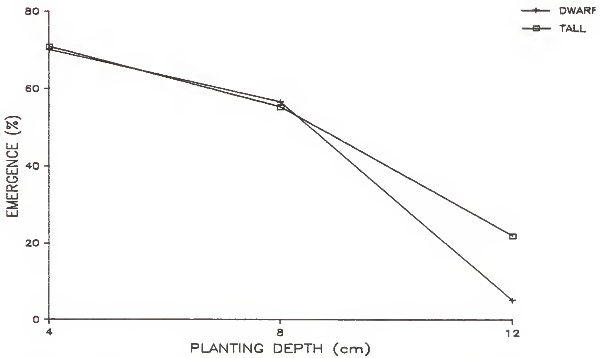

Fig. 4. Dwarf vs. tall x depth relationship. Greenhouse emergence percent at three planting depths.

Table 9. Dwarf means for time to 20% emergence and establishment at three greenhouse planing depths.

Seedlot	Time to 20% emergence 4cm	8cm	12cm	Establishment 4cm	8cm	12cm
		(day)			(%)	
7	4.5	5.0	12.0	94.0	86.0	10.0
10	4.5	5.0	7.0	72.0	80.0	44.0
11	4.5	5.5	9.0	72.0	62.0	26.0
12	4.0	5.5	9.0	68.0	78.0	24.0
13	5.0	5.0	10.0	94.0	74.0	12.0
14	4.5	5.0	6.5	78.0	86.0	54.0
15	4.5	4.5	8.5	90.0	94.0	32.0
16	4.0	4.5	8.0	78.0	82.0	32.0
17	5.0	5.0	8.5	50.0	56.0	26.0
18	5.0	7.5	12.0	68.0	34.0	4.0
19	4.5	5.0	12.0	86.0	66.0	4.0
20	4.5	6.5	11.5	78.0	46.0	10.0
21	4.5	5.0	7.0	74.0	66.0	60.0
22	4.0	5.5	0.0	66.0	62.0	14.0
23	4.0	5.0	10.0	84.0	76.0	48.0
24	5.0	5.0	10.0	64.0	70.0	4.0
25	4.5	5.5	10.0	72.0	68.0	12.0
LSD (.05)	2.6	2.6	2.6	26.9	26.9	26.9

Seedling Height:

Seedling height generally declined as planting depth increased (Table 8). Significant height differences occurred among dwarf seedlots and between dwarf and tall with tall seedlings being taller than dwarf (Tables 7, and 11). Since measurements were made before stem elongation, height differences must be attributed to differences in leaf length and/or developmental stage. As with visual appearance, most of the dwarf vs. tall effects occurred at the 12-cm planting depth, even though the dwarf vs. tall x depth interaction was not significant (Tables 5, 7, and 8, and Fig. 7).

Table 10. Tall seedlot means for time to 20% emergence,emergence index and establishment at three greenhouse planting depths.

Seedlots	Time to 20% emergence			Emergence			Emergence index			Establishment		
	Planting depth											
	4	8	12	4	8	12	4	8	12	4	8	12
		(days)			(%)						(%)	
1	4.5	5.0	10.0	78.0	88.0	00.0	4.0	4.3	0.0	82.0	94.0	8.0
2	5.0	7.0	6.0	82.0	40.0	32.0	4.0	1.9	1.7	88.0	64.0	80.0
3	4.5	4.5	5.0	68.0	70.0	68.0	3.8	3.5	3.1	78.0	72.0	60.0
4	4.5	5.0	10.0	64.0	54.0	00.0	3.6	2.6	0.3	74.0	64.0	14.0
5	4.5	7.5	6.0	48.0	36.0	8.0	2.5	1.3	1.2	66.0	38.0	56.0
6	5.0	6.5	12.0	76.0	28.0	00.0	3.7	1.3	0.0	80.0	60.0	4.0
8	4.0	5.0	6.5	68.0	66.0	16.0	3.9	3.3	0.9	74.0	80.0	52.0
9	4.0	5.0	6.5	82.0	58.0	8.0	4.1	3.1	0.7	86.0	68.0	42.0
LSD (.05)		2.6	2.6	29.9	29.9	29.9	1.6	1.6	1.6	26.9	26.9	26.9

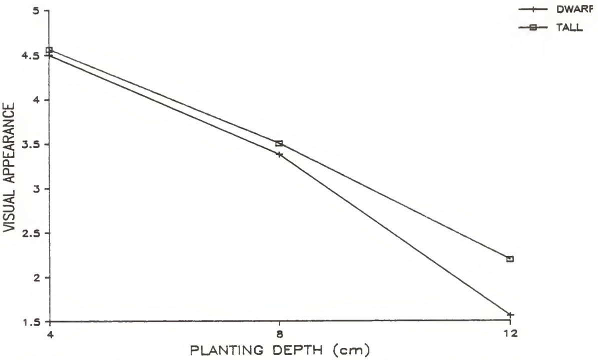

Fig. 5. Dwarf vs. tall x depth relationship. Greenhouse visual appearance at three planting depths.

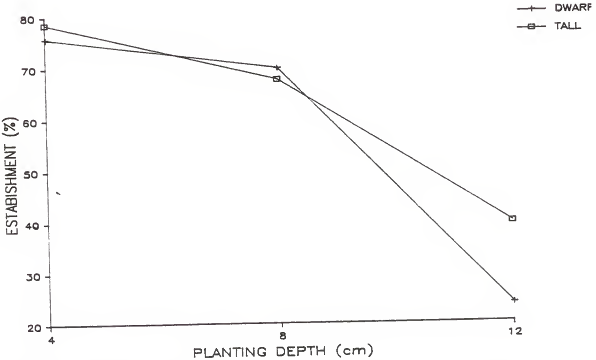

Fig. 6. Dwarf vs. tall x depth relationship. Greenhouse stand establishment at three planting depths.

Seedling Dry Weight:

Results for seedling dry weight were similar to those for seedling height (Tables 7, 8, and 11). Significant differences occurred among planting depths, among dwarf seedlots, and between dwarf and tall seedlots with talls being heavier than dwarfs. There were no significant interactions although most of the dwarf vs. tall effects occurred at the 12-cm planting depth (Fig. 8).

Table 11. Dwarf seedlot means for visual appearance,seedling height,and seedling dry weight in greenhouse study.

Seedlot	Visual appearance	Seedling height	Seedling Dry weight
		(cm)	(cm)
7	3.00	14.16	27.00
10	3.50	13.83	12.00
11	3.33	17.33	30.83
12	3.50	16.33	31.50
13	3.00	15.83	23.83
14	4.33	21.33	41.00
15	3.17	17.50	32.00
16	3.17	20.33	37.67
17	2.83	16.17	27.17
18	2.83	14.33	31.00
19	2.50	15.50	32.67
20	2.67	13.50	26.17
21	4.00	22.00	47.33
22	4.00	13.83	28.67
23	3.17	13.33	21.50
24	2.50	10.17	16.17
25	2.83	13.00	29.00
LSD (.05)	0.87	4.30	13.00

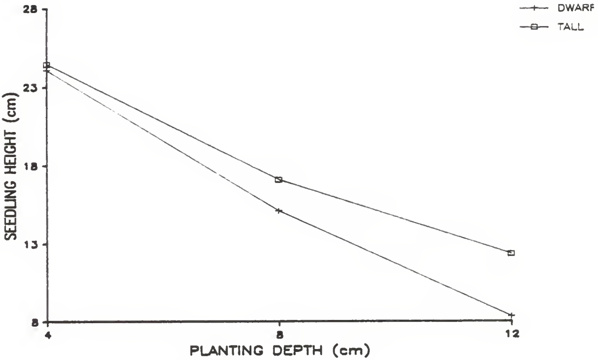

Fig. 7. Dwarf vs. tall x depth relationship. Greenhouse seedling height at three planting depths.

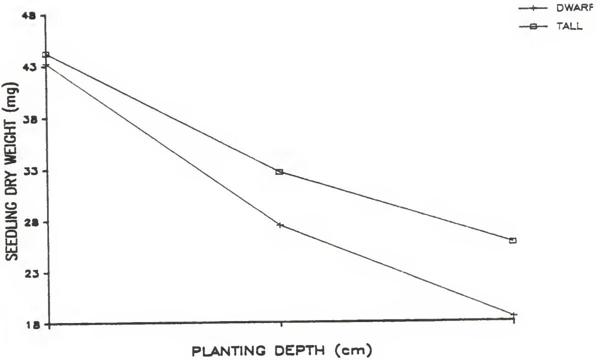

Fig. 8. Dwarf vs. tall x depth relationship. Greenhouse seedling dry weight at three planting depths.

Simple Correlations

Simple correlation coefficients are presented in Appendix Tables 2 through 10. Significant correlations are presented in Tables 12 through 17 of the text.

Simple correlations among laboratory variables for dwarf and tall seedlots are presented in Table 12. Among tall seedlots there were only three significant correlations, and two of those,

Table 12. Simple correlations among laboratory variables for dwarf and tall seedlots #.

	Mesocotyl length	Coleoptile length	Shoot Shoot length	Germination	Germination index	Seed weight
	cm	cm	cm	%		g/1000 seed
			Dwarf (n=17)			
Radicle length	0.53	--	0.70	0.64	0.49	--
Mesocotyl length		--	0.93	0.56	--	--
Coleoptile length			--	--	--	0.63
Shoot length				0.69	0.61	--
Germination %					0.93	--
Germination index						--
			Tall (n=8)			
Radicle length	--	0.78	--	--	--	--
Mesocotyl length		--	0.97	--	--	--
Coleoptile length			--	--	--	--
Shoot length				--	--	--
Germimnation percent					0.96	--
Germination index						--

All correlations are significant at 0.05.

mesocotyl length with shoot length and germination with germination index, were expected on the basis of built-in relationships. Correlation of radicle length with coleoptile length among tall seedlots was unexpected, since tall seedlots did not differ significantly in either of those variables (Table 1). Correlation without significant seedlot differences must originate in the error term and may involve errors in measurement and/or genuine within-seedlot variation. Radicle length and coleoptile length were not correlated among dwarfs where significant seedlot differences occurred in both variables. The correlation noted with tall seedlots was presumably obscured among dwarfs by the high level of variability represented by true seedlot differences. Significant relationships were common with dwarf seedlots where all possible simple correlations occurred among radicle length, mesocotyl length, shoot length, germination, and germination index. Seed weight was correlated significantly with coleoptile length with dwarf seedlots. A similar correlation was reported in Russian wildrye by Berdahl and Baker (1984).

The only significant correlation between laboratory and field variables was germination with establishment among dwarf seedlots (r = 0.59). A similar correlation was reported in pearl millet by Mwageni (1978). There were no significant relationships with tall seedlots. Scarcity of significant correlations between laboratory and field variables is disappointing, but probably reflects the fact that few significant effects occurred in the the field where the environment apparently was not sufficiently uniform and stressful to elicit true seedlot differences during establishment.

Among field variables (Table 13), significant correlations were more numerous with tall seedlots, where all possible simple correlations were significant, than with dwarf seedlots, where establishment was uncorrelated with any other variable. Significant correlations involving visual appearance indicate the usefulness of this trait as a means of rapidly evaluating the general well being of young stands. Previous research indicated a relationship between visual appearance and seedling dry weight in pearl millet (Anonymous, 1977-78) and sorghum (Maiti et al., 1981).

Simple correlations between laboratory and greenhouse variables for dwarf seedlots are shown in Table 14. Those for tall seedlots are shown in Table 15. With dwarf seedlots, significant correlations were most numerous and generally of greatest magnitude at the 8-cm planting depth. With tall seedlots, significant relationships occurred only at the 12-cm planting depth. With dwarf seedlots, coleoptile length was involved in significant correlations only at the 4-cm planting depth, while radicle, mesocotyl, and shoot lengths tended to be involved in more significant relationships at the 8- and 12-cm depths. Also among the dwarfs, germination and germination index were associated with a number of greenhouse variables at the 4- and 8-cm planting depths but with none at the 12-cm depth. Comparison of correlations for dwarf and tall seedlots is complicated by the fact that more degrees of freedom are available for testing among-dwarf coefficients than for testing among-tall coefficients. The importance of various laboratory parameters obviously depends upon conditions of stress in the establishment environment as well as upon the genetic constitution of the plant materials (seedlots). Similar correlations have been reported in intermediate wheatgrass (Hunt and Miller, 1965), winter wheat (Burleigh et al.,

Table 13. Simple correlations among field variables #.

	Establishment	Seedling height	Seedling dry weight
		Dwarf (n=17)	
Visual appearance	--	0.80	0.72
Establishment		--	--
Seedling height			0.81
		Tall (n=8)	
Visual appearance	0.86	0.80	0.77
Establishment		0.81	0.95
Seedling height			0.80

All correlations are significant at 0.05.

1965), rice (Turner et al., 1982), and corn (Grant and Buckle, 1977).

Simple correlations among greenhouse variables for dwarf seedlots are shown in Table 16. Those for tall seedlots are presented in Table 17. With dwarf seedlots, the frequency and magnitude of significant correlations increased with planting depth. With the tall seedlots that relationship was less apparent although there were more significant associations at the 8- and 12-cm depths than at 4-cm. Asay and Johnson (1980) observed significant correlations among seedling height, emergence index, seedling dry weight,and field emergence in Russian wild ryegrass. A significant negative correlation between seedling height and time to emergence was observed by McKenize et al., (1980) in rice.

Table 14. Simple correlations between laboratory and greenhouse variables for dwarf seedlots at three greenhouse planting depths (n=17) #.

Laboratory Variables	Time to 20% emerg-ence	Emerg-ence	Emerg-ence index	Visual appea-rance	Estab-lish-ment	Seedl-ing height	Seedl-ing weight
	Greenhouse variables						
	4-cm planting depth						
	r						
Radicle length	--	--	--	--	--	--	--
Mesocotyl length	--	--	--	--	--	--	--
Coleoptile length	--	0.51	0.52	--	--	0.56	0.63
Shoot length	--	--	--	--	--	--	--
Germination %	--	0.60	0.58	--	0.59	--	--
Germ. index	--	0.68	0.65	--	0.69	--	--
Seed weight	--	--	--	--	--	--	0.59
	8-cm planting depth						
Radicle length	--	--	--	--	0.49	--	--
Mesocotyl length	-0.58	0.72	0.66	0.71	0.75	--	--
Coleoptile length	--	--	--	--	--	--	--
Shoot length	-0.65	0.80	0.87	0.67	0.85	--	--
Germination %	-0.71	0.56	0.60	--	0.76	--	--
Germ. index	-0.65	0.60	0.57	--	0.80	--	--
Seed weight	--	--	--	--	--	--	--
	12-cm planting depth						
Radicle length	--	0.52	--	--	0.51	0.55	0.56
Mesocoty length	-0.54	--	--	--	0.49	--	0.49
Coleoptile length	--	--	--	--	--	--	--
Shoot length	-0.56	--	--	0.54	0.55	0.57	0.55
Germination %	--	--	--	--	--	--	--
Germ. index	--	--	--	--	--	--	--
Seed weight	--	--	--	--	--	--	--

All correlations are significant at 0.05.

Table 15. Simple correlations between laboratory and greenhouse variables for tall seedlots at three greenhouse planting depths (n=8) #.

	Greenhouse variables						
Laboratory Variables	Time to 20% emerg- ence	Emerg- ence	Emerg- ence index	Visual appea- rance	Estab- lish- ment	Seedl- ing height	Seedl- ing weight
			4-cm planting depth				
				r			
Radicle length	--	--	--	--	--	--	--
Mesocotyl length	--	--	--	--	--	--	--
Coleoptile length	--	--	--	--	--	--	--
Shoot length	--	--	--	--	--	--	--
Germination %	--	--	--	--	--	--	--
Germ. index	--	--	--	--	--	--	--
Seed weight	--	--	--	--	--	--	--
			8-cm planting depth				
Radicle length	--	--	--	--	--	--	--
Mesocotyl length	--	--	--	--	--	--	--
Coleoptile length	--	--	--	--	--	--	--
Shoot length	--	--	--	--	--	--	--
Germination %	--	--	--	--	--	--	--
Germ. index	--	--	--	--	--	--	--
Seed weight	--	--	--	--	--	--	--
			12-cm planting depth				
Radicle length	--	0.72	--	--	--	--	--
Mesocoty length	--	--	--	--	--	--	--
Coleoptile length	--	0.86	0.79	--	--	--	--
Shoot length	--	--	--	0.75	0.75	--	--
Germination %	--	--	--	--	--	--	--
Germ. index	--	--	--	--	--	--	--
Seed weight	--	--	--	--	--	--	--

All correlations are significant at 0.05.

Table 16. Simple correlations among greenhouse variables for dwarf seedlots at three planting depths (n=17) #.

	Emergence	Emergence index	Visual appearance	Establishment	Seedling height	Seedling weight
			4-cm planting depth			
			r			
Time to 20% emerg	--	--	--	--	--	--
Emergence		0.97	0.61	0.93	--	--
Emergence index			0.61	0.88	--	--
Visual appearance				0.53	0.56	0.61
Establishment					--	--
Seedling height						0.81
			8-cm planting depth			
Time to 20% emerg	-0.83	-0.83	--	-0.83	--	--
Emergence		0.99	0.56	0.84	--	--
Emergence index			0.56	0.90	--	--
Visual appearance				0.54	0.78	0.58
Establishment					--	--
Seedling height						0.88
			12-cm planting depth			
Time to 20% emerg	-0.74	-0.74	-0.91	-0.84	-0.90	-0.71
Emergence percent		0.96	0.84	0.79	0.80	0.71
Emergence index			0.90	0.89	0.83	0.69
Visual appearance				0.95	0.91	0.71
Establishment					0.85	0.59
Seedling height						0.84

All correlations are significant at 0.05.

Table 17. Simple correlations among greenhouse variables for tall seedlots at three planting depths (n=8) #.

	Emergence	Emergence index	Visual appearance	Establishment	Seedling height	Seedling weight
		4-cm planting depth				
			....r....			
Time to 20% emerg	--	--	--	--	--	--
Emergence percent		0.91	--	0.83	--	--
Emergence index			--	0.97	--	--
Visual appearance				--	0.81	0.85
Establishment					--	--
Seedling height						0.87
		8-cm planting depth				
Time to 20% emerg	-0.79	-0.80	-0.79	-0.74	--	--
Emergence percent		1.00	0.77	0.83	--	--
Emergence index			0.77	0.84	--	--
Visual appearance				0.75	--	--
Establishment					--	--
Seedling height						--
		12-cm planting depth				
Time to 20% emerg	-0.81	--	-0.95	-0.92	-0.78	--
Emergence percent		0.96	0.78	0.79	--	--
Emergence index			--	--	--	--
Visual appearance				0.95	0.75	--
Establishment					--	--
Seedling height						--

All correlations are significant at 0.05.

SUMMARY AND CONCLUSIONS

Significant differences occurred among dwarf seedlots in all variables, and among tall in all variables except radicle and coleoptile lengths. Dwarf seedlots differed significantly from tall in radicle length, seed weight, and germination index. Dwarf seedlots had higher seed weight and longer radicles than tall, but tall seedlots germinated sooner than dwarfs. No significant dwarf-tall differences occurred in mesocotyl, coleoptile, or shoot length, or in germination percent. Absence of a dwarf vs. tall difference in mesocotyl length indicated that that variable is controlled by loci other than those determining dwarf-tall height differences.

In the field, planting depth did not affect any of the variables, and there were no depth x seedlot interactions. Dwarf seedlots differed from tall in seedling height although measurements were taken before stem elongation. Significant differences occurred among tall seedlots in establishment and seedling dry weight.

In the greenhouse, the effect of planting depth was more pronounced at 12-cm than at the other depths, resulting in significant depth x seedlot interactions. Tall seedlots exceeded dwarf in percent emergence, emergence index, and establishment, and they reached 20% emergence sooner than dwarf at 12-cm but not at the 4- or 8-cm depths. Significant differences occurred among dwarf seedlots in all variables, and among tall in all variables except visual appearance, seedling height, and seedling dry weight. Dwarf seedlots differed significantly from tall in all variables except emergence index.

The only significant correlation between laboratory and field variables was between percent germination and establishment with dwarf seedlots. Lack of correlation of laboratory and field variables can be attributed to stand variability resulting from uneven weed infestation and soil crusting in the field planting. Also, it is likely that field planting depths were not sufficiently different to elicit significant depth and depth x seedlot effects.

With dwarf seedlots, correlations were more numerous and generally of greatest magnitude at the 8-cm greenhouse planting depth. With tall seedlots, significant relationships occurred only at the 12-cm depth. Coleoptile length was signifcantly correlated at 4-cm in dwarfs with emergence, emergence index, seedling height, and seedling dry weight, and at the 12-cm depth in tall seedlots with emergence and emergence index. Radicle and mesocotyl lengths tended to be involved in more significant correlations at the 8- and 12-cm depths in dwarfs. Laboratory germination was associated with a number of greenhouse variables at the 4- and 8-cm depths, but with none at the 12-cm depth. Seed weight was correlated only with seedling dry weight at 4-cm with dwarf seedlots.

With laboratory variables, there were more significant correlations among dwarf seedlots than among tall. Seed weight was correlated only with coleoptile length with dwarf seedlots and was unassociated with any other variable with tall seedlots.

Among field variables, significant correlations were more numerous with tall seedlots, where all possible correlations were significant. Among dwarfs there was no observed relationship between establishment and any other field variable. Among greenhouse variables, the frequency and magnitude of significant correlations increased with planting depth. Significant correlations involving visual appearance indicate the usefulness of this trait as a mean of rapidly evaluating the general well-being of young stands.

Significant correlations between laboratory and greenhouse variables indicate that radicle, mesocotyl, and coleoptile lengths, as well as seed germination, all have potential as criteria of establishment capability. Dwarf and tall millets appear to differ in ability to emerge from deep planting, even though laboratory measurements indicated no differences between dwarf and tall seedlots in mesocotyl length. Failure of mesocotyl and coleoptile lengths, as measured in the laboratory, to account for depths from which seedlings emerged in the greenhouse suggest that the full potential for mesocotyl elongation was not realized in the laboratory. There is a need for further evaluation and improvement of the laboratory technique for measuring maximium elongation of the mesocotyl and coleoptile.

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Appendix Table 1. Seed Sources.

Seed-lot	Year seed produced	Series#	Identification	Height##
1	1983	83-5175	Togoshort-17-14-2 (414)	T
2	1983	83-5056	WJR-32/210779-USSR	T
3	1983	83-5006	Meknes - Morocoo	T
4	1980	80-3204	P-924B Niger	T
5	1982	82-5221	YPN No. 11 Yemen	T
6	1982	82-5237	YPN NO. 19 Yemen.	T
7	1982	82-5271	23 blr Oklahoma chinchbug Res.	D
8	1982		HMP 556 (Population)	T
9	1982		81-1083/HMP 559 (Tall Fl)	T
10	1982		Tift 23 DA, E/78-7088 Fl	D
11	1982	83-1817	81-1088/79-4104 Fl	D
12	1982	83-1773	81-1047/79-4104 Fl	D
13	1982	83-1818	81-1088/79-4104 Fl	D
14	1981	82-3103	Bulk of 5 plants	D
15	1984		Fr-RM(4) C2SO (Popln) Hawaii	D
16	1982	83-1816	82-1088/78-7088 Fl	D
17	1982	83-1771	81-1050/79-1137 Fl	D
18	1981	81-1056	Female Parent	D
19	1982		81-1083/79-1137	D
20	1981	81-1163	Female Parent	D
21	1982	83-1770	81-1050/78-7088	D
22	1981	81-1049	Female Parent	D
23	1982	78-7088	Male Parent	D
24	1982	79-1137	Male Parent	D
25	1982	79-4104	Male Parent	D

From pearl millet breeding project, Hays Exp. Sta., Fort Hays, Kansas.

D = Dwarf, T = Tall.

Appendix Table 2. Simple correlations among laboratory variables for dwarf and tall seedlots.

	Mesocotyl length	Coleoptile length	Shoot length	Germination percent	Germination index	Seed weight
			Dwarf (n=17)			
	....		r	....		
Radicle length	0.53	0.38	0.70	0.64	0.49	0.28
Mesocotyl length		-0.28	0.93	0.56	0.47	- 0.46
Coleoptile length			0.09	0.29	0.32	0.63
Shoot length				0.69	0.61	-0.24
Germination percent					0.93	0.03
Germination index						0.06
			Tall (n=8)			
Radicle length	0.31	0.78	0.46	0.27	0.32	0.58
Mesocotyl length		0.36	0.97	-0.01	0.07	-0.30
Coleoptile length			0.56	0.11	0.14	0.41
Shoot length				0.02	0.10	-0.17
Germination percent					0.96	0.15
Germination index						-0.01

Appendix Table 3. Simple correlations between laboratory and field variables for dwarf and tall seedlots.

	Field variables			
Laboratory variables	Visual appearance	Establish-ment	Seedling height	Seedling dry weight
	Dwarf (n=17)			
	r			
Radicle length	0.34	0.30	0.31	0.23
Mesocotyl lenght	0.05	0.27	0.01	-0.02
Coleoptile length	0.44	0.08	0.45	0.43
Shoot length	0.22	0.31	0.17	0.13
Germination %	0.33	0.59	0.24	0.44
Germ. index	0.26	0.48	0.20	0.41
Seed weight	0.31	0.10	0.21	0.28
	Tall (n=8)			
Radicle length	0.11	0.10	-0.32	-0.02
Mesocotyl lenght	0.40	0.28	0.33	0.06
Coleoptile length	0.25	0.02	-0.34	-0.18
Shoot length	0.42	0.26	0.21	0.01
Germination %	-0.35	-0.02	-0.27	-0.09
Germ. index	-0.49	-0.24	-0.41	-0.31
Seed weight	0.26	0.44	-0.08	0.44

Appendix Table 4. Simple correlations among field variables.

	Establishment	Seedling height	Seedling Dry weight
		Dwarf (n=17)	
		r	
Visual appearance	0.40	0.80	0.72
Establishment		0.27	0.29
Seedling height			0.81
		Tall (n=8)	
Visual appearance	0.86	0.80	0.77
Establishment		0.81	0.95
Seedling height			0.80

Appendix Table 5. Simple correlatations between laboratory and greenhouse variables for dwarf seedlots at three greenhouse planting depths (n = 17).

	Greenhouse variables						
Laboratory variables	Time to 20% emerg	Emerg-ence	Emerg-ence index	Visual appea-rance	Estab-lish-men	Seedl-ing height	Seedl-ing dry weight
	4-cm planting depth						
	.... r						
Radicle length	-0.12	0.48	0.42	0.25	0.33	-0.13	0.12
Mesocotyl length	-0.13	0.18	0.21	0.09	0.17	-0.41	-0.40
Coleoptile length	-0.29	0.51	0.52	0.19	0.36	0.56	0.63
Shoot length	-0.25	0.38	0.42	0.17	0.31	-0.22	-0.18
Germination %	-0.11	0.60	0.58	0.19	0.59	-0.21	-0.14
Germ. index	-0.14	0.68	0.65	0.26	0.69	-0.70	-0.08
Seed weight	-0.20	0.31	0.25	0.23	0.20	0.41	0.59
	8-cmplanting depth						
Radicle length	-0.39	0.44	0.37	0.27	0.49	0.21	0.03
Mesocotyl length	-0.58	0.66	0.72	0.71	0.75	0.36	0.05
Coleoptile length	-0.12	0.16	0.17	-0.16	0.21	-0.11	-0.06
Shoot length	-0.65	0.80	0.74	0.67	0.85	0.32	0.03
Germination %	-0.71	0.60	0.56	0.28	0.76	0.01	-0.30
Germ. index	-0.65	0.60	0.57	0.23	0.80	-0.03	-0.27
Seed weight	0.25	-0.30	-0.30	-0.27	-0.23	-0.08	0.12
	12-cm planting depth						
Radicle length	-0.32	0.52	0.40	0.41	0.51	0.55	0.56
Mesocotyl length	-0.54	0.46	0.39	0.48	0.49	0.48	0.49
Coleoptile length	0.02	0.03	0.03	0.12	0.10	0.17	0.32
Shoot length	-0.56	0.48	0.40	0.54	0.55	0.57	0.55
Germination %	-0.36	0.21	0.15	0.34	0.34	0.44	0.30
Germ. index	-0.27	0.09	0.02	0.23	0.21	0.34	0.24
Seed weight	0.37	-0.09	-0.08	-0.20	-0.24	0.17	0.23

Appendix Table 6. Simple correlatations between laboratory and greenhouse variables for tall seedlots at three greenhouse planting depths (n = 8)

Laboratory variables	Greenhouse variables						
	Time to 20% Emerg	Emerg- ence	Emerg- ence index	Visual appea- rance	Estab- lish- men	Seedl- ing height	Seedl- ing dry weight
4-cm planting depth							
Radicle length	-0.09	0.33	0.37	-0.48	0.36	-0.21	-0.42
Mesocotyl length	0.09	0.11	0.07	0.01	0.41	0.52	0.09
Coleoptile length	0.01	0.39	0.48	-0.28	0.49	0.09	-0.04
Shoot length	0.08	0.19	0.18	0.02	0.24	0.48	0.07
Germination %	0.04	0.36	0.23	-0.05	0.37	-0.36	-0.42
Germ. index	0.24	0.31	0.11	-0.26	0.42	-0.48	-0.61
Seed weight	-0.54	0.08	0.63	0.01	0.40	-0.08	-0.09
8-cm planting depth							
Radicle length	-0.19	0.14	0.16	0.44	0.19	-0.41	0.18
Mesocotyl length	0.42	0.52	0.50	-0.30	0.30	-0.70	-0.50
Coleoptile length	-0.32	0.08	0.08	0.61	0.13	-0.07	0.22
Shoot length	0.30	-0.44	-0.43	-0.12	0.24	-0.64	0.40
Germination %	0.13	0.39	0.39	0.26	0.33	-0.09	0.38
Germ. index	0.24	-0.28	-0.29	0.26	0.29	-0.13	0.38
Seed weight	-0.60	0.47	0.45	0.45	0.41	-0.09	0.13
12-cm planting depth							
Radicle length	-0.51	0.72	0.65	0.54	0.46	-0.07	-0.38
Mesocotyl length	-0.44	0.25	0.31	0.67	0.69	0.37	-0.67
Coleoptile length	-0.57	0.86	0.79	0.62	0.56	0.13	-0.37
Shoot length	-0.53	0.43	0.47	0.75	0.75	0.36	-0.71
Germination %	-0.39	0.19	0.20	0.22	0.40	0.16	-0.03
Germ. index	-0.36	0.30	0.30	0.22	0.43	0.02	-0.23
Seed weight	-0.13	0.16	0.06	0.02	0.14	0.08	0.31

Appendix Table 7. Simple correlation among greenhouse variables for dwarf seedlots at three planting depths (n=17)

	Emergence	Emergence index	Visual appearance	Establishment	Seedling height	Seedling dry weight
			4-cm planting depth			
Time to 20% emergence	-0.35	-0.46	-0.19	-0.15	-0.28	-0.31
Emergence %	1.00	0.97	0.61	0.93	0.41	0.39
Emerg. index		1.00	0.58	0.88	0.44	0.41
Visual appearance			1.00	0.53	0.56	0.61
Establishment				1.00	0.28	0.21
Seedling heigh					1.00	0.81
Seedling dry weight						1.00
			8-cm planting depth			
Time to 20% emergence	-0.83	-0.83	-0.43	-0.83	-0.26	0.09
Emergence %	1.00	0.99	0.56	0.84	0.31	0.04
Emerg. index		1.00	0.55	0.90	0.30	0.04
Visual appearance			1.00	0.54	0.78	0.58
Establishment				1.00	0.20	-0.11
Seedling heigh					1.00	0.81
Seedling dry weight						1.00
			12-cm planting depth			
Time to 20% emergence	-0.74	-0.74	-0.91	-0.84	-0.90	-0.71
Emergence %	1.00	0.96	0.90	0.89	0.83	0.69
Emerg. index		1.00	0.84	0.79	0.80	0.71
Visual appearance			1.00	0.95	0.91	0.71
Establishment				1.00	0.85	0.59
Seedling heigh					1.00	0.84
Seedling dry weight						1.00

Appendix Table 8. Simple correlation among greenhouse variables for tall seedlots at three planting depths (n=8).

	Emerg-ence	Emerg-ence index	Visual appear-ance	Estab-lish-ment	Seedl-ing hight	Seedl-ing weight
			4-cm planting depth			
			r			
Time to 20% emerg	-0.26	-0.13	-0.68	0.21	-0.54	-0.55
Emergence	1.00	0.91	0.01	0.97	-0.01	0.10
Emerg. index		1.00	0.24	0.85	0.25	0.38
Visual appearance			1.00	-0.06	0.81	0.85
Establishment				1.00	-0.06	0.03
Seedling height					1.00	0.87
			8-cm planting depth			
Time to 20% emerg	-0.79	-0.80	-0.79	-0.74	-0.49	-0.26
Emergence	1.00	1.00	0.77	0.84	0.50	0.52
Emerg. index		1.00	0.77	0.83	0.50	0.54
Visual appearance			1.00	0.75	0.48	0.51
Establishment				1.00	0.21	0.06
Seedling height					1.00	0.67
			12-cm planting depth			
Time to 20% emerg	-0.81	-0.81	-0.69	-0.95	-0.78	0.01
Emergence	1.00	0.96	0.68	0.67	0.18	-0.36
Emerg. index		1.00	0.78	0.79	0.37	-0.29
Visual appearance			1.00	0.95	0.75	-0.21
Establishment				1.00	0.70	-0.34
Seedling height					1.00	0.30

Appendix Table 9. Simple correlation between field and greenhouse variables (dwarf seedlots) at three greenhouse planting depth (n=17).

Field variables	Time to 20% Emerg- ence	Emerg- ence	Emerg- ence index	Visual Appea- rance	Estanb- lish- ment	Seedl- ing height	Seedl- ing dry weight
	Greenhouse variables						
	cm planting depth						
	r						
Visual appear- ance	-0.65	0.58	0.64	0.50	0.40	0.41	0.61
Establish- ment	-0.09	0.44	0.46	0.09	0.56	-0.24	-0.10
Seedling height	-0.29	0.58	0.58	0.41	0.48	0.48	0.53
Seedling dry weight	-0.26	0.48	0.48	0.32	0.44	0.30	0.37
	8-cm planting depth						
Visual appear- ance	-0.38	0.41	0.43	0.14	0.36	0.12	-0.02
Establish- ment	-0.21	0.18	0.14	0.11	0.33	-0.04	-0.19
Seedling height	-0.35	0.53	0.55	-0.01	0.30	0.06	0.03
Seedling dry weight	-0.45	0.03	0.52	-0.13	0.36	-0.13	0.20
	12-cm planting depth						
Visual appear- ance	-0.30	0.42	0.28	0.49	0.55	0.34	0.30
Establish- ment	-0.19	0.24	0.16	0.31	0.40	0.20	-0.03
Seedling height	-0.17	0.31	0.18	0.34	0.42	0.27	0.13
Seedling dry weight	-0.16	0.09	0.02	0.23	0.28	0.18	0.11

Appendix Table 10. Simple correlation between field and greenhouse variables (dwarf seedlots) at three greenhouse planting depths (n=8).

Field variables	Time to 20% Emergence	Emergence	Emergence index	Visual Appearance	Estanblishment	Seedling height	Seedling dry weight
				Greenhouse variables			
				4-cm planting depth			
				r			
Visual appearance	-0.73	0.23	0.11	0.61	0.23	0.81	0.66
Establishment	-0.80	-0.02	0.25	0.69	-0.04	0.65	0.56
Seedling height	-0.68	0.41	0.16	0.79	-0.47	0.78	0.62
Seedling dry weight	-0.79	0.19	0.06	0.62	-0.23	0.49	0.47
				8-cm planting depth			
Visual appearance	-0.21	-0.10	-0.10	-0.17	-0.27	0.19	-0.18
Establishment	-0.12	0.01	0.01	-0.27	-0.13	0.39	-0.27
Seedling height	0.06	-0.13	-0.13	-0.53	-0.28	-0.24	-0.35
Seedling dry weight	-0.07	-0.01	-0.02	-0.39	-0.21	-0.30	-0.20
				12-cm planting depth			
Visual appearance	-0.52	0.08	0.19	0.60	0.38	0.74	0.27
Establishment	-0.25	-0.21	-0.10	0.42	0.24	0.65	0.40
Seedling height	-0.41	-0.40	-0.24	0.32	0.17	0.69	0.44
Seedling dry weight	-0.27	-0.36	-0.23	0.22	0.05	0.57	0.59

EMERGENCE, SEEDLING VIGOR, AND STAND ESTABLISHMENT OF PEARL MILLET AS AFFECTED BY MESOCOTYL ELONGATION AND OTHER SEED AND SEEDLING TRAITS

by

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Low seedling vigor and poor stand establishment are among the factors limiting production of pearl millet [*Pennisetum americanum* (L.) Leeke] in the less developed countries. Effects of seed size and density on stand establishment of millet have been researched at length, but little if any attention has been given to the importance of such early seedling traits such as mesocotyl, coleoptile, and radicle development. This study investigated relationships among radicle length, mesocotyl length, coleoptile length, other seed and seedling traits, and field establishment in pearl millet.

Seedlots of 17 dwarf and eight normal pearl millets (dwarf and tall seedlots, respectively) were examined in the laboratory for seed weight, germination, and lengths of radicle, mesocotyl, and coleoptile. Emergence from various planting depths, seedling vigor, and establishment were observed in the field and greenhouse.

Dwarf seedlots differed significantly in length of radicle, mesocotyl, and coleoptile, and in germination and seed weight. Tall seedlots differed in mesocotyl length, germination and seed weight, but not in radicle or coleoptile length. Dwarf seedlots exceeded tall in radicle length, and seed weight. Tall seedlots were superior to dwarf in a germination index designed to emphasize earliness of germination. On the average, dwarf seedlots were not different from tall in either mesocotyl or coleoptile length.

In the field, differences in establishment and seedling dry weight occurred among tall seedlots but not among dwarf. Tall seedlots exceeded dwarf in seedling height even though measurements were made before stem elongation. Field seeding depths (3.2 and 5.4 cm) were not sufficiently different to affect emergence or other seedling traits. There were no depth x seedlot interactions.

In the greenhouse, planting depth (4, 8, and 12 cm) significantly affected all variables. Seedlot effects frequently were more pronounced at the 12-cm depth, resulting in significant depth x seedlot interactions. Tall seedlots exceeded dwarf in percent emergence, emergence index, and establishment. They reached 20% emergence sooner than dwarf at the 12-cm planting depth but not at the 4- or 8-cm depths.

There was little correlation between laboratory and field variables, but laboratory and greenhouse traits were frequently correlated. Coleoptile length was correlated with greenhouse emergence and seedling vigor at the 4-cm depth with dwarf seedlots and with emergence at 12-cm with tall seedlots. Mesocotyl length was correlated with greenhouse emergence, establishment, and seedling vigor with dwarfs at the 8- and 12-cm planting depths. Correlations were more numerous and higher at 8-cm than 12-cm with dwarfs.

Significant correlations among laboratory variables were more common with dwarf seedlots than with tall. In the greenhouse, seed weight correlated with no other variable except seedling dry weight of dwarf seedlots at the 4-cm planting depth.

In the field, significant correlations occurred among all variables, except that, with dwarfs, establishment was not associated with any other variable. Among greenhouse variables, more numerous and higher correlations occurred at the 12-cm depth than at the other planting depths.

There was some indication that seedling potential for mesocotyl elongation was not fully realized in laboratory measurements. Significant correlations between laboratory and greenhouse variables indicate that radicle, mesocotyl, and coleoptile lengths, as well as seed germination all have potential as criteria of establishment capability.