FIELD EVALUATION OF EFFECTS OF SEED SIZE AND DENSITY ON ESTABLISHMENT AND GRAIN YIELD IN PEARL MILLET.

by

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INTRODUCTION

Pearl millet [Pennisetum glaucum (L.) R. Br. syn. Pennisetum americanum (L.) Leeke] is one of the major food crops in the semi-arid regions of Africa and Asia because it tolerates their harsh environments : low, irregular rainfall and high temperature (40). Low plant stands are a major problem, stemming partly from small seed size compared with that of other crops. Small seeds require shallow planting for easy emergence, which increases the risk of drought stress during emergence and early seedling growth. Small amount of nutrient reserves in the seeds mean that seedlings quickly become dependent on the environment. As a result, unfavorable environmental conditions reduce stands (16, 23, 37).

Okonkwo and Vanderlip (37) reported that head selection and spikelet removal, as management practices, increased seed size and density, thereby improved emergence and grain yield in pearl millet. Similar results were reported by Gardner (17), when pearl millet seedlots were physically separated by seed size and density. Berhe and Mohamed (5) found that pearl millet seed produced by head cut weighed more, were denser, and produced taller, more vigorous seedlings. However, Freyenberger (16) and Modiagotla (36) reported little or no effect of large seed size on establishment or grain yield in pearl millet.

Because of conflicting results, the effects of seed size and density on establishment, seedling vigor, and grain yield were evaluated using (a) seeds produced by management practices (spikelet removal, head cut, and head selection) and (b) seeds differing in size and density separated by sieving and sucrose flotation, planted at low and high plant populations.

LITERATURE REVIEW

Seed size and seed density are important seed characteristics since they affect seed vigor, stand establishment, and grain yield (17, 37). Problems of low seed vigor and low plant establishment in millet necessitated a search for ways to improve seed quality: seed size and density (37). Spikelet removal and head selection were found to improve seed size and density (37).

Effects of seed size and density on germination.

Seed size, as measured by round-hole sieves, is a measure of seed diameter. However, it also is used to denote seed weight. In this study, seed size refers to seed diameter. Seed density is a measure of seed weight per unit volume. Density has the ability to distinguish fully filled, mature seeds from immature seeds as indicated by embryo:total seed weight ratios (3). Generally, seeds high in density have more organic and inorganic materials available to the seedling regardless of the size.

Use of standard germination as an indicator of seed vigor has been investigated. Working with sorghum [Sorghum bicolor (L.) Moench], Maranville and Clegg (35) found that denser and larger seeds had a higher percent germination. Abdullahi and Vanderlip (1) separated sorghum seeds into three sizes: large, medium, and small. After a standard germination test, they stated that large seed tended to perform better than medium and small seed in the laboratory. Using increasing air velocities, Krieg and Bartee (30) separated cotton [Gossypium hirsutum (L.)] seeds into apparent density fractions. Seed density was highly related to germination and they concluded that seed density in cotton was the best predictor of germination. Bishnoi (6) reported that heavier seed of triticale (Triticosecale spp.) was superior in germination tests.

However, germination is meaningful only if it is related to performance of the seed in the field. A lot of studies have proven that standard germination is a poor indicator of seed vigor. Vanderlip et al. (47) found that the standard germination test overestimated field establishment of sorghum. Working with cotton and field beans [Vicia faba (L.)], respectively, Buxton et al. (9) and Hegarty (20) reported that laboratory germination tests did not consistently predict field emergence.

Effects of seed size and density on establishment.

Establishment will refer to the period after the seedling is two to three weeks old during which counts of surviving plants are taken. Gardner (17) separated pearl millet seed by density and size. He found that both size and density improved field establishment. Berdahl and Barker (4) graded seed of open-pollinated progenies of

Russian wild ryegrass [Psathyrostachys juncea (Fisch.)] into large, medium, and small sizes (range 2.1-4.5 mg/seed). Increased establishment was associated with increased seed weight but diminished when seed weights of parents increased beyond 3.0 mg/seed. Turner and Ferguson (46) reported better stands with high density seeds of cotton.

In contrast, Lawan et al. (31) found little advantage to using either high density or large seed of pearl millet in field emergence. Freyenberger (16) graded seed of pearl millet into large, dense, and bold (satisfying both large and dense seed requirements) classes. He found little effect of seed characteristics on stand establishment. Modiakgotla (36) tested pearl millet seed produced in 1980, 1981, and 1982 for establishment. Seeds were characterised for size, weight, density, and protein content. He did not find consistent differences in establishment even though seed differed in size and weight. Several studies with soybean [Glycine max (L.)] by Hoy and Gamble (21,22), Johnson and Leudders (24), and Smith and Camper (44) failed to show a relationship between plant stands and seed size.

Effects of seed size and density on seedling vigor.

Seedling vigor has been related to seed size and density in a number of crops. Seedling vigor is defined as the dry matter of seedling shoots during early plant growth (41). Because of their greater reserves, large seeds produce large, vigorous seedlings which have superior early seedling photosynthesis, and more developed root systems for absorbing water and nutrients. Larger, more vigorous seedlings also are more capable of competing with weeds, escaping from diseases, and tolerating insect damage (13). Kaufmann and Guttard (26) separated 2 barley [Hordeum vulgare (L.)] varieties into large and small seed sizes by sieving. Plants grown from large seed were superior to those grown from small seed in rate of seedling growth and size of the first two leaves. Boyd et al. (7), working with F_3 barley lines, found that marked differences in seedling vigor, as measured by seedling dry weights two weeks after emergence, was largely accounted for by differences in seed size. Chhina and Phul (12) studied 94 genotypes of pearl millet under irrigated and non-irrigated conditions. Seed size was significantly and positively correlated with seedling vigor. Hawkins and Cooper (19), after grading maize [Zea mays (L.)] seed into three seed sizes: large, medium, and small, found that initial plant size was larger with large seed but that differences in plant size became smaller as the crop matured. Positive results on the influence of seed size on seedling vigor have been reported by several researchers working with different crops (5,8,15,28,34,41,42).

Bishnoi (6) divided triticale seed into 3 densities using a gravity table for separation. He included an unsorted sample as a control. He stated that high density seeds were superior for seedling dry weight in the greenhouse studies. Turner and Ferguson (46) sorted 4 cultivars of cotton into full and partially filled seed by X-ray inspection. Plants grown from filled seeds were significantly superior to those from partially filled and control seed for seedling vigor as measured by dry weights eight weeks after emergence.

Effects of seed size and density on grain yield.

Larger, more vigorous seedlings produced from 'high' quality seed may remain superior until final yield. This is most likely to be realised where specific yield components are determined during early growth stages (such as tillering) or when the major factor determining yield in a particular season is significantly affected at that early stage. Using a single cultivar of barley, Kaufmann and McFadden (25) studied the yield of plants from large (50g/1000 seeds) and small (24g/1000 seeds) seeds. Large and small seeds were planted in an alternate arrangement within rows using 10 or 5 cm spacing between plants with rows spaced 15 cm apart. Plants grown from large seeds outyielded those grown from small seeds. The yield difference was largely a result of a difference in heads per plant, and was greater when plants were closely spaced than when they were widely spaced. Austenson and Walton (2) found that grain yield, straw yield, and heads and seeds per plant at maturity were all highly significantly correlated with initial seed weight in spring wheat [Triticum aestivum (L.)]. They suggested that wheat seed size was one crop production variable that could easily be controlled by sieving. Okonkwo and Vanderlip (37) produced pearl millet seed of differing seed size through cultural management practices (spikelet removal and head selection). The subsequent crop produced from treated seeds yielded significantly higher than the control at St. John and Garden City but not at the high yielding location (Manhattan). They suggested that small differences in seed quality may not be critical in crop performance under good growing conditions.

Geiszler and Hoag (18) separated a certified lot of wheat seed into large and small sizes by sieving. These fractions were further graded into low density and high density seeds using a gravity cleaner. Large, high density seed produced significantly higher yields than large, low density and small, low density seeds when an equal number of seeds were planted. Since the difference between large, high density and small, high density seed was not significant, they concluded that density had greater influence on yield than seed size. Small but significant yield differences have been reported for pearl millet (17), sorghum (45), triticale (6), and winter wheat (43) when 'good' quality seed was compared to control seed.

Kiesselbach (27) summarised work on winter and spring wheats and oats. Plants from small seed yielded 18% less than plants from large seed at low seeding rate; 10% less when equal numbers of seeds were planted at an optimum rate for large seed, and 5% less when equal weights were used at optimum rate for large seed. When large seed was compared to unselected seed on an equal-weight and equal-number basis, the yield advantage was only 4% and 1%, respectively. He concluded that there was no practical advantage to grading seed into different categories. Turner and Ferguson (46) did not find significant differences for final yield in cotton, but in each of four cultivars mean yields were highest with high density seed. Maranville and Clegg (35) separated sorghum seed by size and density. They stated that grain yield was not a function of seed size or density when the same number of viable seeds was planted in the field. Lack of improved final yield from 'high' quality seed has been reported in maize (19), pearl millet (31,36), rapeseed [<u>Brassica napus</u> (Koch.)] (29,34), soybean

(21,22,24,44), and winter wheat (11).

Effects of establishment and seedling vigor on grain yield.

Work on stand establishment has been done by planting either equal number of seeds or equal weights. Differences in establishment from plots planted to seeds of equal weights but different seed size and /or density can be a result of differences in number of seeds planted. However, when an equal number of seed is planted, differences in seedling establishment are due to differences in seed quality (seed vigor).

Geiszler and Hoag (18) demonstrated that when equal weights and equal number of seeds were planted in the field, the differences between large, high density seed and small, high density seed were 20 and 94 kg/ha, respectively (not significantly different in either case). They suggested that more plants which resulted from seeding the same volume of small seed compensated for the greater vigor of the fewer seedlings produced by the large seed. Okonkwo and Vanderlip (37) reported increased yields with increased establishment but effects of plant density (from establishment differences) were not removed since no thinning was done. However, Maranville and Clegg (35), and Turner and Ferguson (46) stated that improved establishment in sorghum and cotton, respectively, did not improve grain yield when equal number of seeds were planted in the field.

Establishment determines plant stands which in turn influences grain yield. Millet plant populations may be as low as 10,000 plants per hectare in the African Sahel Region and may be as high as 175,000 plants per hectare in the Indian semi-arid tropical regions (39). Carberry et al. (10) investigated the response of pearl millet to increased plant populations using a Nelder fan design. Grain yield per hectare increased to a maximum at 150,000 plants per hectare which was maintained through 400,000 plants per hectare due to the large degree of plasticity in number of productive tillers. Tillers contributed 25% and 77% of the grain yield at 400,000 and 50,000 plants per hectare, respectively. Egharevba (14), working with pearl millet, reported 20% contribution by tillers to total grain yield when 3 to 5 tillers per plant were maintained at 50,000 to 80,000 plants per hectare.

Seedling vigor differences have been measured by visual scores and/or dry matter weights during early seedling growth. Apparent seedling vigor is related to speed of emergence in that earlier emerged seedlings would have the advantage over the later emerged ones, because the larger shoots would have increased photosynthetic activity and more developed root systems to absorb nutrients and water. Larger and more vigorous seedlings can compete with weeds successfully and escape from diseases and/or insect damage (13). However, Hawkins and Cooper (19) found that seedling vigor differences become smaller as plants progress to maturity. Wood et al. (48) hypothesised that superior seedling vigor would be advantageous if it persists through anthesis to affect seed number per plant as a yield component. Mahalakshmi and Bidinger (33) studied millet under irrigated and non-irrigated conditions. Loss of grain yield due to removal of main shoot at panicle initiation stage under both situations was fully compensated for by tiller grain yield. However, the compensation was only partial when the main shoot was removed at flowering. They suggested that tillers offer potential for compensation for yield losses due to pre-flowering water stress damage of the main shoot.

It seems that differences in stand establishment and/or seedling vigor cannot fully explain differences in final grain yield. Environmental factors such as adverse soil conditions (soil crusting or water stress), weed competition, diseases, and pests (which could selectively affect plants of different sizes during the early seedling growth) when present, would then affect the performance of the crop.

Within a seedlot, using only the large seeds usually results in increased stand establishment, vigorous seedlings, and occasionally superior grain yields. As discussed by Paulsen (38), protein content seems to influence seedling vigor since nitrogenous compounds limit metabolism during germination and early seedling growth in low protein species such as wheat. Increasing size or density probably lessens these limitations (38). However, these reserves and early seedling photosynthesis may not persist to increase the final grain yields except where the growing season is short and/or a stressful environment exists (37, 48). Wood et al. (48) suggested that increases in yield are most likely to be realised where specific yield components are determined during early growth stages of the crop. In pearl millet, tillering would be one of the possible yield components to be influenced early in the season. Thus, work on investigating the response of pearl millet crop grown from improved seed under low and high plant populations seems a logical step towards improving millet production under adverse growing conditions in major producing areas.

MATERIALS AND METHODS

Seed source.

Senegal Bulk seed used in this study was originally from the Fort Hays Branch Experiment Station. The following management practices were applied to produce the seed of improved size and/or density:

Control: no special management practices were applied.

Head selection: heads with relatively large seed were selected visually at harvest time. Seeds were bulked irrespective of where the head came from.

Spikelet removal: one third of the spikelets were removed from top to bottom of the panicle at anthesis.

Head cut: one third of the panicle was removed at anthesis.

Table 1 shows seed weights of seed produced at Manhattan in 1985.

Table 1: Effects of management treatments on seed weight of seed produced in 1985.

Management	Seed weight
	--- g/1000 ---
Control	8.47 b*
Spikelet removal	9.43 a
Head selection	9.40 a
Head cut	9.20 a

* Means followed by the same letter do not differ significantly, $p < 0.05$.

Seed size separation.

Three seed sizes were obtained by sieving the control seed using 2.6 mm and 2.2 mm sieves. Large seeds were those that remained on 2.6 mm sieve and medium seeds went through 2.6 mm sieve but stayed on 2.2 mm sieve; small seeds were those that passed through both 2.6 mm and 2.2 mm sieves. Sieves were chosen to give approximately 1:1:1 ratio of seed amount for three size classes for control seed.

Seed density separation.

Sucrose solution (sucrose sugar dissolved in water in the ratio of 57% : 43% by weight, 1.265 g/cc) was used to separate seeds within each seed size class into low and high density fractions. Small amounts of seed were put into a funnel containing a liter of sucrose solution, stirred and seed allowed to sink or float. After separation, both light and dense seeds were rinsed in tap water and air-dried. To counter any effects of soaking seed in sucrose solution, a separate seedlot from control treatment, was soaked in sucrose solution, rinsed, and air-dried. The soaked seed was designated as wet control. Separated seed was kept and used in both seasons.

Treatments (seedlots).

4 management treatments (practices).

6 seed size and density combinations.

1 wet control.

Seed size and density separations for management practices.

To better understand the importance of seed size and density within a single seedlot, 100-gram seed samples, one from control treatment, spikelet removal, head cut, and head selection were separated into the three seed sizes and two densities described earlier. Results are presented in Appendix Table 1.

Germination tests.

All seedlots were tested for germination in both 1986 and 1987 before planting. Twenty-five seeds from each treatment were placed on two layers of filter paper in petri dishes. Filter papers were soaked with 0.26% sodium hypochlorite (chlorox) solution to control microbial infection in germinating seeds. Four replications were used and the petri dishes were left in the germinator for 4-5 days at 30 C. Seeds were considered germinated when both the radicle and the plumule appeared.

Field studies.

Seedlots were evaluated in the field at the Sandyland Experimental Field, St. John and at Manhattan in 1986 and 1987. The same field plot was used at Manhattan in both 1986 and 1987 and was a Eudora silt loam (coarse-silty, mixed mesic Fluventic Hapludoll). However, different fields were used at St. John and soil types were Naron fine sandy loam and Naron loamy fine sand (fine-loamy, mixed, thermic Udic Argiustolls) for 1986 and 1987, respectively.

Data on rainfall and mean temperature are summarised in Tables 2 and 3. Rainfall at St. John was above average in 1986 but below average in 1987. Manhattan received normal rainfall in 1986 and below average in 1987. Fields at St. John had adequate moisture at planting in both seasons while fields at Manhattan had insufficient soil moisture which necessitated replanting in both seasons. Both locations had normal mean temperatures in both years.

Table 2: Rainfall and mean temperature at St. John during 1986 and 1987 growing seasons.

Month	Rainfall			Mean temperature		
	1986	1987	Ave.*	1986	1987	Ave.
	mm			C		
June	176	130	91	25.0	25.1	24.3
July	63	18	74	27.9	26.6	27.1
August	139	63	59	25.2	25.0	26.1
September	103	31	70	21.9	20.7	21.2

* 30-year average.

Table 3: Rainfall and mean temperature at Manhattan during 1986 and 1987 growing seasons.

Month	Rainfall			Mean temperature		
	mm			C		
	1986	1987	Ave.*	1986	1987	Ave.
June	197	62	134	24.7	24.9	23.8
July	85	31	101	26.9	27.5	26.6
August	127	100	79	22.7	25.0	26.1
September	166	30	103	22.0	20.5	20.7

* 30-year average.

Low plant population (4,400 plants/ha) and high plant population (44,000 plants/ha) were used to give chance to seedlots with high vigor to express themselves. A split plot design was used with plant populations as main plots and seedlots as subplots. The experiment was replicated four times. Four rows, 0.75 m apart, were planted for all subplots but row lengths were 10.5 m and 7.5 m for low and high plant populations, respectively. Desired plant populations were obtained by thinning three weeks after planting. At St. John, planting was done on 11 and 8 June in 1986 and 1987, respectively. Replantings at Manhattan were done on 17 and 23 June in 1986 and 1987, respectively (poor emergence resulting from inadequate soil moisture at planting necessitated replanting). In 1986, seeding rate was 27 seeds/m for both St. John and Manhattan. However, seeding rates in 1987 were 33 and 40 seeds/m at Manhattan and St. John, respectively. Furadan (2,3-dihydro-2, 2-dimethyl-7-benzofuranyl methyl-carbamate) was applied at the rate of 1.12 kg a.i./ha in 1986 at St. John and in both seasons at Manhattan. Furadan controls chinchbugs (<u>Blissus leucopterus</u>) and greenbugs [<u>Schizaphis graminum</u> (Rondani)].

Propazine [6-chloro-N,N'-bis(methylethyl)-1,3,5-triazine-2, 4 diamine] was applied at Manhattan in 1986 and 1987 at the rate of 2.24 kg a.i./ha at planting. Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile), a postemergence herbicide, was applied at 1.12 kg a.i./ha at St. John in 1987 two weeks after planting to control broadleaf weeds. Both locations were cultivated and then hand-hoed. At St. John in 1987, hoeing was repeated because of heavy crabgrass (Digitaria spp.) infestation.

Three weeks after planting, establishment counts were taken on 4.5 m of the middle two rows of all plots. Seedling dry matter samples were taken from single row portions, 1.5 m in length, in plots where low plant population was to be superimposed. To superimpose low plant population, alternate rows in each plot were destroyed, leaving 2 rows 1.5 m apart. Plants were then thinned to 1 plant every 1.5 m row length. In high plant population, plants were thinned to 1 plant for every 0.3 m. in 0.75 m rows. Seedling dry matter samples were dried at 65 C for 72 hours before weighing.

To estimate yield and yield components, pearl millet heads were harvested from 4.5 m of the middle 2 rows in the high plant population plots (except at Manhattan in 1987) and 7.5 m of both rows of low plant population (10 plants harvested). Poor establishment at Manhattan necessitated harvesting 1 row, 4.5 m long and yields were adjusted by calculating the grain weight per plant and then multiplying the result by the total no. of plants on harvested and adjacent (but not harvested) rows. Head counts were recorded, heads dried, threshed, and grain weights taken. Grain yields were adjusted to 12.5 % moisture using the moisture content at threshing. To get thousand-kernal weight, 500-seed samples were counted from each plot, dried at 65 C for 48 hours and then weighed. Average seeds per head were calculated as a function of head number, total plot weights, and 1000 seed weight.

RESULTS AND DISCUSSION

Germination.

Analyses of variance are presented in Appendix Table 2. There was no year*seedlot interaction. Germination of control seed was not statistically different from seed produced after spikelet removal, headcut or head selection. However, high density fractions from small and large size classes had significantly lower germination than control seed in 1986. High density fractions from large and medium seed classes were significantly lower than control seed in 1987 (Table 4). All seedlots had lower germination percentages in 1987 than in 1986, possibly as a result of seed deterioration in storage.

Lower germination from high density seed could be attributed to restricted water intake which could delay germination and gives fungus a chance to attack. No reference in the literature was found regarding pearl millet; however, Krieg and Bartee (30) noted that seedcoats of high density cotton seed were more intact and somewhat harder than those of low density seed. They reported a slower rate of radicle elongation for the highest density seed of cotton during the first 2 to 3 days of germination, which was related to a decreased rate of imbibition during the first 8 hours of contact with water.

Table 4: Germination tests, 1986 and 1987.[1]

Seedlot	1986	1987
	----------- %	------------
Control	61.0 a[2]	50.0 a
Small light	52.0 ab	46.0 a
Small dense	37.0 b	36.0 ab
Medium light	53.0 ab	43.0 ab
Medium dense	49.0 ab	27.0 b
Large light	60.0 a	41.0 ab
Large dense	44.0 b	28.0 b
Head sel.	61.0 a	43.0 ab
Sp. Removal	70.0 a	56.0 a
Headcut	59.0 a	55.0 a
Wet Control	48.0 ab	49.0 a

[1]General Linear Model used. (LS means used to separate means).

[2]Means with the same letter do not differ significantly, $p < 0.05$.

Field studies.

Plant population * seedlot interactions observed for yield/head and seed weight (g/1000) at St. John and heads/plant and grain yield at Manhattan are presented in Appendix Tables 3 and 4. All interaction effects were examined within plant population so as to be consistent with the objectives of the study.

At St. John, only large-light seed and headcut seed showed small but significant differences in yield per head at low plant population but not at high plant population. Seed weights lacked meaningful trends when data were plotted (plots not presented) and were not examined further (Appendix Table 3). At Manhattan, no seedlot was better than control seed for either heads/plant or grain yield when compared within either low or high plant population (Appendix Table 4).

St. John field study.

Establishment and seedling vigor. Analyses of variance on establishment, seedling vigor, grain yield, and yield components are presented in Appendix Table 6.

Differences in establishment were observed in both 1986 and 1987 but no seedlot was better than the control (Table 5). However, among physically separated seed, small-light, large-light, and large-dense seed had significantly poorer establishment than control in 1986. In 1987, all physically separated seed but small-light, had poorer establishment than the control (Table 5). Seed separated into size and density fractions tended to perform equally to or more poorly than the original seedlot.

Small but significant reductions in establishment were found between control seed and seed produced by spikelet removal, headcut, and head selection (Table 5) despite higher seed weights from management produced seed (Table 1). Though no causes were identified for poor establishment with large seed, seed damage during threshing could be one possible cause. Establishment for the two seasons was similar even though there was evidence of seed deterioration as observed with germination (Table 4). Similar establishment might be attributed to using different planting machines in the two seasons or differences in soil moisture or other environmental factors at planting.

Seeds produced by spikelet removal, headcut, and head selection produced significantly larger seedlings three weeks after planting in 1986 than those from control seed. But this advantage was associated with poorer establishment (Table 5). Physically separated large seed also produced larger seedlings which could have been the result of more stored food in the seed, though effects of poor establishment cannot be ruled out. Positive correlation between seed weight and seedling vigor in wheat was reported by Evans and Bhatt (15) and Lopez and Grabe (32).

Table 5: Effects of seed size and density on establishment and seedling weights, St. John, 1986 and 1987.

Seedlot	Establishment 1986	Establishment 1987	Dry matter 1986	Dry matter 1987
	--------- % ---------		--- g/plant --	
Control	23.4 a*	25.2 a	3.7 de	1.5
Small light	18.9 bcd	24.8 a	3.5 e	0.8
Small dense	22.0 ab	15.8 cd	3.7 de	0.5
Medium light	21.2 abc	20.5 b	4.4 bcde	1.2
Medium dense	24.2 a	15.6 d	4.2 bcde	1.1
Large light	18.1 bcd	17.0 bcd	4.8 abc	1.5
Large dense	16.3 d	15.6 d	4.8 abc	1.7
Head sel.	17.3 cd	16.8 bcd	5.3 ab	1.2
Sp. Removal	17.6 cd	17.2 bcd	5.6 a	1.4
Headcut	17.9 bcd	18.5 bcd	5.2 ab	2.3
Wet Control	20.8 abc	19.9 bc	3.9 cd	1.3
LSD(0.05)	4.5	4.3	1.1	NS

* Means with the same letter do not differ significantly, $p < 0.05$.

Yield and yield components. No yield differences were found in 1986 although significant differences in yield/head, g/1000 seed, and seed no./head were found. These yield components did not have a substantial effect upon yield (Table 6). In 1987, differences in seed weight were observed (Table 7).

Differences in yield and yield components between the two seasons could be a direct result of weed competition during the first 4 weeks after planting and/or a possible water stress that occurred in July, 1987 (Table 2).

Table 6: Effects of seed size and density on yield and yield components, St. John, 1986.

Seedlot	Yield, Kg/ha	Yield, g/head.	Seed wt., g/1000	Seed/head.
Control	2022	20.5 b*	9.1 bc	2255 ab
Small light	2231	21.6 ab	8.8 bc	2247 ab
Small dense	1944	20.5 b	8.7 c	2322 ab
Medium light	1899	20.0 b	9.3 ab	2142 b
Medium dense	2162	19.8 b	8.7 c	2289 ab
Large light	2096	23.5 a	9.7 a	2416 ab
Large dense	2336	23.6 a	9.6 ab	2451 ab
Head sel.	2168	23.8 a	9.3 ab	2550 a
Sp. Removal	2125	21.5 ab	9.3 ab	2315 ab
Headcut	2125	22.4 ab	9.2 b	2412 ab
Wet Control	2022	21.1 ab	9.0 bc	2348 ab
LSD(0.05)	NS	2.9	0.5	330

* Means with the same letter do not differ significantly, $p < 0.05$.

Table 7: Effects of seed size and density on yield and yield components, St. John, 1987.

Seedlot	Yield, Kg/ha	Yield, g/head	Seed wt., g/1000	Seed/head
Control	1394	17.1	7.7 b*	2224
Small light	1511	16.6	7.8 b	2122
Small dense	1284	15.7	7.5 b	2088
Medium light	1261	16.2	7.6 b	2146
Medium dense	1372	15.6	7.7 b	2028
Large light	1526	17.8	8.2 ab	2158
Large dense	1354	17.2	8.2 ab	2093
Head sel.	1456	17.4	8.3 a	2093
Sp. Removal	1092	15.0	7.6 b	1969
Headcut	1436	16.5	7.7 b	2157
Wet Control	1247	15.1	7.9 ab	1923
LSD(0.05)	NS	NS	0.5	NS

* Means with the same letter do not differ significantly, $p < 0.05$.

<u>Plant population and yield.</u> The purpose of planting the seedlots at extremely low plant populations was to give more vigorous plants a chance to express their yield potential under conditions of unlimited soil moisture, nutrients, and light. However, the absence of useful interactions between plant population and seedlots indicate no seedlot was substantially more vigorous than others perhaps because of the high tillering capability of pearl millet under good growing condition.

Differences in heads/plant, heads/ha, and yields/ha were expected between plant populations since high plant population was 10 times that of the low plant population (Table 8). Tillering (heads/plant) greatly compensated for low plant population. Small but significant effects of plant population on yield/head, 1000 seed weight (1986), and seed no./head (1987) were observed (Table 8). Less competition for light, water, and nutrients could be the major factor accounting for greater tillering, higher yield/head, 1000 seed weight, and seed no./head in low plant population as opposed to high plant population.

Table 8: Effects of plant population on yield and yield components, St. John, 1986 and 1987.

Season	Component	Plant population	Results	LSD (0.05)
1986	Yield, kg/ha	4400	1839 b*	213
		44000	2367 a	
	Heads/plant	4400	16.9 a	0.7
		44000	2.9 b	
	Heads/ha	4400	75162 b	8388
		44000	127912 a	
	Yield, g/head	4400	24.7 a	3.4
		44000	18.6 b	
	Seed wt., g/1000	4400	9.5 a	0.2
		44000	8.8 b	
	Seed/head	4400	2590 a	329
		44000	2128 b	
1987	Yield, kg/ha	4400	971 b	522
		44000	1745 a	
	Heads/plant	4400	12.8 a	2.3
		44000	2.5 b	
	Heads/ha	4400	56869 b	27533
		44000	111751 a	
	Yield, g/head	4400	17.2 a	1.6
		44000	15.6 b	
	Seed wt., g/1000	4400	7.9	NS
		44000	7.8	
	Seed/head	4400	2184 a	160
		44000	1998 b	

* Means with same letter do not differ significantly, $p < 0.05$.

Manhattan field study.

Establishment and seedling vigor. Analyses of variance for establishment, seedling vigor, grain yield, and yield components are in Appendix Table 7.

Both seasons were characterised by inadequate moisture at planting, necessitating replanting. No differences in establishment were found in either season (Table 9). Lower establishment in 1987 could be partly due to soil crusting (23 mm of rain fell before seedlings emerged) and to seed deterioration (Table 4).

Small seeds produced less dry matter than control seed in seedlings three weeks after planting in 1986 (Table 9). However, these differences were too small to be of practical significance in overall crop performance. No differences in dry matter production were found among seedlots in 1987.

Table 9: Effects of seed size and density on establishment and seedling vigor, Manhattan, 1986 and 1987.

	Establishment		Dry matter	
Seedlot	1986	1987	1986	1987
	--------- % ---------		---- g/plant---	
Control	19.8	10.1	1.6 a*	2.2
Small light	22.4	8.0	0.7 c	2.5
Small dense	22.9	8.7	0.9 bc	2.9
Medium light	20.7	9.6	1.6 a	3.0
Medium dense	24.5	8.2	1.4 ab	2.9
Large light	19.3	8.4	1.6 a	3.3
Large dense	17.9	7.2	1.6 a	2.9
Head sel.	19.3	10.2	1.7 a	2.7
Sp. Removal	19.2	8.6	1.1 bc	3.6
Headcut	17.7	8.0	1.5 ab	2.3
Wet Control	20.5	11.4	1.0 bc	2.0
LSD(0.05)	NS	NS	0.5	NS

* Means with the same letter do not differ significantly, $p < 0.05$.

Yield and yield components. In 1986, plants from small dense seed produced significantly lower yields than those from the control seed due to lower yield/head. However, other physically separated seed and management produced seed did not produce statistically different yield or yield components (Table 10).

In 1987, grain yields were computed by multiplying grain weight per plant by total no. of plants on harvested and adjacent (not harvested) rows for all plots where single rows were harvested. No seedlot produced significantly better yield than control seed (Table 11), but small light and head selection seed had significantly lower yields than control seed. No differences were observed for heads/plant and yield/head at Manhattan in 1987 (Table 11).

Table 10: Effects of seed size and density on yield and yield components, Manhattan, 1986.

Seedlot	Yield, Kg/ha	Heads/ plant	Yield, g/head
Control	2148 abc*	10.3 abc	19.1 ab
Small light	2089 bcd	10.9 ab	17.7 bc
Small dense	1923 d	10.8 ab	16.0 c
Medium light	2188 abc	11.0 a	18.0 abc
Medium dense	2276 ab	10.3 abc	19.7 ab
Large light	2139 abc	9.4 c	19.7 ab
Large dense	2308 a	10.9 a	20.1 a
Head sel.	2058 cd	11.0 a	19.2 ab
Sp. Removal	2092 bcd	9.9 c	19.1 ab
Headcut	2090 bcd	10.3 abc	18.5 ab
Wet Control	2119 abcd	10.2 abc	19.4 ab
LSD(0.05)	214	1.0	2.1

* Means with the same letter do not differ significantly, $p < 0.05$.

Table 11: Effects of seed size and density on yield and yield components, Manhattan, 1987.

Seedlot	Yield, Kg/ha	Heads/plant[+]	Yield, g/head
Control	2769 abc*	17.0	23.4
Small light	2381 de	16.1	25.7
Small dense	2669 bcde	15.8	25.7
Medium light	2615 bcde	15.9	26.9
Medium dense	2558 cde	16.0	28.6
Large light	2956 ab	17.5	23.9
Large dense	3044 a	15.4	27.6
Head sel.	2332 e	15.6	24.3
Sp. Removal	2956 ab	17.1	27.8
Headcut	2716 abcd	15.8	26.9
Wet Control	2676 bcde	16.6	24.7
LSD(0.05)	356	NS	NS

* Means with the same letter do not differ significantly, $p < 0.05$

[+] Based on low plant population.

<u>Plant population and grain yield.</u> At low plant population, heads/plant contributed substantially to grain yields in both seasons (Table 12). However, other yield components were not responsive to plant population. Lack of response of yield components may reflect absence of or little competition for water and nutrients during the growing season.

Table 12: Effects of plant population on yield and yield components, Manhattan, 1986 and 1987.

Season	Component	Plant population	Results	LSD (0.05)
1986	Yield, kg/ha	4400	1442 b*	594
		44000	2818 a	
	Heads/plant	4400	17.5 a	3.8
		44000	3.4 b	
	Heads/ha	4400	77849 b	32427
		44000	150438 a	
	Yield, g/head	4400	18.9	NS
		44000	18.7	
	Seed wt., g/1000	4400	8.8	NS
		44000	8.8	
	Seed/head	4400	2184	NS
		44000	2140	
1987	Yield, kg/ha	4400	1800 b	454
		44000	3595 a	
	Heads/ha	4400	72256 b	11599
		44000	168799 a	
	Yield, g/head	4400	25.2	NS
		44000	26.7	
	Seed wt., g/1000	4400	7.7	NS
		44000	7.8	
	Seed/head	4400	3252	NS
		44000	3424	

* Means with same letter do not differ significantly, $p < 0.05$.

SUMMARY AND CONCLUSIONS

Neither seed produced by three management procedures nor physical separation of seed by size and density improved establishment. Lower establishment was found with management produced seed and some physically separated seed at St. John in both 1986 and 1987. Differences were small and not considered of practical significance. Though no causes for poor establishment with large seed were identified, damage of large seed through threshing might have affected germination in the field.

Seedlings produced from large seeds had significantly more dry matter three weeks after planting in 1986 than those from control seed but not in 1987 at St. John. However, these differences were not translated into higher yields. In this case, mature plants, originating as smaller seedlings produced as much grain as those originating as larger seedlings.

In both seasons, it was difficult to demonstrate that improved seed size or density directly affected grain yield in the field. Difficulties arise because as plants grow, effects of seed size or density diminish while those of environmental factors increase. Hawkins and Cooper (19) stated that early differences in plant size in maize became progressively smaller as plants grew to maturity. This means that substantial differences in seed size or density might influence establishment or seedling vigor but not subsequent grain yield.

Presently, there is limited understanding of processes that influence performance of seeds differing in size or density or differences resulting from the environment where seed was produced. More work is needed in identifying morphological as well as physiological barriers to getting better establishment and seedling vigor using seed produced in different environments (soil fertility, rainfall, and temperature). Little progress may be expected in improving establishment and seedling vigor through separation of seeds by size and/or density in a single seedlot. Work with diverse genetic materials of known response to environment (poor or good establishment) may provide a basis for understanding seedling establishment and vigor.

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Appendix Table 1: Proportions (per cent) of seed separated by sieving and sucrose flotation.[1]

Seed size[3]	Management							
	Control		Sp. removal		Head selec.		Head cut	
	Density[2]		Density		Density		Density	
	Low	High	Low	High	Low	High	Low	High
Large	24.7	10.8	49.4	15.7	40.4	20.6	38.5	20.6
Medium	18.1	8.8	16.1	4.9	14.5	8.5	11.6	9.1
Small	23.4	14.2	10.8	3.6	11.2	4.8	12.8	7.4

[1]These proportions were tested by Chi-Square and all management practices differed significantly from control.

[2]Low, < 1.265 g/cc; high, > 1.265 g/cc.

[3]Large, > 2.6 mm; Medium, 2.2-2.6 mm; Small, < 2.2 mm

Appendix Table 2: Analyses of variance, germination percent, 1986 and 1987.

Source	df	Mean squares
Rep	3	94.4
Year	1	2590.9 **
Trt	10	590.8 **
Year*Trt	10	117.2
Error	62	107.9

**, Significant at $p < 0.01$

Appendix Table 3: Interaction effects between plant population and seedlots, St. John, 1986 and 1987.

Seedlots	Yield, 1986		Seed wt., 1987	
	Population		Population	
	4400	44000	4400	44000
	----- g/head-----		----- g/1000 -----	
Control	21.4	19.6	7.5	8.0
Small light	26.2	17.1	7.5	8.2
Small dense	24.7	16.2	7.4	7.7
Medium light	21.2	18.7	7.8	7.4
Medium dense	21.4	18.3	7.9	7.5
Large light	27.4	19.6	8.4	8.0
Large dense	26.1	21.1	8.1	8.4
Head sel.	26.3	21.2	8.8	7.9
Sp. Removal	23.6	19.4	7.8	7.5
Headcut	27.4	17.4	8.0	7.5
Wet Control	25.6	16.7	7.8	8.0
LSD 0.05 (within pop.)	5.9	5.9	1.0	1.0

Appendix Table 4: Interaction effects between plant population and seedlots, Manhattan, 1986 and 1987.

Seedlots	Heads/plant, 1986		Yield, 1987	
	Population		Population	
	4400	44000	4400	44000
			kg/ha	
Control	17.2	3.3	1725	3812
Small light	18.2	3.6	1794	2967
Small dense	17.8	3.8	1671	3668
Medium light	18.3	3.8	1810	3419
Medium dense	17.3	3.2	1775	3342
Large light	15.6	3.3	1858	4054
Large dense	18.7	3.2	1881	4206
Head sel.	19.0	2.9	1711	2953
Sp. Removal	16.4	3.4	2100	3811
Headcut	17.2	3.3	1842	3589
Wet Control	17.2	3.2	1631	3722
LSD 0.05 (within pop.)	2.1	2.1	503	503

Appendix Table 5: Analyses of variance (mean squares), St. John, 1986 and 1987.

Source	Df	Establishment, %[1]	Dry matter/ plant, g[2]	Heads/ plant	Heads/ ha, thousands	Yield, kg/ha '000	Seed, g/1000	Yield, g/head	Seeds/ head '000
1986									
Rep	3	43.7*	5.7**	1.9	297.5	83.5	0.4	47.0	521.0
Pop	1	---	---	4332.7**	61218.3**	6127.4**	12.9**	799.8**	4705.0*
E(a)	3	---	---	1.2	152.8	98.9	0.1	25.8	234.8
Trt	10	56.9**	2.2**	2.3	245.5	127.7	0.9**	17.1*	99.9
Pop*Trt	10	---	---	1.3	54.3	161.6	0.2	17.7*	206.2
E(b)	60	19.9	0.6	2.3	167.3	107.4	0.3	8.4	108.8
1987									
Rep	3	157.9**	1.7*	6.5	654.4*	292.7	1.5	12.6	18.5
Pop	1	---	---	2324.7**	66264.9**	13175.8*	0.2	57.3*	767.8*
E(a)	3	---	---	11.4	1646.7	590.8	0.3	5.4	55.3
Trt	10	96.8*	0.9	1.2	234.6	133.5	0.6**	7.1	62.2
Pop*Trt	10	---	---	1.0	198.5	119.5	0.5	9.4	177.5
E(b)	60	18.4	0.6	2.9	225.3	100.4	0.3	6.4	104.2

* = Significant at $p < 0.05$

** = Significant at $p < 0.01$

[1]Analysed as randomised complete block with df for rep = 7 and error = 70

[2]Analysed as randomised complete block with df for error = 30.

Appendix Table 6: Analyses of variance (mean squares), Manhattan, 1986 and 1987.

Source	Df	Establishment, %[1]	Dry matter/ plant, g[2]	Heads/ plant[3]	Heads/ ha, thousands.	Yield, kg/ha '000	Seed, g/1000	Yield, g/head	Seeds/ head '000
1986									
Rep	3	104.3**	6.7**	38.0**	3173.8**	1729.9**	0.2	16.4*	209.2*
Pop	1	---	---	4411.1**	115922.4**	41695.6**	1.3*	0.7	43.4
E(a)	3	---	---	31.6	2284.2	766.6	0.1	12.2	14.5
Trt	10	35.6	0.5	2.1*	267.2	87.7	0.4	11.1*	79.3
Pop*Trt	10	---	---	2.1*	289.4	44.8	0.1	4.2	47.0
E(b)	60	23.3	0.1	1.0	173.6	45.8	0.3	4.5	61.2
1987									
Rep	2	4.3	6.8**	43.2**	1631.5*	39.8	0.2	24.1	391.5
Pop	1	---	---	---	153790.2**	53143.7**	0.1	37.7*	480.6
E(a)	2	---	---	---	119.9	312.1	0.3	10.1	413.8
Trt	10	9.2	0.7	1.4	478.8	183.6*	0.1	18.1	226.1
Pop*Trt	10	---	---	---	439.5	216.4*	0.2	10.3	160.2
E(b)	40	5.9	0.7	3.8	451.5	92.8	0.2	9.2	155.0

* = Significant at $p < 0.05$

** = Significant at $p < 0.01$

[1]Analysed as randomised complete block with df for rep = 7 and error = 70 in 1986 and rep = 5 and error = 50 in 1987.

[2]Analysed as randomised complete block with df for rep = 3 and error = 30 in 1986 and rep = 2 and error = 20 in 1987.

[3]Analysed as randomised complete block in 1987 with df for rep = 2 and error = 20.

FIELD EVALUATION OF EFFECTS OF SEED SIZE AND DENSITY ON ESTABLISHMENT AND GRAIN YIELD IN PEARL MILLET.

by

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ABSTRACT

Low plant stands resulting from inadequate soil moisture at planting and poor seed quality are a common sight in major pearl millet [Pennisetum glaucum (L.) R. Br.] growing areas in Africa and Asia. Seed size and density have been associated with improved establishment and grain yield in some crops. Previous work on pearl millet at Kansas State University has shown inconsistent results. The objective of this study was to determine whether separating seed by size and density or improving seed size by management practices would improve establishment, seedling vigor, or grain yield of crops grown from such seed.

Effects of pearl millet seed size and density on stand establishment, seedling growth, and grain yield were evaluated in field studies at the Sandyland Experimental Field, St. John and Manhattan, Kansas in 1986 and 1987. A split plot design with four replicates was used. Plant populations were main plots and seedlots were subplots. All seed used was Senegal Bulk produced in 1985.

Control seed was separated by size (large, medium, or small) and then by density (low or high) within each seed size class. Head selection, head cut, and spikelet removal were the management practices used to produce large seed. At St. John in 1986, seedlings from seed produced

after head selection, head cut, spikelet removal or large, low density seed produced more dry matter per plant than those from control seed. However, these differences were associated with low establishment and were not reflected in the final grain yields. No seedlot was better than control seed in establishment, seedling vigor, or grain yield at St. John in 1987 or either year at Manhattan. Tillering (heads/plant) was the major yield component that compensated for low plant population in both seasons and locations. This implies that poor stands, as found in Africa and Asia, are not a major cause of low yields under favorable growing conditions. However, improved establishment and seedling vigor may be more important in the harsher growing conditions experienced in semi-arid regions of Africa and Asia than in the more favorable growing condition in Kansas.