GENETIC AND TEMPERATURE EFFECTS ON MESOCOTYL AND COLEOPTILE LENGTHS AND TEMPERATURE AND MOISTURE EFFECTS ON GERMINATION OF PEARL MILLET

by

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TO

FATI TAFIRENYIKA CHINAKE

This thesis is dedicated to the memory of my beloved father, Fati T. Chinake, who died on November 23, 1977. He taught me so much about life; and it is through much of his sacrifices that I am who I am today. He had deep concern for my education and welfare, his great desire to teach me all he knew gave me courage and strength to complete my studies. You will always be missed.

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INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is grown mostly in areas of limited rainfall and high soil temperature causing a serious stand establishment problem. Laboratory seed germination tests have been used to estimate the possible percentage and rate of germination in the field. However, simulation of a drought condition using aqueous solutions in the laboratory often does not reflect actual field conditions.

Stand establishment in a dry region might be improved by increasing depth of planting. This could provide the seed sufficient moisture during the critical stage of germination. However, deeper planting means that the coleoptile of the emerging seedling must move a greater distance through the soil before emergence can occur. Failure to move far enough results in the coleoptile rupturing below the soil surface. It has been shown that depth of planting influences the length of time from planting to emergence. Therefore, deeper than normal planting may delay seedling emergence, subject the seeds to lower temperatures, and increase the risk of emergence failure if soil crusting occurs (Stoskopf, 1985). Onwueme and Laude (1972) showed that the ability of coleoptiles to elongate was retarded by high temperature, meaning that under high temperature emergence from greater

soil depths might be delayed or prevented.

Turner et al. (1982) found planting depth to influence mesocotyl and coleoptile length and their relative contributions to emergence. The sum of coleoptile and mesocotyl length of an emerged seedling equaled the maximum planting depth for that seedling.

Objectives of this study were (a) to characterize genetic variability in mesocotyl and coleoptile length of pearl millet, (b) to determine the influence of temperature on mesocotyl and coleoptile elongation, (c) to evaluate the influence of soil temperature, and mesocotyl and coleoptile lengths on seedling emergence, and establishment, and yield from various depths of planting, and (d) to investigate the effects of osmotic potential and temperature on germination of pearl millet.

LITERATURE REVIEW

Good stand establishment reflects combined effects of genotype, farming practice, and environment on seedling emergence. Due to the adverse enviromental conditions of the arid and semi-arid regions, millet growers of that area have been forced to consider improving stands by manipulation of seed traits that appear to be important in determining stand establishment.

Given a viable, nondormant seed, favourable environmental conditions for germination include sufficient moisture,

suitable temperature and oxygen, and the absence of external inhibitory factors. The coleoptile, which serves to protect the first leaf, emerges from the seed and forms a spearlike shoot that is pushed through the soil by the elongating mesocotyl (Cardwell, 1984). Seed physiologists define germination as the process by which the radicle (embryonic root) emerges through the seed coat (Salisbury and Ross, 1985). It must be recognized that germination itself consists of a series of sequential processes for which the environment must provide a specific set of conditions suitable for each particular species.

Availability of sufficient water and appropriate temperatures during germination and emergence are of great importance to most plant species. In foxtail or Italian millet (Setaria italica), temperatures of 5, 20, and 30 C have been reported as minimum, optimum, and maximum temperatures, for germination, respectively (Cardwell, 1984). Minimum and optimum temperatures for germination under field conditions depend upon the seed's ability to survive moisture stress.

Many studies have been conducted to determine the effects of water stress on germinating seed (McGinnies 1960, Kaufmann and Ross 1970, Schneider and Gupta 1985, Fawisi and Agboola 1980). However, the lack of control of temperature under field situations and the inability to separate water and

temperature effects have made investigation difficult. Seeds often have been germinated on filter paper in petri dishes containing an osmotic solution of known solute potential (El-Sharkawi and Springuel 1977, Sharma 1976, Henson 1982, Parmar and Moore 1966). Hadas (1977) showed that reduced water uptake rate by seeds caused by low water potential delayed germination compared to an initial water potential of zero.

Temperature and water potential influence different responses from species to species. Using polyethylene glycol solutions, Kaufmann and Ross (1970) reported that temperature affected germination-water potential relationships for lettuce (Lactuca sativa L.) but not for wheat (Triticum aestivum L.). Smith and Hoveland (1986), also using polyethylene glycol, simulated water stress at 0, -0.3, -0.6, and -1.0 MPa and showed that pearl millet germination was reduced only 6% at the lowest water potential while sorghum (Sorghum bicolor L.) germination was reduced 14% and 44% at -0.6 and -1.0 MPa, respectively. Temperatures from 15 to 40 C did not affect sorghum germination percent while pearl millet germination declined at both 15 and 40 C.

Francois and Goodin (1972) reported that, in the absence of salinity, sugar beet seed germination for sugar beet [Beta vulgaris saccharifera (L.)] was maximum at 25 C, near maximum at 10 to 15 C , markedly depressed over the 25 to 35 C range, and nearly completely inhibited at temperatures

above 40 C. Germination was only slightly affected by increasing salinity at both the low and high temperature ranges, but greatly reduced over the 25 to 35 C range.

Soil moisture exerts a dominant influence on stand establishment because of its effects on soil properties, such as structure, soil water potential, and soil-seed contact which determine the rate of water uptake by the seed (Cardwell, 1984). The process of water uptake consists of two distinct stages of imbibition governed first by the nature of the seed coat plus water quality and later by emergence of the radicle. Many studies have established that the rate of germination decreases with decreasing soil water potential.

Under field conditions, however, soil moisture cannot be compared to osmotic potential in a laboratory, because other factors such as water conductivity and soil/seed contact have important roles. Manohar and Heydecker (1964) found that the area of contact between seeds of pea (Pisum sativum L.) and liquid water may considerably modify the effect of water potential on germination.

Temperature has been recognized by most scientists to be crucial to the rate at which plants develop (Ong, 1983). Increasing temperatures have been found to increase germination rate up to an optimum in some species (Bierhuizen, 1973); hence the minimum, optimum, and maximum

distinctions. Departures from the required ranges can reduce metabolic activities leading to germination. The temperature range over which a given seed lot will germinate is a function of seed quality, genotype, and duration of the germination period.

Investigating the effect of soil temperature on seedling emergence in sorghum (Wilson et al., 1982), showed that with thirty genotypes selected for resistance or susceptibility to drought, earlier and higher emergence occurred at lower temperatures. There was no emergence in a charcoal-surface treatment which reached 60 C. Optimum temperatures for sorghum seed germination ranged from 21 to 35 C while lethal temperatures for germination ranged from 40 to 48 C. Sorghum emergence was reduced from 97.5% at 30 C to 92.5% at 35 C and 82.5% at 40 C with no germination at 45 C (Singh and Dhaliwal, 1972). Rate of emergence was highest at 25 to 30 C.

For optimum emergence of corn (Zea mays L.), warm soil, ample available soil moisture, and good soil-seed contact were suggested by Schneider and Gupta (1985). At supra-optimal temperatures, maize emergence was reduced due to sensitivity of the embryo resulting in reduced rate of protein synthesis and lower activity of enzymes (Riley, 1981).

Soil temperature is extremely variable in semiarid

regions. Diurnal temperature fluctuations in the seedbed zone of shallow-seeded plants normally reach and often exceed 20 C during clear weather and are about 10 C during cloudy, rainy periods (Tadmor et al., 1969). Because of limited and infrequent rainfall in the arid and semi-arid regions, rate of germination and initial seedling growth is critical, especially the rate of seedling root elongation and penetration into the deeper soil layers.

Root extension and penetration into the deeper layers of the soil where moisture is retained longer becomes a problem for most species in the arid regions, because at the time of planting available water is usually in the surface layers necessitating shallow planting. Therefore, it is important to set an appropriate depth of planting which will give the seeds sufficient moisture and suitable temperature to emerge.

What is the critical depth of planting for emergence? Hillel (1972), defines critical depth as the maximum depth from which the seedling, once germinated, can successfully emerge. It has been suggested that depth of planting influences the length of time from planting to emergence. The sooner the seedling emerges from the soil, the sooner photosynthesis can begin to feed the plant (Stoskpf, 1985).

Many studies have focused on testing whether deep planting leads to reduced growth in plants which are able to emerge. In most cases shallow planted seeds emerged faster than deep-

planted where moisture was not a limiting factor. This is why researchers like McKenzie et al. (1980) used time to emergence as a criterion for seedling vigour. Tischler and Voigt (1983) found that days to emergence increased with subcoleoptile internode length.

Mohamed (1985), in a greenhouse study, found pearl millet emergence to decline as planting depth increased. Time to emergence increased with planting depth, and establishment of some seedlots was more affected by depth of planting than others. Pearl millet emergence was reduced 29% when planting depth increased from 1.3 and 5.0 cm (Smith and Hoveland, 1986). Sorghum emergence was unaffected by such a change.

Under field conditions, elongation of the mesocotyl serves to raise the coleoptilar node regardless of the depth at which the seed is planted, provided that the depth does not exceed the potential growth of the internode (Takahashi, 1978).

There is little literature on mesocotyl and coleoptile elongation in pearl millet. There is, however, sufficient evidence in other species that erratic emergence in plantings may be partially explained on the basis of planting depth. Turner et al. (1982) inferred that poor stand establishment in rice (Oryza sativa L.) is frequently associated with short mesocotyl length, implying that a longer mesocotyl is a characteristic for which a breeder should select in

segregating populations. Some semi-dwarf wheats have short coleoptiles which have trouble reaching the soil surface when seeds are planted too deeply (Bohnenblust et al., 1962, Livers, 1958).

There is evidence in the literature that good establishment is directly related to mesocotyl and coleoptile length and depth of planting. In an attempt to determine if short mesocotyls and coleoptiles cause emergence problems in drill-seeded semidwarf rice, Turner et al. (1982) found that planting depth influenced mesocotyl and coleoptile length and their relative contributions to emergence. Tischler and Voigt (1983) concluded that deep planting, in general, adversely affects subsequent plant performance.

Environmentally, both mesocotyl and coleoptile elongation respond to light, temperature, and soil moisture content (Liptay and Davidson 1972, Inouye et al., 1970 and Takahashi 1970). Terao and Inouye (1980) investigated the effect of soil moisture content on mesocotyl and coleoptile elongation among rice cultivars and found that mesocotyl length increased and coleoptile length decreased when soil water content was reduced.

Coleoptile growth is at first promoted by Pfr (the far-red light-absorbing form of phytochrome) but later inhibited by it. Inhibition is associated in time with the rupturing of the coleoptile tip by the primary leaf (Schopfer et al.,

1982). Therefore, if the coleoptile ruptures before reaching the soil surface, emergence ceases.

Coleoptile and mesocotyl development, however, are affected by growth regulators and oxygen, in addition to soil moisture, light and temperature. Allan et. al. (1961) studied the inheritance of coleoptile length and its association with culm length in four winter wheat crosses and reported that heritability of coleoptile length was high and governed by complex mechanisms.

MATERIALS AND METHODS

SEED SOURCES

Two millet genotypes each were chosen for short, medium, and long mesocotyl and short, medium, and long coleoptile based on preliminary measurements at the Fort Hays Branch Experiment Station (Table 1). Mesocotyl length classes were of similar coleoptile length while coleoptile length classes were similar in mesocotyl length.

Table 1. Radicle, mesocotyl, coleoptile, and shoot lengths and seed weights of genotypes selected for studies.

I.D. No.	Class	Doll #	Series #	Radicle	Mesocotyl	Coleoptile	Shoot	Seed wt.
				(cm)	(cm)	(cm)	(cm)	g/1000
1	SM	1158	8330	18.14	3.58	2.48	6.06	11.2
2	SM	1170	2222	18.72	4.52	2.50	7.02	10.6
3	MM*	1169	1164	17.58	5.35	2.67	8.02	16.6
4	MM*	1136	8318	17.07	5.58	2.17	7.75	17.3
5	LM*	1165	1049	12.60	6.65	2.95	9.60	13.6
6	LM	1164	23	17.09	6.73	2.06	8.79	7.0
7	SC*	1123	8306	15.83	6.25	2.10	8.35	16.0
8	SC	1110	7205	17.40	5.94	2.12	8.06	13.6
9	MC	1129	8317	12.82	5.65	2.45	8.11	17.8
10	MC*	1170	2222	18.72	4.52	2.50	7.02	10.6
11	LC	1165	1049	12.60	6.65	2.95	9.60	13.6
12	LC*	1166	1057	20.79	5.23	2.97	8.20	15.0

I.D. No. = Identification number assigned for each genotype.

\# From pearl millet breeding project, Hays Experiment Station, Fort Hays, Kansas.

* Seeds used in a 2nd run of the laboratory seedling measurement experiment.

SM = Short mesocotyl
MM = Medium mesocotyl
LM = Long mesocotyl
SC = Short coleoptile
MC = Medium coleoptile
LC = Long coleoptile

LABORATORY MEASUREMENTS

Twenty seeds were arranged in a line across the middle of a 30.5 x 45.7 cm heavy duty seed germinator paper. Clorox solution (0.26%) was used to moisten the germinator paper. Handi-wrap was placed on top of the germinator paper to secure seeds' position. Germinator papers were rolled left to right at a 180 degree angle, and were placed upright in 2 liter plastic bottles placed in dark growth chambers at 30, 35, and 40 C for 10 days. Water was added daily according to need.

Experimental design was a split plot with three replications. Main plots were temperatures and subplots were genotypes. Measurements were:

1. mesocotyl length: the distance from the seed to the coleoptilar node.
2. coleoptile length: this is the spearlike shoot which serves to protect the first leaf (Cardwell, 1984).
3. shoot length: mesocotyl plus coleoptile length.

Since measurements were not in good agreement with preliminary data (Table 1), a second run was made at 30 C only. Seeds were available for only six of the original twelve genotypes (Table 1).

Five hundred seeds of each genotype were weighed. Measurements were replicated twice, and seed weights were expressed on a 1000-seed basis.

FIELD STUDIES

Field studies were conducted at the Ashland Agronomy Farm, Manhattan and at Fort Hays Branch Agricultural Experiment Station, Hays, Kansas. The objective was to evaluate the influence of seeding depth on emergence, establishment, and yield of the twelve millet genotypes. The soil at Manhattan was a Haynie fine sandy loam (coarse-silty, mixed, mesic, Mollic Udifluvent) while at Hays it was a Roxbury silt loam (fine-silty, mixed, mesic, Cumulic Haplustoll). Monthly rainfall for June, July, August, and September was 6.2, 3.1, 10.0, and 3.0 cm at Manhattan and 9.6, 6.7, 11.4, and 1.1 cm at Hays. Mean monthly temperatures for June, July, August, and September were 24.9, 27.5, 25.0, and 20.5 C at Manhattan and 23.7, 26.0, 24.1, and 20.2 C at Hays.

Experimental design for both field studies was a split plot with three replications. Depths of planting were main plots, and 6m long single rows of each genotype were subplots. Planting was by a two row planter set to plant at 10 cm (deep) or 5 cm (shallow). Planting date was 8 June 1987 at both locations. Desired depths of planting were obtained easily at Manhattan but slighty shallower depths were obtained at Hays. At Hays rows were mistakenly planted twice, and seedlings had to be pulled out to maintain statistical design structure and consistency between locations. Row widths were 0.76 and 0.91 m at Manhattan and

Hays, respectively. Eighty seeds were planted in each subplot. Furadan (2, 3-dihydro-2, 2-dimethl-7-benzofuranyl methyl-carbamate) was applied with the seeds at 1.12 kg A.I./ha to control chinch bugs (Blissus leucopterus Say). Propazine (2-Chloro-4, 6-bis(isopropyl amino)-s-triazine) was applied preemergence at the rate of 2.24 kg A.I./ha for weed control in 75.6 liters of water. To control weeds, plots at both locations were cultivated and hand hoed about 4 weeks after planting. Seeding rate was 172,900 seeds/ha at Manhattan and 143,300 seeds/ha at Hays.

Determinations were as follows:

Mesocotyl, Coleoptile and Shoot Lengths:

Ten days after planting, 4 randomly selected seedlings were dug from each plot and measurements of the mesocotyl and coleoptile were taken. Shoot length was computed as the sum of mesocotyl and coleoptile lengths.

Seedling Dry Weight:

Above-ground parts of the same 4 seedlings were dried at 70 C for 3 days. Then they were weighed and an average seedling weight was calculated.

Establishment:

Stand counts were taken 3 weeks after emergence. Seedlings were counted in 3.0 m of row in each subplot.

Seedling Vigour:

Three weeks after emergence, a visual rating of the

subplots was recorded on a scale of 0-5. Zero represented no emergence, 1 the least vigorous, and 5 the most vigorous seedlings.

Seedling Height:

Seedling height was measured from the surface of the soil to the top of the extended leaves 3 weeks after emergence. Measurements were made from 4 randomly selected seedlings, (or fewer if 4 had not emerged) from each subplot. Measurements for each subplot were averaged to give a single value.

Mature Plant Height:

Four plants were randomly selected from each subplot and final plant height was measured from the ground to the top of the tallest panicle. An average was calculated for the four plants.

Yield:

A 3 m section of each subplot was harvested. Heads per plot were recorded, dried, and threshed. Grain moisture was taken and recorded by means of a grain moisture meter. Grain yield per hectare was adjusted to 13% moisture. A 1000-seed weight was recorded for each plot.

GREENHOUSE TEMPERATURE/DEPTH STUDY

Twenty seeds of each of the twelve genotypes were planted in plastic pots in the greenhouse at depths of 6 and 12 cm. Planting dates were 2 October for three replications and 6

November 1987 for the fourth. The experimental design was a split-split plot with temperatures as mainplots, depth of planting as subplots, and genotypes as sub-subplots. There were four replications. Lamps were positioned above the high temperature mainplots to raise soil temperature and adjusted to prevent seedlings from burning. Charcoal dust was sprinkled on top of the high soil-temperature plots to increase heat absorption from the lamps. Seeds were planted at the clay loam-sand interface in pots, which contained 14 cm clay loam and 6 cm sand for the shallow depth and 8 cm clay loam with 12 cm sand for the deeper depth. The clay loam and sand were sterilized before placement in the pots. Eight thermocouples were placed in randomly selected pots at 6 and 12 cm to monitor soil temperatures which were approximately 25/19 C day and night for the low temperature and 30/19 C for the high temperature. Pots were watered at planting and as necessary thereafter.

The following determinations were made:

Emergence:

Number of seedlings emerged was counted daily for 14 days after planting.

Emergence Index:

Emergence index was computed as indicated previously for the stress treatment test (Maguire, 1962) at 10 and 14 days.

Time to emergence

Time until 20% of the seeds had produced emerged seedlings was reported as 14 when no seedlings emerged by day 14, 10 when emergence by the 14th day was less than 20%, and actual day for all pots that had 20% or more emerge before the 14th day (Gubbles, 1975 and McKenzie et al., 1980).

Establishment:

Stand counts were reported as number of plants surviving and percentage of seeds planted at 10 and 14 days.

Seedling Vigour:

Vigour was recorded as previously described in the field studies. Ratings were made 14 days after planting.

Seedling Height:

Seedling height was measured and recorded using the same procedure as outlined in the field studies.

Mesocotyl, Coleoptile, and Shoot Length

Lengths were recorded using the same techniques as in the field studies.

Seedling dry weight

Dry weight was measured on 4 seedlings as in the field experiments.

LABORATORY TEMPERATURE AND WATER STRESS TEST

Twenty seeds of each genotype were germinated on two layers of filter paper in 9-cm petri dishes in polyethylene glycol (PEG) solutions. Clorox (Sodium hypoclorite) solution

(0.26%) was used to surface sterilize the seeds. PEG with a molecular weight of 8000 was used to establish solutions of 0, -0.6 and -1.2 MPa osmotic potential (O.P.). These solutions were prepared by dissolving the appropriate amount of PEG (g/kg) in distilled water for each of the temperatures (Appendix Table 1). The PEG concentrations were obtained by using Michel and Kaufmann's (1973) equation:

$$Y = -(1.18*10^{-2})C - (1.18*10^{-4})C + (2.67*10^{-4})CT + (8.39*10^{-7})C^2T$$

where

Y = osmotic potential.
C = the concentration of PEG 8000 in g/kg H2O.
T = the temperature in degrees C.

Three replicates (petri dishes) of each treatment were placed in dark growth chambers for 8 days at temperatures of 30, 35, and 40 C at 100% relative humidity. Germinated seeds were counted daily for 0 MPa O.P. and every other day for -0.6 and -1.2 MPa and then discarded. Germination was recorded when both the radicle and plumule had appeared. Germination was the total number of seeds germinated after 8 days, expressed as a percentage of 20. Maguire's (1962) formula was applied to daily germination counts to provide a germination index (rate) as:

$$X = \frac{\text{number of normal seedlings}}{\text{days to first count}} + \ldots + \frac{\text{number of normal seedlings}}{\text{days to final count}}$$

To consider the slow germination of some seeds, George's (1967) promptness index (PI) was computed as:

$$PI = [nd(9-D)] + [nd(9-D)] + \ldots\ldots\ldots + [nd(9-D)]$$

where

D = number of the day of observation, counting as 0 the day on which the test was begun and 1 as the day on which counting was begun.

nd = number of seeds observed to germinate on day of observation D.

The experimental design was a split-split plot with temperatures as main plots, osmotic potentials as subplots, and genotypes as sub-subplots.

RESULTS AND DISCUSSION

LABORATORY MEASUREMENTS

Analyses of variance (Table 2) show that both mesocotyl and coleoptile lengths were sensitive to temperature changes. Mesocotyl length increased with increasing temperature while coleoptile length decreased with increasing temperature. Shoot length, which is the sum of the mesocotyl and coleoptile lengths, changed according to whether the mesocotyl length increase was greater than the coleoptile length decrease and vice versa (Figure 1). Both the mesocotyl and coleoptile lengths were expected to be reduced at higher temperatures following the results of the preliminary experiment. Germination decreased from 78% to 72% to 65% as temperature increased from 30 to 35 to 40 C.

Following the deviations of the measurements recorded for the mesocotyl, coleoptile, and shoot length from the preliminary data (Figure 2), a second run of this experiment was repeated at 30 C. Table 3 shows analyses of variance on preliminary data and measurements at 30 C of the first run only. These combined analyses show differences between runs, but the lack of run by genotype interaction shows that the relative genotype performance was consistent. When data from the two runs at 30 C were analyzed there were no significant differences between runs or run by genotype

interactions (Table 4) implying consistent measurements. All mesocotyl and coleoptile lengths in run 1 and 2 were shorter than those in the preliminary experiment (Table 5).

Genotypes differed significantly for all measured variables on the first run. The combined analyses on preliminary and run 1 showed genotypes to differ significantly for shoot length while on the combination of runs they differ for mesocotyl and coleoptile lengths. Investigation of which genotypes caused the significant differences indicated that categorization of genotypes was not effective for mesocotyl and coleoptile lengths (Figure 2). Therefore, the remaining analyses will not focus on categorization differences but on overall genotypic differences.

Genotypic differences in mesocotyl and coleoptile lengths were reported by Mohamed (1985). He observed significant differences in the laboratory among dwarf genotypes in both variables and in mesocotyl length for tall genotypes. No difference in mesocotyl length was found between tall and dwarf genotypes indicating that this variable is controlled by loci other than those determining plant height.

Table 2. Analyses of variance for laboratory seedling measurements.

Source of Variation	df	Mean Squares			
		Shoot	Meso-cotyl	Coleo-ptile	Germi-nation
Total	107				
Rep	2	0.50	0.25	0.07	434.26
Temperature (T)	2	2.25*	6.65*	2.38*	1475.23*
Error (a)	4	0.17	0.68	0.35	117.94
Genotype (G)	11	5.33**	4.87**	0.48*	905.98**
Among Mesocotyl (M)	2	8.62**	12.50**	0.68	1126.39**
Among Coleoptile (C)	2	10.97**	7.50**	0.47	2858.80**
M vs C	1	2.40*	0.60	0.61	3.70
Within	6	2.85*	2.27**	0.40	331.95
T x G	22	0.45	0.39	0.29	177.25
Error (b)	66	0.43	0.56	0.23	162.27
CV (Error a)		7.50	20.88	38.17	15.13
CV (Error b)		11.97	18.93	30.66	17.75

* Significant at 0.05 level
** Significant at 0.01 level.

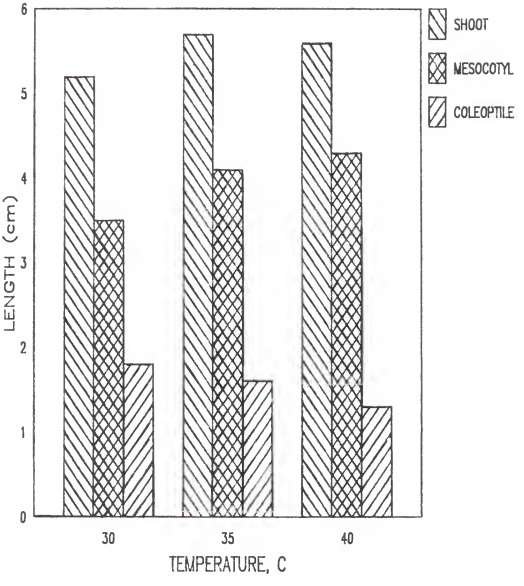

Figure 1. Mesocotyl, coleoptile, and shoot lengths in the laboratory at three temperatures. LSD's: Shoot = 0.62, Mesocotyl = 0.70 and Coleoptile = 0.45.

Table 3. Analyses of variance for laboratory measurements of preliminary data and 30 C only of first run.

Source of Variation	df	Mean Squares		
		Shoot	Mesocotyl	Coleoptile
Total	47			
Run	1	71.81**	39.20*	4.90*
Error (a)	1	0.18	0.68	0.25
Genotype (G)	11	1.76**	1.69	0.22
Among Mesocotyl (M)	2	4.85**	5.22**	0.03
Among Coleoptile (C)	2	3.00**	2.05**	0.62
M x C	1	1.41*	1.41*	0.01
Within	6	0.41	0.49	0.18
Run x Genotype	11	0.71	0.66	0.07
Error (b)	22	0.33	0.28	0.12
CV (Error a)		7.15	20.67	25.77
CV (Error b)		9.74	13.35	17.93

* Significant at 0.05 level
** Significant at 0.01 level.

Table 4. Analyses of variance for laboratory measurements of runs 1 and 2 at 30 C.

Source of Variation	df	Mean Squares		
		Shoot	Mesocotyl	Coleoptile
Total	35			
Run	1	0.01	0.80	0.63
Error (a)	4	0.25	0.31	0.18
Genotype (G)	5	1.69	2.61**	0.50**
Run x Genotype	5	0.91	1.11	0.10
Error (b)	20	0.76	0.57	0.10
CV (Error a)		9.84	15.82	27.20
CV (Error b)		17.18	21.50	20.66

* Significant at 0.05 level
** Significant at 0.01 level.

Table 5. Mesocotyl, coleoptile, and shoot length for preliminary data, run 1 and 2 at 30 C.

Genotype I.D.	Genotype Class	Preliminary data			Run 1			Run 2		
		Meso-cotyl	Coleo-ptile	Shoot	Meso-cotyl	Coleo-ptile	Shoot	Meso-cotyl	Coleo-ptile	Shoot
		(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
1	SM	3.58	2.48	6.06	2.78	1.68	4.46	-	-	-
2	SM	4.52	2.50	7.02	3.41	1.69	5.10	-	-	-
3	MM	5.35	2.67	8.02	2.49	1.78	4.27	3.55	1.76	5.31
4	MM	5.58	2.17	7.75	2.78	2.14	4.92	-	-	-
5	LM	6.65	2.95	9.60	3.72	1.95	5.67	4.52	1.00	5.52
6	LM	6.73	2.06	8.79	4.40	1.18	5.58	-	-	-
7	SC	6.25	2.10	8.35	3.27	1.79	5.06	3.80	1.60	5.40
8	SC	5.94	2.12	8.06	5.10	1.60	6.70	-	-	-
9	MC	6.65	2.45	8.11	2.59	1.47	4.06	3.75	1.35	5.10
10	MC	4.52	2.50	7.02	3.35	1.63	4.99	2.04	1.66	3.70
11	LC	6.65	2.95	9.60	3.87	1.92	5.79	4.39	1.19	5.58
12	LC	5.23	2.97	8.20	3.85	2.21	6.06	-	-	-
LSD					0.90	0.59	0.98	1.73	0.39	2.08

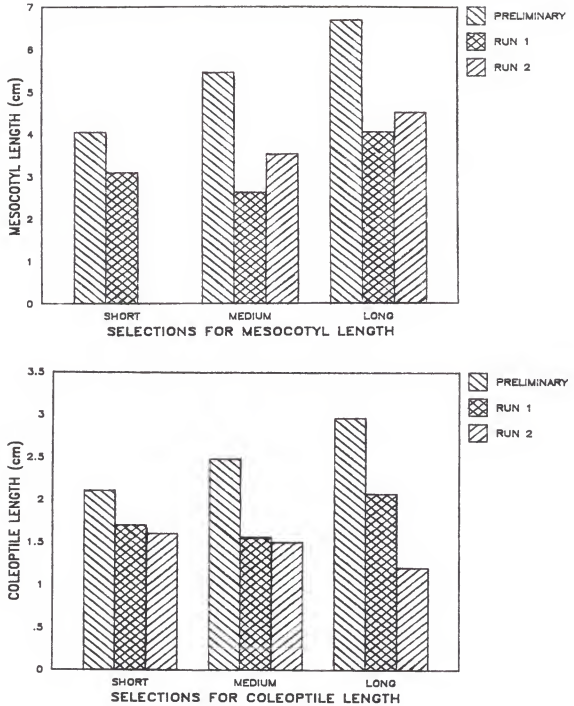

Figure 2. Mesocotyl and coleoptile lengths in the laboratory at 30 C.
LSD's Run 1: Mesocotyl = 0.90 Coleoptile = 0.12 Run 2: Mesocotyl = 1.73 Coleoptile = 0.39.

FIELD STUDIES

Soil temperatures measured at time of planting at Manhattan were 27 and 24 C, at intended depths of planting of 5 and 10 cm, respectively. Those were much below temperatures recorded at the time of planting in the semi-arid regions (Peacock, 1977). No further soil temperatures, therefore, were recorded.

No emergence variable was affected by depth of planting (Table 6). This could be because just hours before planting, the field was tilled deeply, allowing good aeration. Sufficient moisture may have been available already, facilitating shoot movement through the loose soil to the soil surface even from the deeper depth. In this experiment, total emergence was very low with some plots showing no emergence.

Genotypes differed significantly in shoot, mesocotyl, and coleoptile lengths, seedling vigour, dry weight, seedling height, and mature plant height. The depth by genotype interaction was significant only for establishment, indicating the non similarity effect of depth on genotypes. Some of the genotypes had higher establishment from shallow and others from deep plantings (Figure 3). In a previous laboratory seedling measurement study, the aim was to see if mesocotyl, coleoptile, and shoot lengths could be used to predict establishment from varying depths. However, the

measurements failed to predict the establishment of genotypes.

Table 7 shows variance analyses for yield and yield components. There was no association of yield and depth of planting. The genotypes again had different yields.

Table 6. Analyses of variance for emergence and establishment at Manhattan.

Source of Variation	df	Mean Squares							
		Meso-cotyl	Coleo-ptile	Shoot	Vigour	Establi-shment	Dry wt.	Seedling height	Mature height
Total	71								
Rep	2	0.37	0.11	0.18	1.29	53.77	0.16	3.66	115.89
Depth (D)	1	3.28	1.05	8.05	0.06	66.13	0.68	5.63	21.05
Error (a)	2	0.97	0.20	0.43	0.18	23.79	0.09	22.47	203.66
Genotype (G)	11	0.57	0.22**	0.44	1.08**	24.83	0.13*	95.95**	2739.48**
D x G	11	0.55	0.78	0.73	0.84	31.55*	0.05	8.14	109.29
Error (b)	44	0.38	0.07	0.48	0.55	14.29	0.05	11.51	258.41
CV (Error a)		24.62	24.85	11.30	30.00	66.36	49.18	20.73	18.01
CV (Error b)		15.45	14.24	11.97	52.55	51.46	36.64	14.83	20.29

* Significant at 0.05 level
** Significant at 0.01 level.

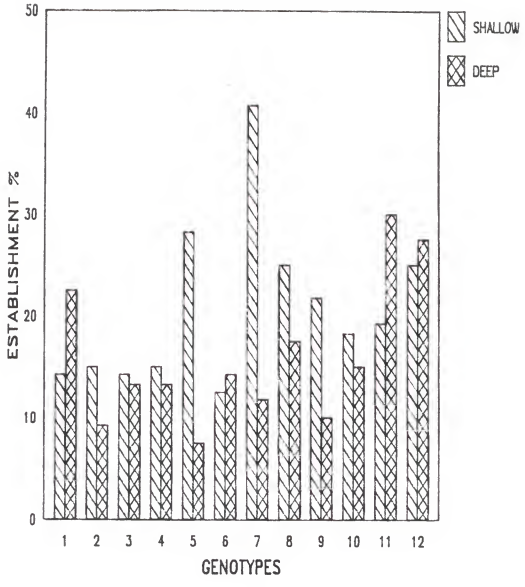

Figure 3. Effects of depth of planting and genotypes on establishment at Manhattan. LSD = 4.4.

Table 7. Analyses of variance, Manhattan, yield and yield components.

Source of Variation	df	Mean Squares		
		Heads/Ha x 10^6	Yield, Kg/Ha x 1000	Seed wt. g/1000
Total	67			
Rep	2	9268	246	4.23
Depth (D)	1	1432	216	0.14
Error (a)	2	895	138	1.95
Genotype (G)	11	10823**	1691**	7.03**
D x G	11	2189	402	1.68
Error (b)	40	1921	284	1.36
CV (Error a)		24	17	16.28
CV (Error b)		35	24	13.59

* Significant at 0.05 level
** Significant at 0.01 level.

Soil temperature measured at time of planting at Hays were 34 and 32 C, at intended depths of planting of 5 and 10 cm, respectively.

Generally, emergence, establishment, and yield were much better at Hays than at Manhattan. A possible explanation could be the difference in soil nutrition, also rainfall and temperatures.

Although the intended depths of planting of 5 and 10 cm were not obtained, depth of planting significantly increased mesocotyl length (Table 8). Normally the mesocotyl varies in length depending on the seeding depth.

Genotypes significantly affected shoot and mesocotyl lengths and seedling and mature plant height. Depth by

genotype interaction significantly affected coleoptile length which indicated the non similarity of performance of genotypes under different depths. Some genotypes had long coleoptiles with deeper planting and others with shallow (Figure 4).

Yield analyses of variance are shown in Table 9. As expected, depth of planting did not affect yield. Genotypes had significantly different yield and yield components.

Table 8. Analyses of variance for emergence and establishment at Hays.

Source of Variation	df	Mean Squares						
		Shoot	Coleoptile	Mesocotyl	Vigour	Establishment	Seedling height	Mature height
Total	77							
Rep	2	4.64	0.26	2.78	2.33	40.77	26.86	159.84
Depth (D)	1	8.33	0.20	5.93*	4.71	40.20	150.50	487.01
Error (a)	2	0.11	0.02	0.21	0.90	5.80	8.74	51.92
Genotype (G)	11	4.30*	0.26	2.87*	1.33	62.66	49.37**	2508.58**
D x G	11	3.63	0.36**	1.89	0.85	53.52	9.05	96.15
Error (b)	50	1.84	0.14	1.13	1.12	56.64	10.71	198.80
CV (Error a)		6.12	7.60	12.84	51.56	55.18	17.00	7.92
CV (Error b)		25.02	19.82	29.80	57.53	65.52	18.83	15.49

* Significant at 0.05 level
** Significant at 0.01 level.

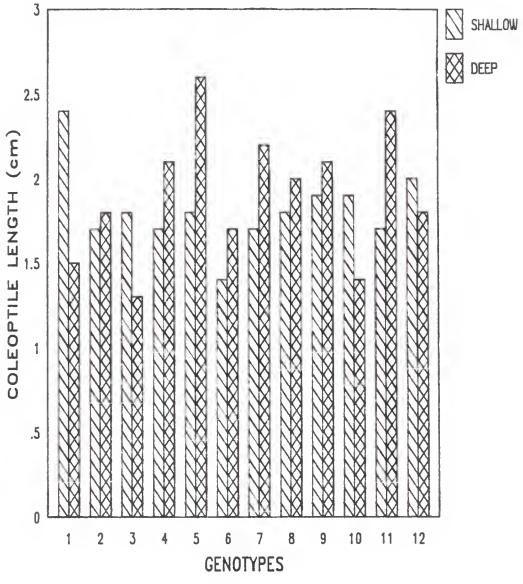

Figure 4. Effects of depth of planting and genotypes on coleoptile lengths at Hays. LSD = 0.41.

Table 9. Analyses of variance, Hays, yield and yield components.

Source of Variation	df	Mean Squares		
		Head/Ha x 10^6	Yield Kg/Ha	Seed wt. g/1000
Total	74			
Rep	2	14215	960	0.79
Depth (D)	1	465	7	4.03
Error (a)	2	15796	1044	2.69
Genotype (G)	11	28492*	4631**	3.94**
D x G	11	14317	496	0.91
Error (b)	47	12831	557	1.03
CV (Error a)		48.80	10.77	19.74
CV (Error b)		43.98	21.39	12.21

* Significant at 0.05 level
** Significant at 0.01 level.

GREENHOUSE TEMPERATURE/DEPTH STUDY

Emergence started by the third day after planting, with the higher soil temperature and shallow depth of planting germinating first and the remaining treatment combinations following a day or two later. Soil temperatures which reached 30 C did not affect establishment or total germination percentage. However, increased temperature significantly increased mesocotyl length, shoot length, and seedling height. Coleoptile length was reduced 14%, though not significantly, at the high temperature. This observation is consistent with laboratory seedling measurements. Most seedlings under lamps were stocky and strong while those at lower temperatures were spindly and weak. Normally high soil temperature in the seed zone can inhibit germination and stop plumule extension any time after germination (Soman and Peacock, 1985). The higher temperature in this study was much lower than the 65 C temperature recorded in the field at the time of planting in a semi-arid region (Peacock, 1977).

In this study most of the coleoptiles failed to reach the soil surface but the shoot came through. Shoot length, which is the sum of the mesocotyl and coleoptile length, averaged less than either depth of planting (Table 10).

Deeper planting (12 cm) significantly increased time to emergence, and reduced germination index at 10 and 14 days after planting, seedling vigour, and establishment percent

after 10 and 14 days. Depth of planting did not have a significant effect on mesocotyl, coleoptile, and shoot lengths, seedling height or seedling dry weight. Generally, deeper planting increases time to emergence because the deeper the seed is planted, the longer the distance the mesocotyl has to push the coleoptile to the soil surface (Stoskopf, 1985). There was no significant interaction of temperature by depth on any of the measured variables, which indicates that effects of temperature were not changed by increasing depth of planting.

Genotypes affected all establishment variables except seedling dry weight (Table 11). In a previous study, Mohamed (1985) also found genotypic differences in time to emergence, emergence percent, and establishment.

Emergence after 10 and 14 days is shown in Table 12. In wheat, some semidwarf lines were found to have shorter coleoptiles than normal lines and, as a result in some instances have had emergence difficulties (Allan et al. 1961). The shoot length, averaging less than the depth of planting, might have caused emergence difficulties in this study. However, there were no interactions between temperature by genotype, depth by genotype, or temperature by depth by genotype indicating that the effects of the genotypes were consistent with increasing soil temperatures and increasing depth of planting.

Table 10. Effects of planting depth on establishment variables in the greenhouse.

Variables	Planting Depth (cm) 6	12	LSD
Mesocotyl length (cm)	4.08	3.87	n.s.
Coleoptile length (cm)	1.85	1.68	n.s.
Shoot length (cm)	5.92	5.52	n.s.
Seedling height (cm)	11.24	10.93	n.s.
Seedling dry weight (g)	0.57	0.56	n.s.
Time to 20% emergence (days)	7.13	9.71	2.04
Emergence index at 10 days	5.16	1.95	1.84
Emergence index at 14 days	7.13	2.67	2.39
Seedling vigour	3.25	1.33	1.05
Establishment at 10 days (%)	30.72	11.20	0.09
Establishment at 14 days (%)	30.54	10.90	0.09

Table 11 (a) Analyses for greenhouse seed emergence as influenced by temperature and depth of planting.

Source of Variation	df	Mean Squares				
		Mesocotyl	Coleoptile	Shoot	Seedling height	Seedling dry wt.
Total	165					
Rep	3	19.31	1.67	30.99	24.63	0.33
Temperature (T)	1	6.30*	0.47	2.98*	80.33*	4.50
Error (a)	2	0.27	0.35	0.04	3.26	0.09
Depth (D)	1	7.19	1.86	15.47	0.77	0.02
D x T	1	21.76	2.35	37.21	6.20	0.04
Error (b)	5	4.21	0.80	3.44	15.38	0.11
Genotype (G)	11	3.86*	0.36*	5.16*	33.67**	0.08
T x G	11	1.47	0.28	2.04	9.92	0.03
D x G	11	2.33	0.12	3.14	3.44	0.06
T x D x G	11	1.00	0.19	1.40	3.35	0.05
Error (c)	108	1.65	0.17	2.17	6.56	0.09
CV (Error a)		13.02	33.42	3.48	16.27	53.74
CV (Error b)		51.42	50.53	32.26	35.33	59.23
CV (Error c)		32.21	23.27	25.65	23.07	53.74

* Significant at 0.05 level
** Significant at 0.01 level.

Table 11 (b). Analyses for greenhouse seed emergence as influenced by temperature and depth of planting.

Source of Variation	df	Mean Squares: Time to 20% Emerge-	Index after 10 days	Index after 14 days	Vigour	Estab at 10 days	Estab at 14 days
Total	165						
Rep	3	65.41	62.59	120.89	24.07	2.33	0.25
Temp. (T)	1	64.00	0.10	0.17	3.36	0.005	0.02
Error (a)	2	78.07	64.09	114.96	16.86	0.18	0.19
Depth (D)	1	210.04**	413.32**	799.18**	144.68**	1.54**	1.56**
D x T	1	2.38	6.82	14.30	0.03	0.02	0.03
Error (b)	5	5.50	18.76	33.88	4.07	0.05	0.06
Genotype (G)	11	13.95*	25.11**	44.08**	5.47**	0.07**	0.06**
T x G	11	6.77	8.82	16.16	2.73	0.02	0.03*
D x G	11	12.35	10.49	17.83	1.95	0.03	0.03
T x D x G	11	8.09	5.59	10.04	1.60	0.02	0.02
Error (c)	108	7.26	5.91	9.98	1.94	0.02	0.01
CV (Error a)		103.58	224.88	218.82	179.31	202.03	207.56
CV (Error b)		27.49	121.67	118.79	88.10	110.66	116.64
CV (Error c)		31.58	68.35	64.45	60.91	58.63	58.73

* Significant at 0.05 level
** Significant at 0.01 level.

Table 12. Genotype means for greenhouse emergence and establishment variables.

Genotype I.D	Time to 20% Emerge	Index after 10 days	Index after 14 days	Establishment 10 days	Establishment 14 days	Seedling Vigour
	days			%	%	
1	8.17	3.18	4.12	15.42	14.17	2.17
2	9.14	3.41	4.60	18.21	18.21	2.21
3	9.79	1.88	2.74	13.57	13.57	1.36
4	9.44	2.72	3.82	16.88	16.56	2.06
5	6.36	5.92	8.14	33.93	33.93	3.57
6	7.71	4.05	5.50	22.14	22.86	2.57
7	8.36	4.70	6.41	27.14	26.07	2.43
8	9.33	2.85	4.03	17.91	18.33	2.25
9	8.86	3.21	4.48	19.64	19.64	2.07
10	9.69	1.33	2.03	10.77	10.77	1.15
11	7.50	5.34	7.28	31.07	29.64	2.86
12	8.07	3.87	5.37	23.33	23.33	2.67
LSD	2.04	1.84	2.39	9.00	9.00	1.05

LABORATORY TEMPERATURE AND WATER STRESS TEST

Analyses of variance for seed germination under water and temperature stress through day 8 and promptness index indicated significant differences for genotypes, temperature, and osmotic levels existed (Table 13). There were highly significant PEG by genotype and temperature by genotype interactions suggesting that genotypes responded differently to both temperature and water stress levels. There were significant effects of temperature and genotypes on germination index of the control seeds. Germination index decreased with increasing temperatures for most genotypes (Table 14). This indicated the genotypes to have lower germination at higher temperatures.

Germination of genotypes was significantly different at all temperatures, 30, 35, and 40 C and all water stress levels, 0, -0.6, and -1.2 MPa. Table 14 shows germination percent, germination index, daily germination and promptness index at three temperatures. Most of the genotypes germinated well at the control and -0.6 MPa O.P., while the germination percent reduced from 55% at control, 30 C to 42% at -0.6 MPa, 30 C to as low as 20% at -1.2 MPa, 30 C. Germination of genotypes was dependent on both water and temperature stress levels (Figures 5 and 6). Differences in ability to germinate under controlled stress was observed and this difference was maximized at -1.2 MPa osmotic potential

and 35 C temperature (Figures 7 and 8). The significant interactions of the effects of temperature and water potential on germination agrees with El-Sharkawi and Springuel (1977) findings on sorghum, barley, and wheat seeds.

Table 13. Analyses of variance for seed germination and promptness index under water and temperature stress.

Source of Variation	df	Mean Squares: Germination Day 2	Day 4	Day 6	Day 8	Promptness Index
Total	323					
Rep	2	0.25	2.11	0.25	0.45	44.19
Temperature (T)	2	201.58**	331.26**	319.19**	326.87**	11558.62**
Error (a)	4	9.01	11.69	13.81*	13.63*	517.68
Osmotic Potential (OP)	2	591.43**	617.07**	558.08**	552.64**	23517.37**
T x OP	4	101.49**	140.96**	159.29**	160.31**	5517.56**
Error (b)	12	8.29	8.02	8.60	8.35	397.15
Genotype (G)	11	120.78**	159.04	171.65**	169.05**	6989.74**
G x T	22	8.84	8.47	9.40*	9.03*	462.05*
G x OP	22	18.80**	17.66**	16.55**	16.49**	837.03**
G x T x OP	44	6.38	8.90**	9.44**	9.55**	389.60
Error (c)	198	5.77	5.33	5.28	5.34	272.80
CV (Error a)		61.38	58.05	60.52	59.93	59.07
CV (Error b)		58.87	48.00	47.76	46.91	51.74
CV (Error c)		49.12	39.16	37.43	37.49	2.88

* Significant at 0.05 level
** Significant at 0.01 level.

Table 14. Germination, germination index, and promptness index at three temperatures.

	TEMPERATURE								
	30 C			35 C			40 C		
Genotype I.D.	Germination %	Index	PI	Germination %	Index	PI	Germination %	Index	PI
1	45.0	4.5	55.2	34.4	4.1	42.6	36.1	1.8	47.3
2	23.9	3.8	29.7	21.1	3.2	27.1	15.6	1.9	19.0
3	16.7	1.3	19.1	13.3	1.2	16.2	2.2	0.2	2.2
4	34.4	4.9	42.4	30.6	3.9	39.6	11.7	0.8	14.6
5	45.0	6.0	56.2	41.7	3.6	51.9	30.6	2.7	41.4
6	59.4	6.6	73.1	50.0	7.9	67.6	43.9	6.0	55.8
7	51.1	6.7	62.8	42.2	5.8	55.9	15.0	1.2	19.3
8	48.9	6.1	66.4	34.4	4.4	39.1	34.4	2.3	45.6
9	26.7	4.0	32.9	17.2	1.6	20.0	6.1	0.4	7.6
10	23.9	3.8	29.7	21.1	3.2	27.1	15.6	1.9	19.0
11	53.3	6.8	62.6	46.7	5.6	55.1	36.1	3.4	45.8
12	37.8	5.7	46.0	31.7	3.3	38.6	11.7	1.1	12.3
LSD	13.7	3.0	20.0	13.2	2.3	17.7	9.9	1.3	13.4

Note: Germination index is measured on control only.

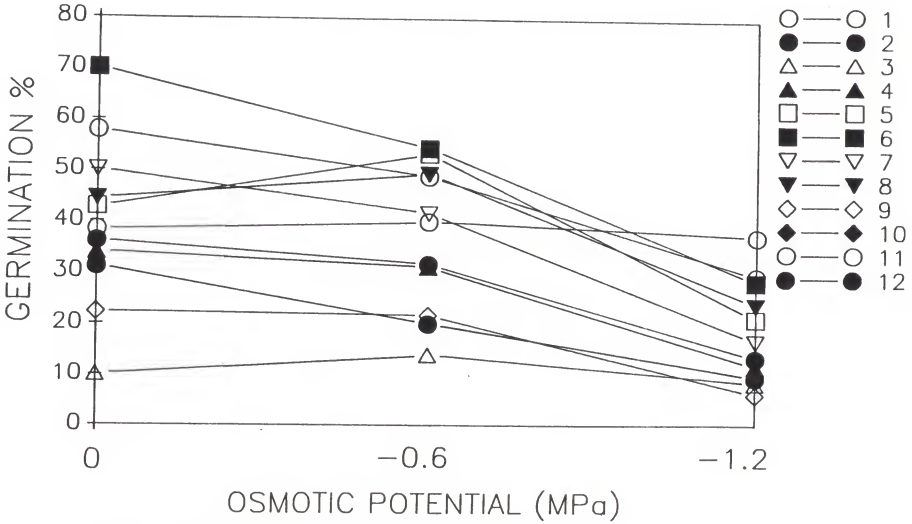

Figure 5. Effect of water stress on germination of genotypes.

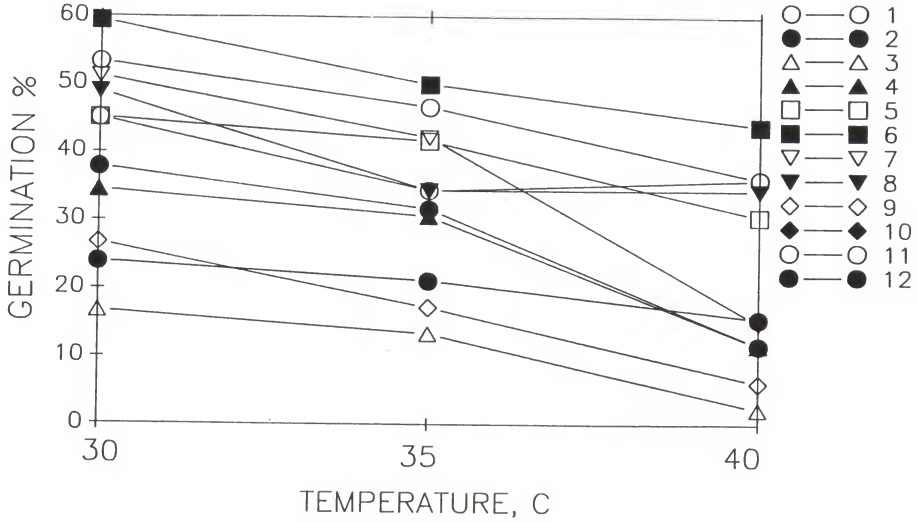

Figure 6. Effect of temperature on germination of genotypes.

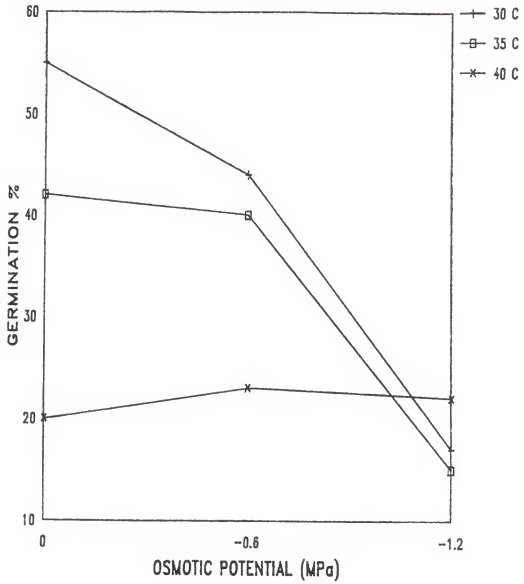

Figure 7. Germination percent as affected by water stress and temperature.

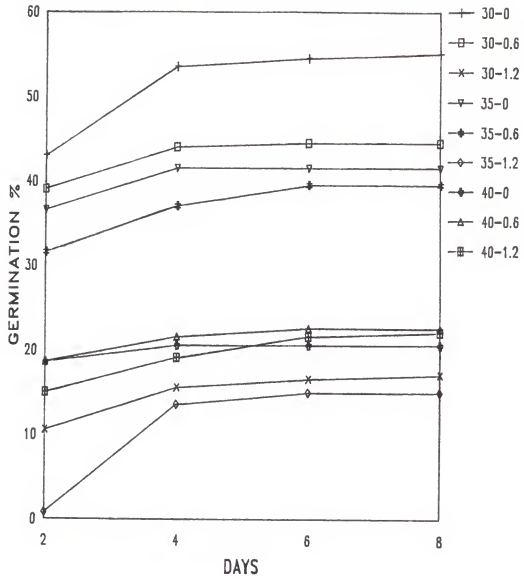

Figure 8. Cumulative daily germination percent based on PEG stress and temperature stress level.

SIMPLE CORRELATIONS

Simple correlations among laboratory variables are shown in Table 15 and Appendix Table 3. Mesocotyl length was significantly related to shoot length and germination percent, and shoot length was related to germination percent. The implication is that the mesocotyl length contributed most of the genotypic variability.

Simple correlations among Manhattan germination and establishment variables (Table 16 and Appendix Table 4) shows a significant relationship of shoot length with mesocotyl length. Seedling vigour was related to establishment and seedling height. In previous analyses of Manhattan field germination and establishment variables, vigour was significantly affected by the depth by genotype interaction. Table 17 and Appendix Table 5 shows seedling vigour to be significantly related to establishment and seedling height at shallow planting, but there was no relationship between vigour and seedling height at deeper planting. Depth of planting was previously shown not to affect germination and establishment variables. Thus, the failure of consistent correlation between seedling vigour, establishment and seedling height from varying depths of planting shows no genotypic consistency. Again there was a significant relationship between shoot and mesocotyl lengths.

A comparison between laboratory and Manhattan field

variables shows seedling vigour to be related to mesocotyl and shoot length and germination percent in the laboratory (Table 18 and Appendix Table 6). Seedling height was significantly related to coleoptile length and and shoot length. Therefore, both mesocotyl and coleoptile differences contributed to some field variables.

Simple correlations among Hays germination and establishment variables (Table 19 and Appendix Table 7) show a significant relationship of shoot length with mesocotyl and coleoptile lengths, seedling vigour, and seedling height. Mesocotyl length was positively correlated with coleoptile length and seedling height was related to mesocotyl length. Seedling vigour was also related to establishment and seedling height. Simple correlations between laboratory and Hays field variables (Table 20 and Appendix Table 8) show shoot length in the field and laboratory to be related. Mesocotyl length in the the field was related to mesocotyl and shoot length in the laboratory. In a previous analysis, the depth by genotype interaction was found to affect coleoptile length.

Table 21 and Appendix Table 9 shows various relationships between Manhattan and Hays variables. Length of shoot at Manhattan compared to length of shoot at Hays and length of mesocotyl at Manhattan compared to length of mesocotyl at Hays were not significantly related.

Simple correlations among greenhouse variables are shown in Table 22 and Appendix Table 10. There was high shoot to mesocotyl correlation which serves to explain the genetic variability being mostly accounted for by the mesocotyl length. Shoot, mesocotyl, and coleoptile lengths were not well correlated with establishment, therefore, they are not good indicators of establishment.

Table 23 and Appendix Table 11 shows simple correlations between laboratory and greenhouse variables. The negative relationship between time to emergence and mesocotyl length might be because of rate of development, that is, the longer the mesocotyl length, the shorter time to emergence. Both mesocotyl and shoot lengths in the laboratory correlated with establishment variables in the greenhouse, meaning the mesocotyl length again contributed most to the genotypic differences.

Simple correlations between Manhattan field and greenhouse variables do not show any significant relationships with germination and establishment variables (Table 24 and Appendix Table 12). This shows that results obtained in the greenhouse cannot predict germination and establishment in the field. Table 25 and Appendix Table 13, which gives simple correlations between the Hays study and the greenhouse study, shows no establishment relationships with shoot, mesocotyl, or coleoptile lengths.

Table 15. Simple correlations among laboratory variables

	Mesocotyl	Coleoptile	Shoot	Germination
Mesocotyl	--	--	0.95	0.78
Coleoptile		--	--	--
Shoot			--	0.76
Germination %				--

Correlations significant at 0.05 level.

Table 16. Simple correlations among Manhattan field germination and establishment variables.

	Shoot	Meso-cotyl	Coleo-ptile	Vigour	Estab-lishment	Seedling height	Mature height
Shoot	--	0.79	--	--	--	--	--
Mesocotyl		--	--	--	--	--	--
Coleoptile			--	--	--	--	--
Seedling vigour				--	0.79	0.75	--
Establishment					--	--	--
Seedling height						--	--
Mature height							--

Correlations significant at 0.05 level.

Table 17. Simple correlations among Manhattan field germination and establishment variables at two depths of planting.

	Shoot	Meso-cotyl	Coleo-ptile	Vigour	Estab-lishment	Seedling height	Mature height
Shallow planting							
Shoot	--	0.94	--	--	--	--	--
Mesocotyl		--	--	--	--	--	--
Coleoptile			--	--	--	--	--
Seedling vigour				--	0.74	0.78	--
Establishment					--	--	--
Seedling weight						--	--
Mature height							--
Deep planting							
Shoot	--	0.72	0.58	--	--	--	--
Mesocotyl		--	--	--	--	--	--
Coleoptile			--	--	--	--	--
Seedling vigour				--	0.86	--	--
Establishment					--	--	--
Seedling weight						--	--
Mature height							--

Correlations significant at 0.05 level.

Table 18. Simple correlations between laboratory and Manhattan field variables.

Field variables	Laboratory variables: Meso-cotyl	Coleo-ptile	Shoot	Germi-nation
Shoot	--	--	--	--
Mesocotyl	--	--	--	--
Coleoptile	--	--	--	--
Seedling vigour	0.59	--	0.70	0.58
Establishment	--	--	--	--
Seedling dry weight	--	--	--	--
Seedling height	--	0.70	0.62	--
Mature height	--	--	--	--

Correlations significant at 0.05 level.

Table 19. Simple correlations among Hays field germination and establishment variables.

	Shoot	Meso-cotyl	Coleo-ptile	Seedling Vigour	Estab-lishment	Seedling height	Mature height
Shoot	--	0.98	0.77	0.60	--	0.68	--
Mesocotyl		--	0.64	--	--	0.71	-0.65
Coleoptile			--	--	--	--	--
Seedling vigour				--	0.67	0.70	--
Establishment					--	--	--
Seedling height						--	--
Mature height							--

Correlations significant at 0.05 level.

Table 20. Simple correlations between laboratory and Hays field variables.

	Laboratory variables			
Field variables	Mesocotyl	Coleoptile	Shoot	Germination
Shoot	--	--	0.67	--
Mesocotyl	0.64	--	0.74	--
Coleoptile	--	--	--	--
Seedling vigour	--	--	--	--
Establishment	--	--	--	--
Seedling height	--	--	--	--
Mature height	--	--	--	--

Correlations significant at 0.05 level.

Table 21. Simple correlation between Manhattan and Hays field germination and establishment variables.

Hays variables	Manhattan variables						
	Shoot	Meso-cotyl	Coleo-ptile	Vigour	Establi-shment	Seedling height	Mature height
Shoot	--	--	--	--	--	0.76	--
Mesocotyl	--	--	--	--	--	0.78	--
Coleoptile	--	--	0.64	--	--	--	--
Vigour	0.73	--	--	0.64	0.85	0.61	--
Establishment	0.58	--	--	--	0.63	--	--
Seedling ht.	0.66	0.64	--	--	--	0.85	--
Mature ht.	--	--	--	--	--	--	0.93

Correlations significant at 0.05 level.

Table 22. Simple correlations among greenhouse variables.

	Time 20% emerge	Index 10	Index 14	Vigour	Estab 10	Estab 14	Shoot	Meso- cotyl	Coleo- ptile	Seedling Ht.	Seedling Wt.
Time to 20% emergence	--	-0.91	-0.90	-0.91	-0.87	-0.86	--	--	--	--	--
Index after 10 days	--	--	0.99	0.95	0.98	0.97	--	--	--	0.67	--
Index after 14 days			--	0.95	0.99	0.98	--	--	--	0.69	--
Seedling vigour				--	0.92	0.92	--	--	--	0.67	--
Establishment at 10 days					--	0.99	--	--	--	0.71	--
Establishment at 14 days						--	0.59	--	--	0.71	--
Shoot							--	0.97	--	0.73	--
Mesocotyl								--	--	0.66	--
Coleoptile									--	0.60	--
Seedling height										--	0.73
Seedling weight											--

All correlations are significant at 0.05 level.

Table 23. Simple correlations between laboratory and greenhouse variables.

Greenhouse variables	Laboratory variables			
	Mesocotyl	Coleoptile	Shoot	Germination
Time to emerge	-0.59	--	--	--
Index 10 days	--	--	--	--
Index 14 days	--	--	--	--
Seedling vigour	0.64	--	0.67	0.70
Estab. 10 days	--	--	0.58	--
Estab. 14 days	0.59	--	0.63	--
Shoot	--	--	--	--
Mesocotyl	--	--	--	--
Coleoptile	--	--	--	--
Seedling height	--	--	--	--
Seedling weight	--	--	--	--

Correlations significant at 0.05 level.

Table 24. Simple correlations between greenhouse and Manhattan field variables.

Greenhouse variables	Manhattan variables							
	Shoot	Meso cotyl	Coleo ptile	Seed ling Vigour	Estab lish ment	Seedling wt.	ht.	Mature height
Time to emerge	--	--	--	--	--	--	--	--
Index 10 days	--	--	--	--	--	--	--	--
Index 14 days	--	--	--	--	--	--	--	--
Seedling vigour	--	--	--	--	--	--	--	--
Estab. 10 days	--	--	--	--	--	--	--	--
Estab. 14 days	--	--	--	--	--	--	--	--
Shoot	--	--	--	--	--	--	0.76	--
Mesocotyl	--	--	--	--	--	--	0.78	--
Coleoptile	--	--	--	--	--	--	--	-0.69
Seedling height	--	--	--	--	--	0.57	--	--
Seedling weight	--	--	--	--	--	0.58	--	--

Correlations are significant at 0.05 level.

Table 25. Simple correlations between greenhouse and Hays field variables.

Greenhouse variables	Hays variables						
	Shoot	Meso-cotyl	Coleo-ptile	Seedling Vigour	Establishment	Seedling height	Mature height
Time to emerge	--	--	--	-0.60	--	--	--
Index 10 days	--	--	--	0.69	--	--	--
Index 14 days	--	--	--	0.70	--	--	--
Seedling vigour	--	--	--	0.65	--	--	--
Estab. 10 days	--	--	--	0.72	--	--	--
Estab. 14 days	--	--	--	0.70	--	--	--
Shoot	--	--	--	--	--	--	--
Mesocotyl	--	--	--	--	--	--	--
Coleoptile	--	--	--	--	--	--	-0.60
Seedling height	--	--	--	0.85	--	--	--
Seedling weight	--	--	--	--	--	--	--

Correlations significant at 0.05 level.

SUMMARY AND CONCLUSIONS

Significant differences in shoot, mesocotyl, and coleoptile lengths occurred among genotypes but categorizing for mesocotyl and coleoptile lengths was not effective. Further testing of millet genotypes categorization for mesocotyl and coleoptile development in the laboratory is suggested under a wider range of temperatures. Possibly a microscopic study of cell division and orientation in both mesocotyl and coleoptile tissues could be performed, and a more strict categorization of genotypes should be used.

In the field, planting depth did not affect any of the variables except mesocotyl length at Hays. However, there was a depth by genotype interaction in establishment at Manhattan and in coleoptile length at Hays. Deeper planting was expected to improve establishment but failed to do so at both locations.

In the greenhouse, high soil temperature significantly increased mesocotyl and shoot lengths and seedling height. Deeper planting significantly increased time to emergence but reduced germination index at 10 and 14 days after planting, seedling vigour, and establishment percent at 10 and 14 days. Genotypes differed in all establishment variables except seedling dry weight. There were no interactions between temperature and genotype, depth and genotype, or among temperature, depth and genotype, indicating that effects of

genotype were consistent across increasing soil temperatures and increasing depths of planting.

Establishment and mesocotyl lengths were differentially affected by depth of planting in both the field and greenhouse meaning that the longer the mesocotyl length, the greater the chances of emergence and the deeper the planting the smaller the chances of emergence. Therefore the mesocotyl length is an important characteristic to be considered in selecting genotypes. A critical depth of emergence has to be determined for all genotypes. Laboratory seedling measurements under "ideal" conditions cannot be used to define potential depth of planting in the field.

The important relationship between laboratory, field and greenhouse variables was the genotypic differences being mostly accounted for by mesocotyl length. A possible explanation of lack of correlations of coleoptile length among these experiments might be because of the degree of accuracy of measurements. In general, the laboratory measurements seemed to correlate better with greenhouse variables than with the field.

In the laboratory, significant genotype effects on germination was found at all three temperatures, (30, 35, and 40 C) and all three osmotic potential stress levels, 0, -0.6, and -1.2 MPa. Most of the genotypes germinated well at the control and -0.6 MPa osmotic potential. Genotype differences

in ability to germinate under controlled stress were observed and were maximized at -1.2 MPa osmotic potential and 35 C. Genotypic differences observed in this particular experiment may be confounded with the influence of seed quality. It might be appropriate to evaluate temperature and water stress using seed produced the same year for

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APPENDIX TABLES

Appendix Table 1. Concentrations of PEG 8000 necessary to provide selected osmotic solutions.

Temperature (C)	Osmotic Potential (bars)	PEG 8000 (g/l)
30	-6	235
	-12	340
35	-6	247
	-12	355
40	-6	261
	-12	384

Appendix Table 2. Mesocotyl, coleoptile, and shoot lengths and germination percentages as affected by temperature.

Genotype I.D.	Preliminary data			30 C				35 C				40 C			
	M	C	S	M	C	S	G	M	C	S	G	M	C	S	G
1	3.58	2.48	6.06	2.78	1.68	4.46	85	3.38	1.32	4.70	75	3.69	1.21	4.90	67
2	4.52	2.50	7.02	3.41	1.69	5.10	62	3.67	1.39	5.07	80	4.26	1.15	5.41	53
3	5.35	2.67	8.02	2.49	1.78	4.27	65	3.95	1.94	5.89	53	3.42	1.47	4.89	55
4	5.58	2.17	7.75	2.78	2.14	4.92	73	3.75	1.53	5.28	67	3.20	1.31	4.50	77
5	6.65	2.95	9.60	3.72	1.95	5.67	83	4.66	1.62	6.28	78	5.20	1.36	6.56	73
6	6.73	2.06	8.79	4.40	1.18	5.58	88	5.05	0.93	6.00	85	5.91	0.90	6.81	75
7	6.25	2.10	8.35	3.27	1.79	5.06	85	3.74	1.63	5.38	70	3.81	1.40	5.20	60
8	5.94	2.12	8.06	5.10	1.60	6.70	78	4.57	3.03	7.60	83	5.70	1.20	6.89	83
9	5.65	2.45	8.11	2.59	1.47	4.06	63	3.50	1.58	5.09	55	3.47	1.41	4.87	53
10	4.52	2.50	7.02	3.35	1.63	4.99	75	3.60	1.45	5.05	47	3.23	1.18	4.41	50
11	6.65	2.95	9.60	3.87	1.92	5.79	88	4.54	1.65	6.19	92	5.24	1.40	6.64	65
12	5.23	2.97	8.20	3.85	2.21	6.06	88	4.54	1.50	6.04	82	4.42	1.19	5.61	70
LSD				0.90	0.59	0.98	23	1.71	1.25	1.31	22	1.02	0.16	1.02	20

I.D.	30 C (2nd run)			
4	3.55	1.76	5.31	38
6	4.52	1.00	5.52	52
7	3.80	1.60	5.40	28
9	3.75	1.35	5.10	33
10	2.04	1.66	3.70	15
11	4.39	1.19	5.58	33
LSD	1.73	0.40	2.08	21

M = Mesocotyl length (cm) C = Coleoptile length (cm) S = Shoot length (cm)
G = Germination percent

Appendix Table 3. Simple correlations among laboratory variables. (N=12)

	Mesocotyl	Coleoptile	Shoot	Germination
Mesocotyl	--	-0.01	0.95	0.78
Coleoptile		--	0.29	0.04
Shoot			--	0.76
Germination %				--

Appendix Table 4. Simple correlations among Manhattan field germination and establishment variables. (N=12)

	Shoot	Meso-cotyl	Coleo-ptile	Vigour	Establish-ment	Seedling height	Mature height
Shoot	--	0.79	0.14	0.18	0.47	0.29	0.02
Mesocotyl		--	-0.49	0.18	0.17	0.28	-0.06
Coleoptile			--	-0.03	0.39	-0.04	0.12
Seedling vigour				--	0.79	0.75	-0.20
Establishment					--	0.45	-0.16
Seedling height						--	0.20
Mature height							--

Appendix Table 5. Simple correlations among Manhattan field germination and establishment variables at two depths of planting. (N=12)

	Shoot	Meso-cotyl	Coleo-ptile	Vigour	Estab-lishment	Seedling height	Mature height
Shallow planting							
Shoot	--	0.94	0.02	0.29	0.47	0.22	0.01
Mesocotyl		--	-0.31	0.32	0.32	0.15	0.09
Coleoptile			--	-0.14	0.37	0.16	-0.26
Seedling vigour				--	0.74	0.78	-0.11
Establishment					--	0.53	-0.24
Seedling height						--	-0.16
Mature height							--
Deep planting							
Shoot	--	0.72	0.58	0.39	0.46	0.05	0.08
Mesocotyl		--	-0.14	0.23	0.10	0.16	-0.20
Coleoptile			--	0.29	0.55	-0.11	0.36
Seedling vigour				--	0.86	0.36	-0.14
Establishment					--	0.11	0.14
Seedling height						--	-0.13
Mature height							--

Appendix Table 6. Simple correlations between laboratory and Manhattan field variables. (N=12)

Field variables	Laboratory variables: Meso-cotyl	Coleo-ptile	Shoot	Germi-nation
Shoot	0.21	0.10	0.23	0.27
Mesocotyl	0.34	-0.03	0.31	0.18
Coleoptile	-0.30	0.25	-0.21	0.13
Seedling vigour	0.59	0.47	0.70	0.58
Establishment	0.07	0.35	0.17	0.26
Seedling dry weight	-0.30	0.10	-0.26	-0.07
Seedling height	0.43	0.70	0.62	0.44
Mature height	-0.16	-0.51	-0.30	0.06

Appendix Table 7. Simple correlations among Hays field germination and establishment variables. (N=12)

	Shoot	Meso-cotyl	Coleo-ptile	Seedling Vigour	Estab-lishment	Seedling height	Mature height
Shoot	--	0.98	0.77	0.60	0.34	0.68	-0.06
Mesocotyl		--	0.64	0.55	0.29	0.71	-0.65
Coleoptile			--	0.59	0.40	0.40	-0.01
Seedling vigour				--	0.67	0.70	0.21
Establishment					--	0.34	0.47
Seedling height						--	0.04
Mature height							--

Appendix Table 8. Simple correlations between laboratory and Hays field variables.

Field variables	Laboratory variables: Mesocotyl	Coleoptile	Shoot	Germination
Shoot	0.55	0.46	0.67	0.55
Mesocotyl	0.64	0.41	0.74	0.54
Coleoptile	-0.02	0.33	0.08	0.29
Seedling vigour	0.16	0.39	0.27	0.47
Establishment	0.11	0.37	0.22	0.38
Seedling height	0.28	0.51	0.42	0.36
Mature height	-0.10	-0.45	-0.23	0.23

Appendix Table 9. Simple correlation between Manhattan and Hays field germination and establishment variables. (N=12)

Hays variables	Manhattan variables						
	Shoot	Meso-cotyl	Coleo-ptile	Seed-ling Vigour	Estab-lish-ment	Seedling height	Mature height
Shoot	0.48	0.36	0.16	0.56	0.51	0.76	-0.26
Mesocotyl	0.49	0.46	-0.00	0.58	0.46	0.78	-0.27
Coleoptile	0.31	-0.08	0.64	0.33	0.54	0.49	-0.15
Vigour	0.73	0.45	0.41	0.64	0.85	0.61	-0.04
Establishment	0.58	0.34	0.35	0.45	0.63	0.30	0.39
Seedling ht.	0.66	0.64	-0.04	0.56	0.39	0.85	-0.18
Mature ht.	0.33	0.20	0.18	-0.02	0.13	-0.02	0.93

Appendix Table 10. Simple correlations among greenhouse variables. (N=12)

	Time 20% emerge	Index 10	Index 14	Vigour	Estab 10	Estab 14	Shoot	Meso-cotyl	Coleo-ptile	Seedling Ht.	Seedling Wt.
Time to 20% emergence	--	-0.91	-0.90	-0.91	-0.87	-0.86	0.22	-0.18	-0.25	-.51	-0.12
Index after 10 days		--	0.99	0.95	0.98	0.97	0.46	0.41	0.39	0.67	0.21
Index after 14 days			--	0.95	0.99	0.98	0.50	0.44	0.42	0.69	0.21
Seedling vigour				--	0.92	0.92	0.50	0.44	0.43	0.67	0.32
Establishment at 10 days					--	0.99	0.55	0.49	0.49	0.71	0.19
Establishment at 14 days						--	0.59	0.52	0.49	0.71	0.20
Shoot							--	0.97	0.48	0.73	0.52
Mesocotyl								--	0.28	0.66	0.52
Coleoptile									--	0.60	0.29
Seedling height										--	0.73
Seedling weight											--

Appendix Table 11. Simple correlations between laboratory and greenhouse variables. (N=12)

Greenhouse variables	Laboratory variables			
	Mesocotyl	Coleoptile	Shoot	Germination
Time to emerge	-0.59	0.17	-0.56	-0.53
Index 10 days	0.54	0.02	0.55	0.50
Index 14 days	0.55	0.05	0.57	0.50
Seedling vigour	0.64	0.03	0.67	0.70
Estab. 10 days	0.54	0.13	0.58	0.47
Estab. 14 days	0.59	0.10	0.63	0.48
Shoot	0.33	0.35	0.42	0.33
Mesocotyl	0.37	0.24	0.43	0.32
Coleoptile	0.06	0.53	0.19	0.21
Seedling height	0.18	0.25	0.24	0.30
Seedling weight	0.10	0.03	0.11	0.26

Appendix Table 12. Simple correlations between Manhattan field and greenhouse variables. (N=12)

Greenhouse variables	Manhattan variables							
	Shoot	Meso cotyl	Coleo ptile	Seed ling Vigour	Estab lish ment	Seedling wt.	ht.	Mature height
Time to emerge	-0.26	-0.05	-0.52	-0.10	-0.02	0.00	-0.05	-0.12
Index 10 days	0.19	-0.01	0.48	0.17	0.15	0.08	0.24	-0.26
Index 14 days	0.21	0.02	0.48	0.18	0.17	0.09	0.27	-0.30
Vigour	0.16	-0.02	0.44	0.18	0.02	0.06	0.32	-0.18
Estab. 10 days	0.29	0.08	0.51	0.22	0.24	0.13	0.32	-0.39
Estab. 14 days	0.31	0.12	0.45	0.23	0.21	0.12	0.33	-0.39
Shoot	0.42	0.40	0.05	0.35	0.39	0.55	0.76	-0.18
Mesocotyl	0.50	0.53	-0.10	0.46	0.43	0.53	0.78	-0.01
Coleoptile	-0.13	-0.35	0.56	-0.24	0.02	0.25	0.24	-0.69
Seedling ht.	0.28	0.10	0.43	0.19	0.52	0.57	0.48	-0.13
Seedling wt.	0.08	0.04	0.10	0.21	0.40	0.58	0.44	0.39

Appendix Table 13. Simple correlations between Hays field and greenhouse variables. (N=12)

Greenhouse variables	Hays variables						
	Shoot	Meso- cotyl	Coleo- ptile	Seed ling Vigour	Estab lish ment	Seedling height	Mature height
Time to emerge	-0.41	-0.32	-0.38	-0.60	-0.21	-0.18	0.09
Index 10 days	0.37	0.36	0.14	0.69	0.17	-0.16	-0.03
Index 14 days	0.38	0.38	0.13	0.70	0.16	-0.34	-0.06
Vigour	0.48	0.44	0.26	0.65	0.27	0.02	0.04
Estab. 10 days	0.40	0.41	0.12	0.72	0.13	-0.10	-0.17
Estab. 14 days	0.41	0.43	0.09	0.70	0.12	-0.06	-0.18
Shoot	0.39	0.51	-0.23	0.44	0.05	0.49	-0.11
Mesocotyl	0.34	0.49	-0.32	0.39	0.12	0.56	0.05
Coleoptile	0.30	0.23	0.29	0.43	-0.19	-0.04	-0.60
Seedling ht.	0.20	0.16	0.16	0.85	0.24	0.15	0.05
Seedling wt.	0.10	0.07	0.11	0.41	0.19	0.26	0.46

GENETIC AND TEMPERATURE EFFECTS ON MESOCOTYL AND COLEOPTILE LENGTHS AND TEMPERATURE AND MOISTURE EFFECTS ON GERMINATION OF PEARL MILLET

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ABSTRACT

Mesocotyl, coleoptile and shoot lengths and germination percent were determined in the laboratory at three temperatures for twelve pearl millet [Pennisetum glaucum (L.) R. Br.] genotypes. Mesocotyl, coleoptile, and shoot lengths, and establishment were studied in field and greenhouse experiments with 4 planting depths (5, 6, 10, and 12 cm). Temperature and water stress effects on the germination of millet seed were determined in the laboratory using polyethylene glycol.

Genotypic differences were observed in mesocotyl, coleoptile, and shoot length. Mesocotyl length increased while coleoptile length decreased with increasing temperature. Shoot length (the sum of the mesocotyl and coleoptile lengths) changed according to whether the mesocotyl length increase was greater than the coleoptile length decrease and vice versa. Similar mesocotyl/coleoptile relationships were observed in the greenhouse temperature/depth study.

In the field (Manhattan and Hays), there was no clear advantage of deeper planting. Genotypes significantly differed in shoot and mesocotyl lengths, seedling height, and mature plant height at both locations. Depth and genotype interactions were observed for establishment at Manhattan and coleoptile lengths at Hays which implied that genotypes were

differentially affected by depth of planting.

In the greenhouse, deeper planting (12 cm) significantly increased time to emergence but reduced germination index, seedling vigour, and establishment percent after 10 and 14 days.

Significant correlations among laboratory variables, among field variables, among greenhouse variables, between laboratory and field variables, between laboratory and greenhouse variables, and between greenhouse and field variables indicated the mesocotyl length accounted for most of the genotypic variability. Erratic emergence and establishment in the field and greenhouse may be partially explained on the basis of depth of planting.