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1. Vanderlip, R.L.
2. Gardner, J.C.
3.

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Seed Size and Density Effects on Field Performance of Pearl Millet

J. C. GARDNER[1] AND R. L. VANDERLIP[2]
Department of Agronomy, Kansas State University
Manhattan, Kansas 66506

ABSTRACT

Pearl millet [*Pennisetum americanum* (L.) Leeke] often performs poorly, as a result of inherently low seedling vigor and small seed size. Seed size and seed density were compared as conditioning criteria to improve field performance.

Seven seedlots, six from unique genotypes including four random mating populations and an inbred, plus two different seedlots from one cultivar, were separated into four seed sizes and two or three density fractions. These sizes and densities were compared to the original seedlots in the field with two planting dates each at St. John and Manhattan, Kansas during 1978 and 1979.

Size and density were effective criteria for selection of the most vigorous seeds within a seedlot. The smallest seeds were inferior to the larger sizes in emergence and grain yield. The highest performing seed size varied among seedlots, with the largest size (>2.8 mm diam.) frequently inferior to slightly smaller seed (2.6 to 2.8 mm diam.). Seed density had a positive linear relationship to emergence percentages across all seedlots but was not always associated with increased yield. Heightened vigor from high density seed was expressed during heterotrophic growth, whereas large seed size was associated with vigor during both heterotrophic and autotrophic growth.

In comparing the highest performing treatments to the original seedlot at all locations, large seeds established more plants than the original seedlot 51 percent of the time, whereas high density seeds were superior to the original seedlot in 57 percent of the plantings. For yield, large and high density seeds were superior to the original seedlots in 26 and 13 percent of the cases, respectively.

[1] Former graduate student.

[2] Agronomist, Agronomy Dept., Kansas State University, Manhattan, KS 66506.

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The relationship of seed size not only to stand establishment but to grain yield was dependent upon environment. Yield was most affected by seed size in the lower yielding, moisture stressed environment, which is typical of areas where pearl millet is grown.

Pearl millet [*Pennisetum americanum* (L.) Leeke] is grown in the hot, semi-arid areas of Africa and India, especially in dry and infertile areas where it seems better adapted than other cereal grains. Active breeding and agronomic programs involved with the improvement of pearl millet in the U.S. have shown that it is able to compete in grain yield with traditional crops in drought prone areas of the Central Plains (Christenson et al., 1984). While its ability to overcome stress as an established plant has been recognized, seedling establishment remains a problem wherever it is grown.

Small seed size (4 to 12 mg·seed^{-1}) is a major contributor to the problem of establishing an adequate stand of pearl millet in the field. Selection and inclusion of vigorous genotypes in breeding programs and the improved initial growth rate of hybrid pearl millet (Kittock, 1967) offer hope for the future. Field establishment of both present and future cultivars could be improved, if physical characteristics of the seed that were related to vigor could be identified.

Although research has been inconclusive, the smallest seeds within seedlots usually have been related to low vigor, especially in grass species. Kiesselbach (1924), comparing equal numbers of large and small seeds, found low vigor and reduced yield from small seeds within seedlots of winter wheat, *Triticum aestivum* L., spring wheat, and oat, *Avena sativa* L. Boyd et al. (1971) and Smith and Camper (1975) found similar results with barley, *Hordeum vulgare* L., and soybeans, *Glycine max* (L.) Merr., respectively. In sorghum, *Sorghum bicolor* (L.) Moench, Abdullahi and Vanderlip (1972) and Maranville and Clegg (1977) found small seeds to be lower in germination percentages and vigor under laboratory conditions, but in the field differences among seed sizes were diminished. Large seed size has been reported by Kaufman and Guitard (1967) to provide more carbohydrate reserve for the developing seedling and to result in increased area of the early leaves.

Individual seed weight per unit volume, or density, has also been related to seed vigor. Sung and Delouche (1962) found that rice, *Oryza sativa* L., seeds with high density emerged faster and resulted in higher emergence percentages than lower density seeds within the same seedlot. Maranville and Clegg (1977) and Lawan et al. (1985) also found higher standard germination and often improved emergence percentages from sorghum and pearl millet seedlots by using those seeds highest in density. In cotton,

Gossypium hirsutum L., seed density was used to distinguish fully filled, mature seeds from immature seeds as indicated by embryo:total seed weight ratios (Bartee and Krieg, 1974).

Although large and high density seeds often have improved early growth and development, rarely have vigorous seedlings been reported to provide any yield advantage over non-vigorous seedlings, if enough plants were established for the given environment (Maranville and Clegg, 1977; Lawan et al., 1985).

The objectives of this study were to characterize the emergence and yield response within seed sizes and densities and to determine if conditioning pearl millet seedlots by seed size or density would significantly improve performance under field conditions.

Materials and Methods

Seven seedlots were used, six of which were unique genotypes. Four random mating populations ('World collection', '306E', 'HMP1700', 'RMP1'), a cultivar ('Serere 3A'), and inbred (#771240) were obtained from the Fort Hays Branch Experiment Station, Hays, Kansas. Serere 3A and RMP1 were planted in both years, whereas smaller quantities of seed limited other genotypes to only one year each. Serere 3A seed used in 1978 was produced under dryland conditions at Hays, Kansas, and seed used in 1979 was produced near Manhattan, Kansas under irrigation. RMP1 seed from the same seedlot was used in both years. Seed size and density separations were made on portions from each of the original seedlots.

Seed size was determined through a series of round hole sieves. The four size categories were: seeds retained on a 2.8 mm (7/64"), through a 2.8 mm but retained on a 2.6 mm (6 5/64"), through a 2.6 mm but retained on a 2.2 mm (5 5/64"), and through a 2.2 mm round hole sieve. Seeds were separated by density, regardless of size, by placing a portion of the original seedlot in a solution containing 1.4 g·cm^{-3} of sucrose, then adding distilled water until the solution reached a density that resulted in dividing the seedlot in half by volume. In 1979, the densest portion was divided again to result in a third density fraction. After the sucrose soak, which took approximately 5 minutes, the seeds were washed in distilled water and allowed to air dry. As a check on the density separation technique, an additional portion of each original seedlot was handled identically, after which the density fractions were blended back together.

With a vacuum planter, seeds of the various sizes, densities, sucrose check, and original seedlots were planted 50 seeds·row^{-1}) (143,500 seeds·ha^{-1}) in two-row plots, with rows 76 cm apart and 4.6 m in length. In 1978, the study was planted at Manhattan, Kansas (Smolan silt loam, Pachic Arguistoll, fine, montmorillonitic, mesic soil) on 30 May and 13 June, and at the Sandyland Experiment Field near St. John, Kansas (Pratt loamy fine sand,

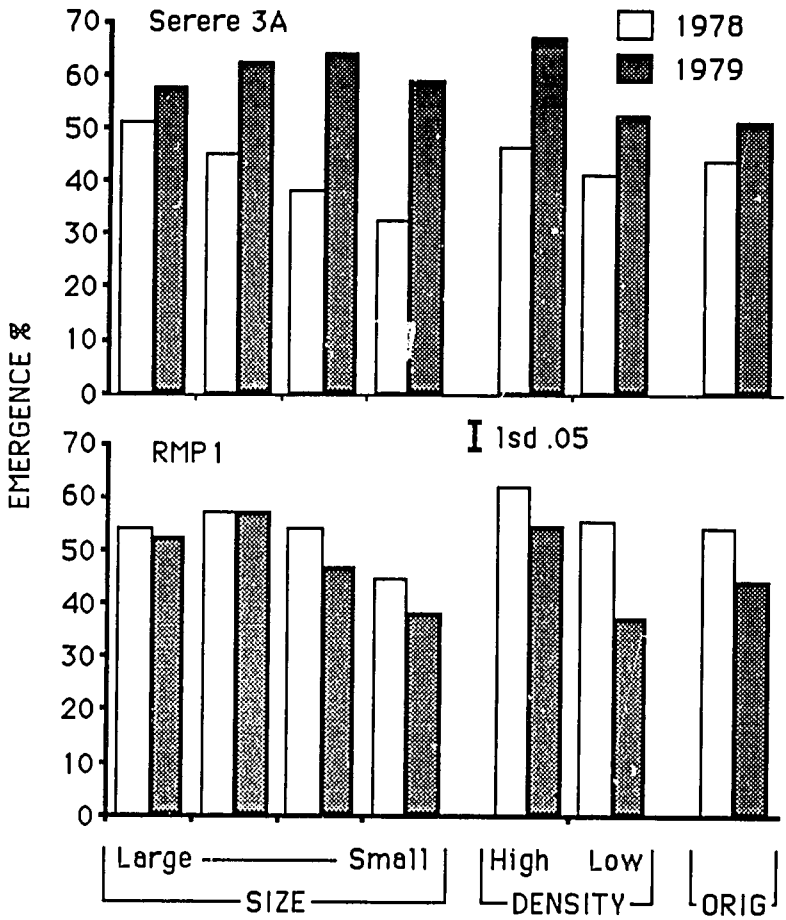

Fig. 1. Mean emergence percentages over planting dates and locations by year and genotype.

Psammentic Haplustalf, sandy mixed, thermic soil) on 10 May and 31 May. In 1979, planting was done near Manhattan at the Ashland Research Farm (Muir silt loam, Cumulic Haplustoll, fine-silty, mixed, mesic soil) on 16 May and 12 June and at St. John on 15 May and 6 June.

The experimental design was a modified split-plot with planting dates (main plots) stripped across all four replications. Emergence counts were made when the seedlings were at the 3- to 5-leaf stage (Maiti and Bidinger, 1981). Heads were hand harvested from each plot and threshed. Grain yield was adjusted to a moisture content of 125 g H_2O kg^{-1} of total weight and expressed as $kg \cdot ha^{-1}$.

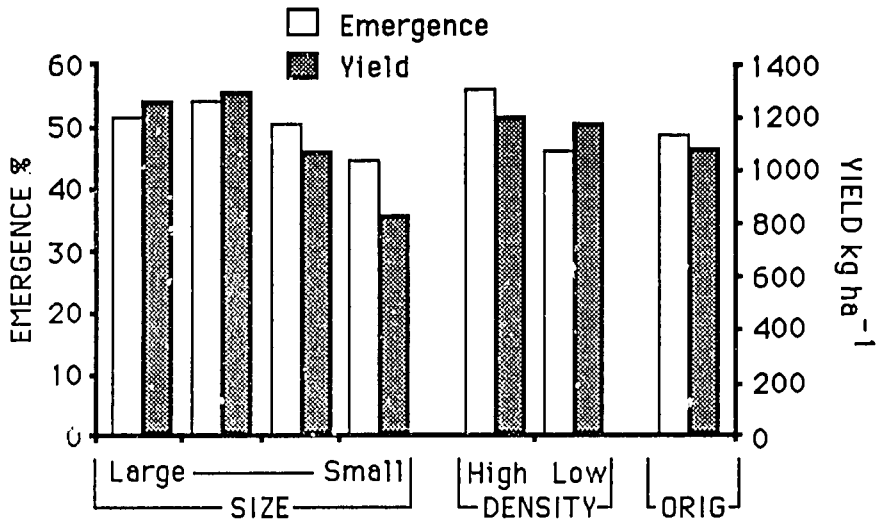

Fig. 2. Mean emergence percentages and grain yield at St. John across all genotypes, dates, and years.

RESULTS

Stability of a seed size or density treatment effect was considered of primary importance, thus data were initially analyzed by pooling the two genotypes, Serere 3A and RMP1, and treatments common to all plantings (Table 1). For emergence, the significant year × genotype × treatment effect was the result of an inconsistent response among the sizes for Serere 3A between years in which different seedlots were used (Fig. 1). Similar analysis for yield, excluding the second planting date at St. John in 1979, which was abandoned at mid-season when herbicide carryover became apparent, also indicated a significant high-order interaction. Thus, each location in each year was analyzed separately as summarized in Table 2. Significant genotype × treatment interactions for emergence percentages (Table 3) and yield at Manhattan in 1978 (Table 4) were due to inconsistency in seed size performance except for the genetically diverse genotype, World collection, in which genotypic selection may have occurred.

Treatments were usually effective in influencing both emergence percentages and yield. At St. John, small seeds not only resulted in poor emergence but also established plants with low yield. Though high density seeds were among the highest in emergence percentages, resulting grain yield was similar to that of poorly emerging low density seeds at St. John (Fig. 2).

Among the environmental factors which influenced yield, chinchbug (*Blissus leucopterus*) infestations at Manhattan in both years increased the vari-

Table 1. Analysis of variance summary for data pooled over locations and years. Sources of variation are only displayed for those effects in which treatment was involved.

Source of variation	df	Emergence	Yield
Treatment (T)	7	**	NS
Year (Y) × T	7	**	NS
Location (L) × T	7	NS	NS
Y × L × T	7	NS	NS
Date (D) × T	7	NS	—
L × D × T	7	NS	—
Y × D × T	7	NS	—
Y × L × D × T	7	NS	—
Y × Genotype (G) × T	7	**	NS
L × G × T	7	NS	NS
Y × L × G × T	7	NS	*
Date (D) × G × T	7	NS	—
L × D × G × T	7	NS	—
Y × D × G × T	7	NS	—
Y × L × D × G × T	7	NS	—

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

ability of response to treatment. Control measures were applied, yet chinchbugs placed additional stress on poorly emerging plots because of a natural preference for isolated plants. The dynamics of insect development during the growing season and differential host preference were evident by significant treatment interactions with planting date and genotype at Manhattan (Table 2).

During the first year of the trial, obvious differences between density treatments during early vegetative stages were noted in most, but not all, of the genotypes. Increasing the number of density separations to three in 1979 revealed a consistent and positive, linear relationship between seed density and emergence (Table 2). Only the high and low density fractions from 1979 are illustrated to allow comparison with 1978 data.

Discussion

Seedlot and genotype effects within this study were confounded because of the insufficient quantities of contrasting seedlots available at the time. The purpose of including several diverse genotypes was to test seedlots produced under different environmental conditions and provide a range of performance potential in which to estimate the effects of selecting seeds by size or density. Differences between the two Serere 3A seedlots used, although tested in different years, demonstrate the importance of the environment in which seed is produced (Fig. 1).

Table 2. Aanalysis of variance summary for emergence and yield by locations and year.

Source of variation	1978 df	1978 Manhattan Emerg.	1978 Manhattan Yield	1978 St. John Emerg.	1978 St. John Yield	1979 df	1979 Manhattan Emerg.	1979 Manhattan Yield	1979 St. John Emerg.	1979 St. John Yield
Date[a]	1	—	—	—	—	1	—	—	—	—
Genotype (G)	4	**	**	**	**	4	**	**	**	**
Treatment (T)	7	**	**	**	**	8	**	**	**	**
size										
linear	1	**	**	**	**	1	NS	**	**	**
quadratic	1	**	NS	*	NS	1	**	**	**	NS
density										
linear	1	**	**	NS	NS	1	**	**	**	NS
quadratic	—	—	—	—	—	1	NS	NS	NS	NS
size and density vs. check and original	1	**	NS	NS	NS	1	**	*	*	NS
check vs. original	1	NS	NS	NS	NS	1	NS	NS	NS	NS
residual	2	NS	NS	NS	NS	2	NS	NS	NS	NS
Date (D) × G	4	NS	**	**	NS	2	NS	**	—	—
D × T	7	NS	NS	NS	NS	8	NS	**	—	—
G × T	28	**	**	*	NS	16	**	NS	**	NS
D × G × T	28	NS	NS	NS	NS	16	NS	NS	—	—

[a] Not testable with experimental design used.
*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 3. Mean emergence percentages for genotypes not in combined analysis, by year and location.

	Treatment (emergence %)							
	Seed sizes				Seed density			
Year, location, and genotype	Largest	Large	Medium	Small	High	Low	Original	LSD 0.05
1978 Manhattan								
306E	53	57	51	39	65	56	52	
World collection	43	45	47	42	49	50	44	
HMP1700	38	38	35	30	37	34	36	6.7
1978 St. John								
306E	56	58	58	51	60	56	57	
World collection	48	56	54	50	56	51	61	
HMP1700	44	43	35	35	41	40	40	9.3
1979 Manhattan								
Inbred #771240	45	55	58	53	59	42	45	6.7
1979 St. John								
Inbred #771240	75	73	70	71	76	64	62	8.5

The ability of a seed characteristic to influence plant performance in the field appears to be affected by the environment in which the plant grows and the nature of the stress present. In sorghum (Maranville and Clegg, 1977) and pearl millet (Lawan et al., 1985), large and high density seeds frequently improved emergence percentages but not grain yield under conditions of relatively high yield potential. In contrast, under moisture-limiting environments with pearl millet, seed characters seem to have a greater influence not only on stand establishment but on yield, as seen in these data and those presented by Okonkwo and Vanderlip (1985).

Locations chosen for this study differed in the nature of stress applied to seeds and seedlings. At St. John, coarse soil texture provided a seedbed capable of rapid moisture loss from evaporation within the shallow zone in which millet had to be planted. Further, this soil had a limited water-holding capacity, and when this was coupled with normally insufficient rainfall and warm temperatures, moisture stress became a common event. Although speed of germination had value under these conditions, establishment of a plant tolerant of stress was necessary for yield. Among all the size and density treatments, only plants from small seeds were reduced in yield at St. John.

The environment at Manhattan placed more emphasis upon the vigor of the seed than the stress tolerance or vigor of established plants. Fine soil texture often caused crusting of the soil surface and reduced emergence percentages by an average of 8 percent as compared to St. John. Treatment

Table 4. Mean grain yield at Manhattan in 1978 for the genotypes not in the combined analysis, by treatment.

	Treatment (yield, kg ha⁻¹)							
	Seed sizes				Seed density			
Genotype	Largest	Large	Medium	Small	High	Low	Original	LSD 0.05
306E	2075	1800	1985	1128	2296	1549	1613	
World collection	1171	1264	1179	1051	1295	1644	1310	
HMP1700	725	638	391	565	501	364	245	413

success was determined by the ability for emergence through crust, and under these conditions, seeds high in density were consistently best. Once established, yield-reducing stress was relatively minor, with the exception of chinchbug stress to those plots poorest in stand establishment. The relationship between seed conditioning treatment and yield under this environment has not been found by others (Lawan et al., 1985; Okonkwo and Vanderlip, 1985), and its significance in this study was probably dependent upon the stress from chinchbugs.

These data indicate a difference in the type of vigor selected when conditioning pearl millet seedlots by size and density. Seed size has been reported to be related to seedling size (Kaufman and Guitard, 1967), which is considered an important visual selection criterion for vigor among millet breeding programs in the semi-arid tropics (P. S. Raju, pers. comm., 1986). Although this study frequently revealed the largest seeds to be associated with a drop in performance, suggesting that the largest seeds in some seedlots may be inefficient in the utilization of reserves (Whalley et al., 1986), the predominant seed size effect was the poor performance of the smallest seeds. Larger seeds resulted in increased emergence percentages and plants with superior vigor after establishment during autotrophic growth in the moisture-limiting environment at St. John. Seeds high in density were vigorous during early heterotrophic growth but usually were not associated with increased yield if enough plants were established for the given environment. These observations are in general agreement with those of Hay and Gamble (1985), who studied soybeans in the laboratory. Using standard germination and seed leachate conductivity tests as estimates of viability and vigor, they found that viability was more closely related to seed density, whereas vigor was affected more by seed size.

The principal objective of this study was to characterize the response in field performance from planting seeds of various sizes and densities. Among seed sizes, a linear or quadratic response was observed; among densities, the response was linear. Although this information is valuable in determining how to condition pearl millet seedlots, it does not address the question of

whether the conditioning will result in superior field performance as compared to the original unconditioned seedlot. This is probably determined by the viability and vigor found in the original seedlot, with conditioning being most appropriate on seedlots poor in vigor and diverse in seed size or density.

To estimate the effect that seed conditioning had in this study, individual mean comparisons (LSD 0.05) within each seedlot were made between the original seedlot and both the highest density treatment and one of two largest seed sizes, whichever was greater, at all locations. For emergence, large seeds established more plants than the original seedlot 51 percent of the time, whereas high density seeds were superior in 57 percent of the plantings. At harvest, plots from large seeds were higher in yield than those from original seedlots in 26 percent of the cases, and plots from high density seeds were higher 13 percent of the time. Based on the seedlots and environments used in this study, seed conditioning can have a significant impact upon the field performance of pearl millet.

In summary, both seed size and seed density were used to select vigorous seeds within a seedlot, but their vigor was expressed at different times. Seed density was positively related to initial seed vigor, whereas seed size had a greater effect upon seedling and plant vigor. The effects of seed characteristics were most apparent during the early stages of growth. As the plants developed, the environment played an increasingly larger role in determining whether a characteristic of the embryonic plant would influence yield.

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