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THE EFFECT OF SEED SIZE AND DENSITY ON FIELD EMERGENCE AND YIELD OF PEARL MILLET [*Pennisetum americanum* (L.) K. Schum.]

by

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INTRODUCTION

Pearl millet [*Pennisetum americanum*(L.)K. Schum.] 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. While its ability to overcome drought and other marginal environmental conditions during its growth cycle has been recognized, seedling establishment remains a major problem with the crop.

Inherent low vigor of the seedling and small seed size contribute to poor stands. Varieties and hybrids with improved seed and seedling vigor are being developed. Present varieties could be improved if selection could be made within a seedlot for the most vigorous seeds. To allow this selection, physical characteristics of the pearl millet seed which are related with vigor would have to be identified.

During 1978 and 1979 seedlots of five varieties and two inbreds of pearl millet were separated on the basis of seed size and seed density. Field performance of the seed fractions was based upon seedling establishment and grain yield.

LITERATURE REVIEW

Crop improvement through careful seed selection has long been of interest because of increased stand establishment, resulting in higher yields. Effort has gone into the study of many measurable seed characteristics which are hoped to result in a vigorous plant. Vigor as defined by Isely (15) is the sum total of all characteristics which favor stand establishment under unfavorable field conditions. The literature reviewed deals with the following characteristics and their relationship with vigor: seed size (1,2,3,7,8,9, 10,11,12,13,16,17,19,24,26,29,31,33,37), seed protein (13,21,22,31,30), seed weight (5,35,38), seed density (6,20,24,32,36), and seed embryo size (4,8,10, 27,34).

Seed Size

Seed size, the actual distance across the seed measured practically by sieves, has taken on great importance in todays mechanized agriculture. Replacing hand planting, the revolving plate or fluted feed cup of mechanical planters have lost the ability to accurately meter different sized seed, and since plant population and yield often are closely related, this accuracy is vital.

Kiesselbach's review of research in 1926 (17), however, noted other seed size influences. Plants from small seeds of winter wheat, spring wheat, and oats yielded only 81.4%, 82.1%, and 82.6% as much as those from the same number of large seeds within the same seedlot. Plants from small seeds were shorter, tillered less, and were slightly later in maturity. When put on a practical scale, planting a bushel of large seeds and a bushel of small seeds, the yield differences narrowed. The increased number of plants from the small seeds made up for what they lacked in individul productivity.

Seedlots of three barley varieties were separated into three sizes and planted at three seeding rates (12). The large seeds produced significantly more tillers and yielded the highest at all seeding rates. Emergence counts were similar among sizes. Boyd (9) found seed size to be positively related to seedling vigor in F_3 lines of barley.

In soybeans, Smith and Camper (33) screened large and small seeds from the same seedlot and compared them with the original seedlot. The large seeds resulted in taller plants, especially at early stages of growth, and tended to outyield both the small seeds and the original seedlot.

Sorghum seed size, as studied by Abdullahi and Vanderlip (2), was found to be a factor related to vigor. In laboratory stress tests large seeds produced higher germination percentages than the small seeds. When placed under field conditions, the largest seed dropped in emergence percentage.

Perhaps the greatest effect of seed size upon the vigor of plants is found in native range grasses. Buffalograss (*Buchloe dactyloides*), indiangrass (*Sorghastrum nutans*), sand bluestem (*Andropogon hallii*), sideoats grama (*Bouteloua curtipendula*), and switchgrass (*Panicaum virgatum*) all showing larger seeds resulting in quicker emergence and a faster rate of growth of the seedling (19). In switchgrass germination percentage of the large seed was 77.5% and the small seed 27.5%.

Physiologically, why do the larger seeds have more vigor? One hypothesis found in the literature is that the large seeds have more carbohydrate reserve for the nourishment of the young plant (16,17,19,33). With this added reserve, leaf area is larger in the first few leaves. In barley (16) the first two leaves produced by large seeds were both longer and wider than plants from small seeds regardless of temperature. The floret count from these same plants was found to be more closely related to the area of the first two leaves than to that of the flag leaf, implying that early leaf area was more important than flag leaf area in determining this yield component.

Somewhat conflicting, Nadrornik (29) found higher germination and vigor in ryegrass seedlings resulting from large seeds even when the endosperm was partially removed.

Seed Protein

Ries and Everson (31), studying wheat seedling vigor, found protein content to be positively related to seed size. Seedlots with higher protein contents resulted in more vigorous seedlings and often higher yields. Further studies (30) showed that by increasing protein with foliar nitrogen application at anthesis, they could improve seedling vigor. Similar studies have shown both high protein seeds and large seeds to be highly correlated with seedling dry weight at 20 days (21).

Lowe and Ries (22) hypothesize that the difference in endosperm protein content would provide different levels of respiratory substate and amino acids for new protein synthesis. Hydrolysis occuring during germination would result in nigher levels of amino acids in high protein seeds and could also induce increased enzyme activity. To further examine the protein factor, amino acids have been studied to determine if any particular constituent is more important than total protein content. Glutamic acid has been found to be positively related to seedling vigor (21), however, protein content still seems a better criterion for vigorous seed selection.

Use of the size-protein relationship as an aid in cultivar selection by plant breeders has been suggested by Evans and Bhatt (13). They found that if size is uniform, differences in seedling vigor are mostly genotypic. This could be used as a mass selection technique in heterogenous bulk populations.

Protein content, seed size, and vigor have been found to be related. Though plant breeders can determine and select for protein content, the ease and utility of size as a selection tool makes it more attractive. It also allows selection within a single seedlot which is more often needed both here and abroad.

Seed Weight

Seed weight is considered separately even though its relationship to vigor has been found to be the same as seed size and density. Considered by many to be synonymous with seed size, seed weight effects are confounded with both seed size and seed density which are more specific.

Bartel (7) suggests that early growth differences between corn, sorghum, and proso millet could be explained by initial seed weights. Seedling weights and seed weights were related logrithmically similarly among all the species.

Within a single sorghum genotype seed weights were compared by the use of the twin seeded character. Twin seeded kernels and single seeded kernels from the same head were found to have similar emergence rates and mature plant performance even though they varied in seed weight (35). Between sorghum genotypes Maiti (23) found that those having large initial seed weights utilized a lower proportion of hydrolized carbohydrates than small seed weights. Though the heavier seeds were less efficient than the light ones, they still utilized more total food reserve. He also noted that the largest seedlings at 15 and 20 days were all from heavy seeds, but, not all heavy seeds produced large seedlings. Other factors apparently were involved.

Seed Density

Specific gravity or density of seeds has been utilized in several crops. In cotton it was the characteristic best associated with seed quality (20). Density has the ability to distinguish fully filled, mature kernels from premature seeds as indicated by embryo:total seed weight ratios (6). Seeds high in density have more organic and inorganic material available to the seedling regardless of the size.

In soybeans there was a slight positive correlation between size and density (32). Density was more strongly related to protein content (positively) than to size.

In sorghum, size and density both seem to be factors related to the vigor of individual seeds (24). Though no yield differences are apparent if enough viable seeds are planted, selection by either parameter has been suggested to improve seedling vigor in questionable seedlots.

Vigor of rice seed in terms of emergence percent, rate of germination, and germination percent were all closely related to the seed density (36). In developing countries, where hand harvesting is predominant, density becomes critical as a seed quality characteristic. In parts of Taiwain and Japan, farmers separate their seed in ammonium sulfate solutions, use for seed those that sink to the bottom, then fertilize with the solution (36). Modern combines are fairly efficient at density separation thus low density seeds may be eliminated at harvest where they are used.

Seed Embryo Size

Ashby's (4) hypothesis of hybrid vigor in corn has long been a subject of controversy. He concluded that the increased embryo size in first generation hybrids was responsible for both increased seedling vigor and heterosis. Evidence that larger seeds have larger embryos which result in vigor for the plant (8,27) are as common as support that embryo size has little effect on growth, and that endosperm size is the factor lending vigor to the seed (10, 34).

A fully filled kernel will have a mature embryo capable of producing a vigorous plant. Premature frosts or drought occuring during grain filling result in poor seed quality because of an underdeveloped embryo (6). Thus the importance of embryo development to its full potential is a vigor factor which may be controlled with density or size selection (6,10,20,32).

Seed Characteristics and Pearl Millet

The knowledge of seed quality factors was applied to pearl millet. Stand establishment is a major problem in millet production, particularly under stress conditions.

In other species it has been found possible to have a high standard germination yet have seedlings which lack enough vigor for field establishment. (39). Mwageni (28), evaluating laboratory vigor tests which were to simulate field stress conditions, found a pregermination sodium hydroxide stress treatment best correlated with field emergence. A harsh stress treatment was necessary to lower germination in the laboratory to the levels found under field conditions.

Misra (25) compares the problem of seed size in pearl millet to that of alfalfa. The physical relationship between the seed and soil particles puts the small seed at a disadvantage. The small seed must be planted shallow to emerge. Millet growing regions however typically have sandy soils where shallow planting results in low moisture problems because of the rapid drying of sands. Millets grown in Africa primarily are landrace varieties, and as such are variable populations, having a variable capacity for seedling vigor. Hybrid pearl millets do offer heightened seedling vigor (18). When hybrids were compared with parental lines, however, increased vigor, as measured by dry matter produced, occurred only for ten days after germination. After that parents and hybrids advanced at nearly the same rate.

Use of seed size or density separations seems appropriate with pearl millet. Garg (14) found a positive relationship between the two characters over 41 varieties of pearl millet. Selection of large seed would improve seed:soil relations and may increase the average density of the seeds. High density seeds would be an effective selection criterion because of the hand harvesting and grain handling in millet growing areas. Immature seeds may also be eliminated through selection for high seed density.

Improvement of pearl millet's ability to establish vigorous seedlings is of concern both here and abroad. The study of pearl millet seed characteristics and their influences upon performance of the resultant crop would help achieve that goal.

MATERIALS AND METHODS

Seed sizes and denisities of pearl millet were studied under field conditions in 1978 at the Agronomy Farm, Manhattan and Sandyland Experiment Field, St. John Kansas, and in 1979, at the Ashland Research Farm south of Manhattan and Sandyland Experiment Field. The St. John site was chosen because it has lower rainfall and sandier soils than the Manhattan area.

In 1978 five varieties of pearl millet were included. Serere 3A, a tall Ugandian variety, and four random mating populations from the Fort Hays Branch Experiment Station breeding program, two tall populations, 306E and the world collection, two with the d_2 dwarfing gene RMP-1 and HMP 1700. In 1979, Serere 3A and RMP-1 used in 1978 along with two inbred lines #771240 and #772043 from Fort Hays were utilized to observe both wide and narrow based genetic material.

Seed size was determined by running a portion of each of the seedlots through a series of round hole sieves. The four size categories were: seeds retained on a 7/64", through a 7/64" but retained on a 6-1/2/64", through a 6-1/2/64" but retained on a 5-1/2/64", and through a 5-1/2/64".

Density separations were made by placing a portion of each original seedlot in a sucrose solution with a density that would result in dividing the seedlot approximately in half. In 1978, two and in 1979 three density fractions were made. In 1979 the technique was improved by holding the separating solution in a funnel which allowed removing the seeds from the bottom of the solution. Density of the solutions used are shown in Table 1.

Table 1. Densities of sucrose solutions used in seed separations.

Variety	1978 Solution density	1979 Solution densities 1	2
Serere 3A	1.298	1.241	1.275
RMP-1	1.286	1.241	1.275
306 E	1.286		
HMP 1700	1.286		
World Collection	1.286		
Inbred 771240 (A)		1.219	1.275
Inbred 772043 (B)		1.156	1.219

After the sucrose soak the seeds were washed in distilled water and allowed to air dry.

To eliminate possible effects of the density separation technique, an additional portion of each original seedlot was soaked in the sucrose solutions and allowed to come to equilibrium. These check seeds were then removed without regard to their density, washed and air dried.

Depletion of the source (leaf area) and sink (heads) was done to produce three seedlots in which the effect of seed size could be tested directly. Alteration of source and sink would alter photosynthate availability and result in altered seed size. In 1978 Serere 3A and inbred B were grown in isolation and at flowering plants were given one of the following treatments: 1) approximately half of the area of each leaf removed 2) approximately the top half of each head cut off 3) left as a control. Seeds from these plants were also planted within the 1979 study.

Protein (Kjeldahl-N determination x 6.25) was determined on each size, density, sucrose check, and original 1979 seedlot.

All the varieties had the sizes, densities, sucrose check, and original seedlot planted 50 seeds/row in two row plots, 76 cm between rows and 4.6 m long, with a vacuum planter. Experimental design was a randomized complete block with four replications and two planting dates per location. Results from each location were combined in the analysis of variance as a split plot with date of planting the main plot. Seed size and density effects were split out of treatment variation with single degree of freedom tests.

In 1978 the first planting at Manhattan was on 2 May, but, because of low temperatures and a heavy rainfall, was replanted on 30 May. The third date was planted on 13 June. Planting dates at St. John were 10 May and 31 May. In 1979 the Manhattan studies were planted on 16 May and 12 June, with those at St. John on 15 May and 6 June.

Emergence counts were made when the seedlings were between the 3 to 5 leaf stage. This was from 10 to 30 days after planting depending upon planting date. At harvest all mature heads were counted, harvested, and threshed. Yields are corrected to 12.5% moisture and are reported as kg/ha based on a 1.52 x 4.6 m plot area whether the plants filled that entire area or not.

In 1978 no herbicides were used and one cultivation was used for weed control. Chinchbugs were apparent in large numbers at Manhattan the entire season. Carbaryl was applied at 2.75kg/ha (2 lb. A.I./acre) twice. Dieldrin was applied to the second date also. In 1979 at Manhattan propazine was applied preemergence at 3.4kg/ha (3 lb. A.I./acre) after each planting as well as one cultivation for weed control. Carbofuran was placed in the furrow with the seed at 1.12kg/ha (1 lb. A.I./acre) at both locations for early season chinchbug control. Two additional applications of carbaryl were used later in the season at Manhattan. Fertilizers applied were based on soil tests to determine the nitrogen and phosphurous needed for common dryland sorghum production.

Analysis of the data utilized the Kansas State University Computing Center and its program GANOVA as well as statistical packages available from SPSS and SAS.

RESULTS AND DISCUSSION

Results from all plantings in both years are in tables 14 to 22.

Date and Variety

At Manhattan in 1978, the 2 May planting was too early for pearl millet. Seedlings were subjected to both low temperatures and a seven cm. rain. Emergence counts were taken but proved to be more a function of the plots drainage than variety or treatment, thus the data are not reported. The planting was destroyed and the land used for the 13 June planting. The 30 May planting had a moist seedbed and generally was more favorable than the 13 June date. Dates were a significant source of variation with the 30 May planting averaging twice the stands and grain yield of the 13 June date (Table 4). Date-variety interactions were significant for head and grain production (Table 4). Though emergence counts were similar between dates, the different environmental conditions of the two dates brought out differences in head number and yield among varieties. (Fig. 1).

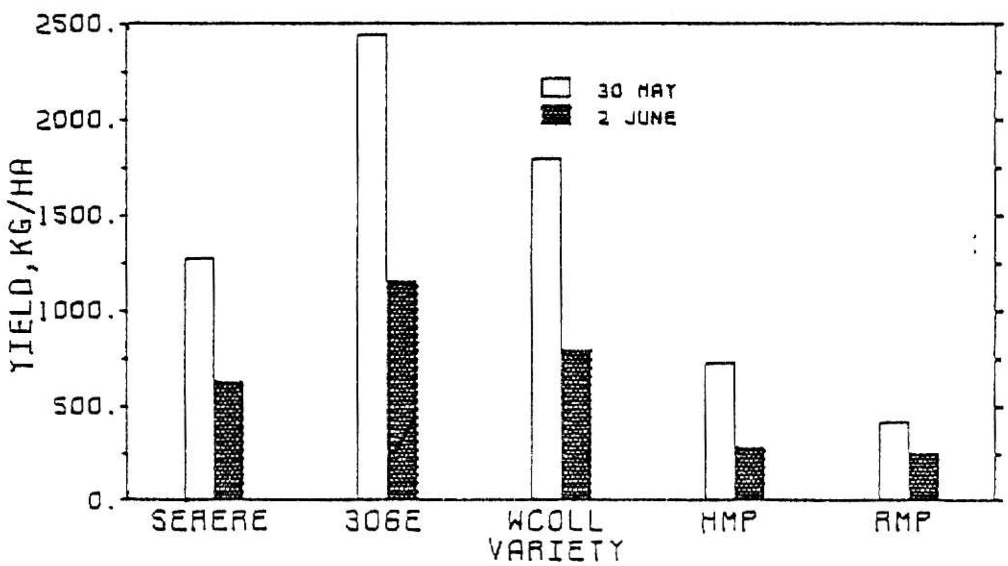

Figure 1. Grain yield at Manhattan in 1978 by variety and planting date.

Sandyland Experiment Field had a below normal rainfall in 1978. Dates were not a factor affecting emergence or grain yield but did significantly affect head production (Table 5). Variety performance was affected by planting date, however unlike Manhattan, the variety-date interaction was found significant for emergence and head production but not for yield. (Fig. 2 and 3). Tillering seemed to compensate for variability in stands and resulted in similar yields for the varieties between dates. Head number was sensitive to the differing environmental conditions of the two dates and illustrates adaptation differences among the varieties. (Fig. 3).

At Manhattan in 1979 the growing season was excellent in the area with well timed rainfall and a dry harvest. Date of planting did not affect emergence or head production, but did affect yield. (Table 6). Date-variety interactions were found significant for yield, again due mostly to the range of response differences among the varieties. (Fig. 4 and Table 6).

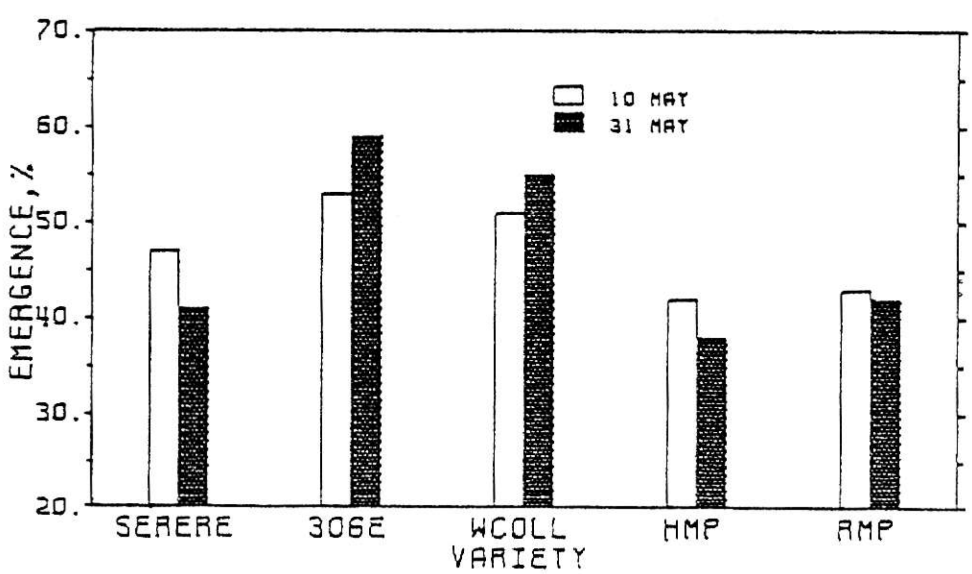

Figure 2. Emergence percentage at St. John in 1978 by variety and planting date.

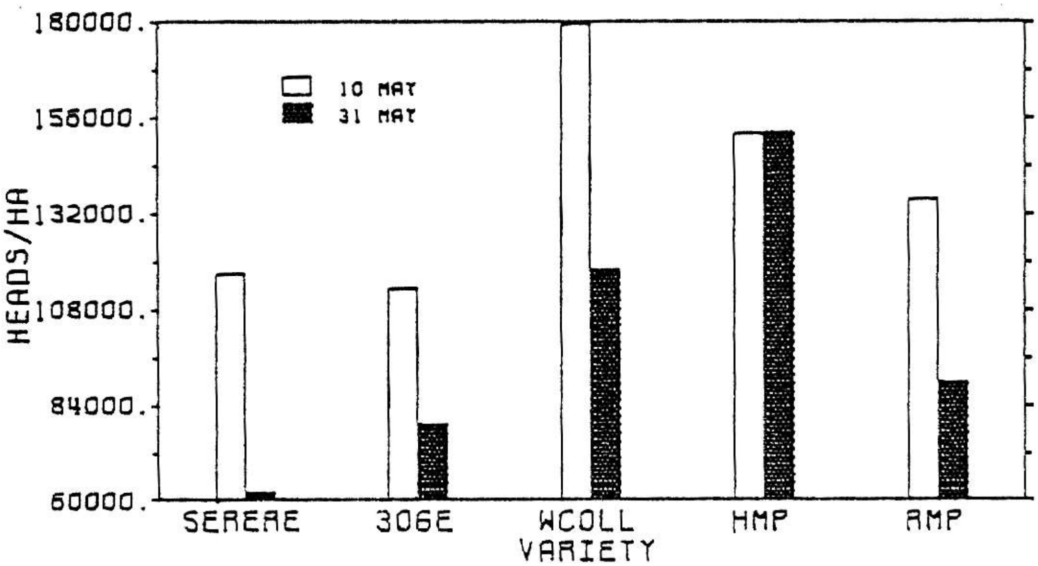

Figure 3. Head number per hectare at St. John in 1978 by variety and planting date.

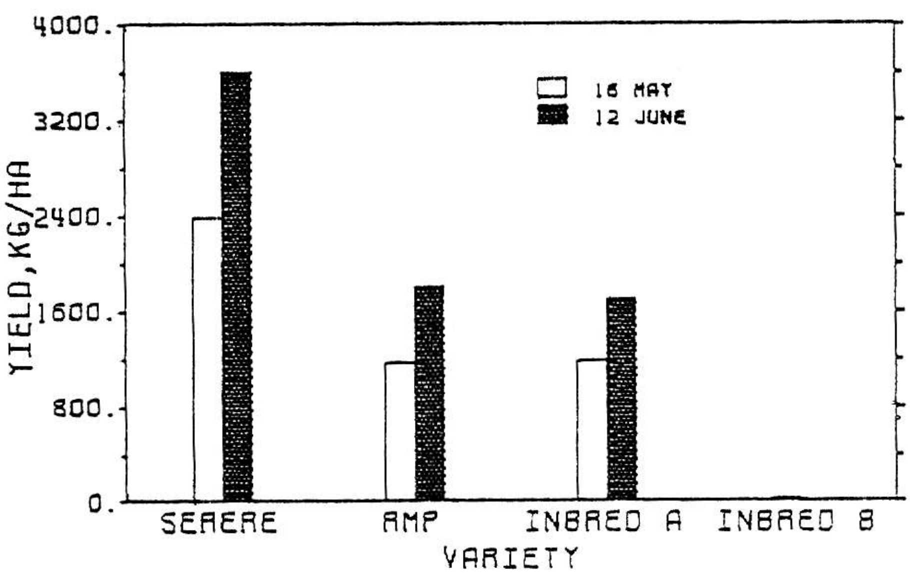

Figure 4. Grain yield at Manhattan in 1979 by variety and planting date.

Inbred B had very poor performance as compared to the other varieties (Fig. 4) and was dropped from the analysis of variance. Though the date-treatment interaction was significant for yield (Fig. 5 and Table 5), it is consistent with the final hypothesis that small and low density seeds were associated with poor field performance.

At St. John in 1979, date of planting could not be analyzed. Both dates were planted in good conditions, however, the second planting was on ground which had varied carryover both of fertilizer and herbicide. After emergence counts were taken on the second date it was decided these other factors would result in variation preventing a valid test for treatments. The first planting was carried on to harvest though it showed nitrogen stress.

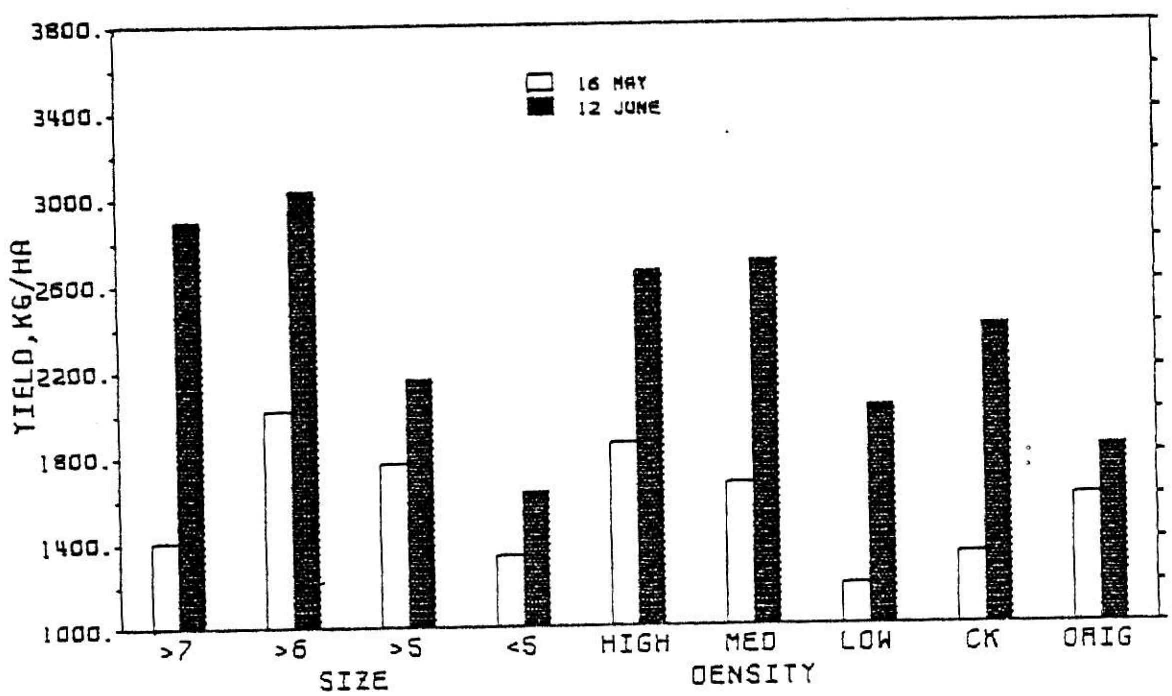

Figure 5. Grain yield at Manhattan in 1979 by treatment and planting date.

Seed Size

Size of the seed planted affected stand establishment, head production, and grain yield. The smallest seed size was lowest in vigor. The relationship between seed size and quality does not seem to be linear, however, because the largest seeds also often were associated with a drop in performance.

In 1978 at both locations and dates the larger two seed sizes resulted in the highest emergence percentages. Emergence was higher at St. John across all sizes most likely because the sandy soils offered less resistance to the emerging seedling. At both locations significant variety by treatment interactions were found (Fig. 6 and 7, Tables 4 and 5). Although not totally a result of seed size, differences among varieties were apparent. The smallest seed consistently had the lower percentages, while the larger sizes would switch in order of performance among varieties, often with the largest size showing lower emergence than the intermediate sizes.

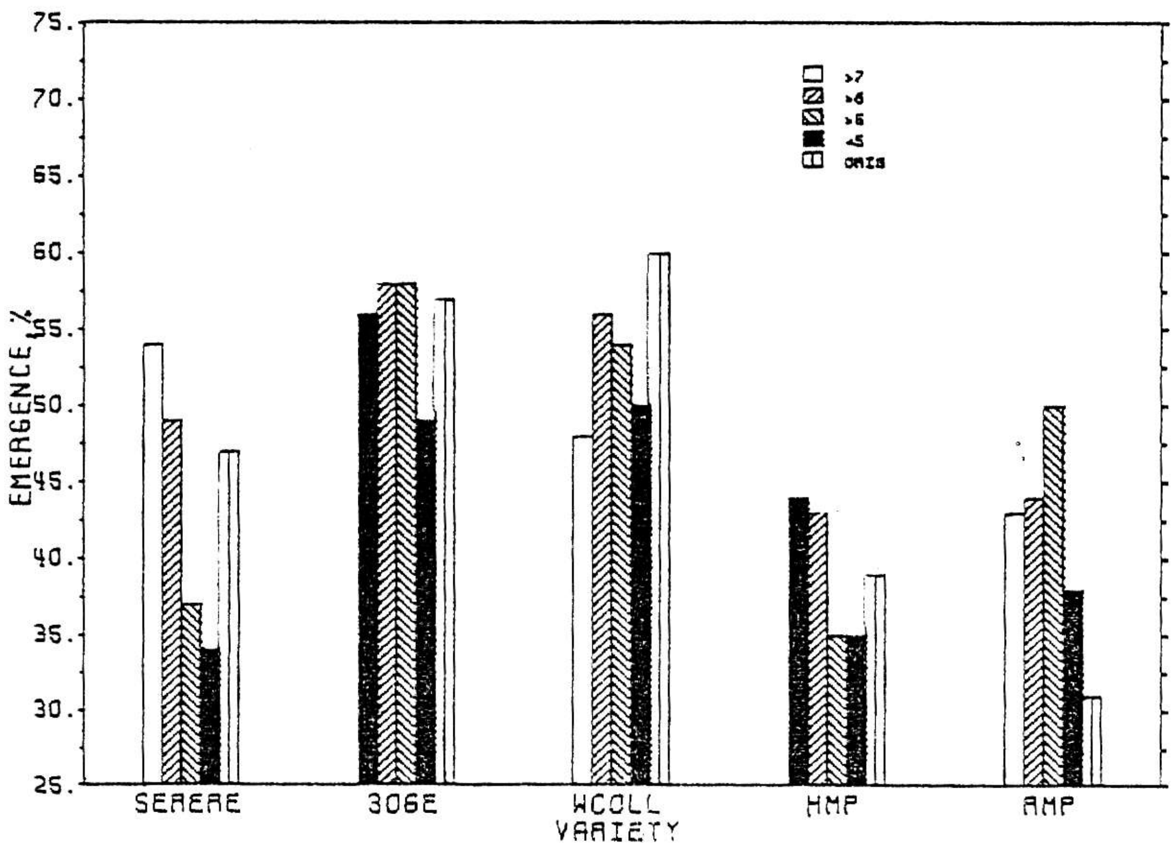

Figure 6. Emergence percentage at St. John in 1978 for the size treatments, by variety.

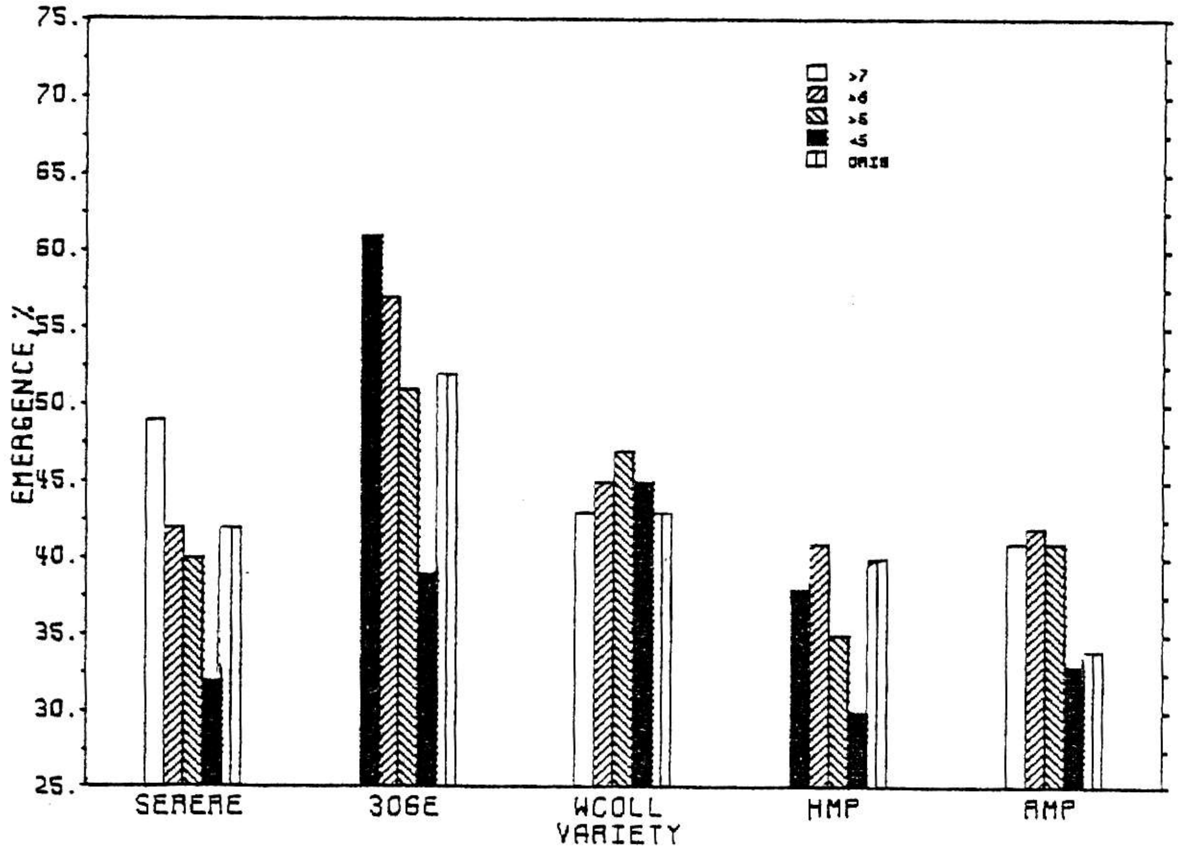

Figure 7. Emergence percentage at Manhattan in 1978 for the size treatments. by variety.

In 1979 the smallest seed size again resulted in the poorest stands. Variety-treatment interactions were significant at both locations for emergence (Fig. 8 and 9, Tables 6 and 7). Emergence data for all the varieties show the tendency for the largest seed to emerge poorly.

Though the variety_treatment interaction did exist, linear and quadratic models of response describing the effect of size upon emergence were tested. In 1978 both linear and quadratic effects were significant at both locations, but the linear effect accounted for more variation (Tables 4 and 5). In 1979 at St. John with all varieties included and both dates used in the analysis, the results are similar to the 1978 data (Table 7). With Inbred B removed from the data the linear and quadratic effects account for nearly the same amount of variation (Table 7). At Manhattan in 1979 with Inbred B removed, the linear effect was not significant while the quadratic effect was (Table 6).

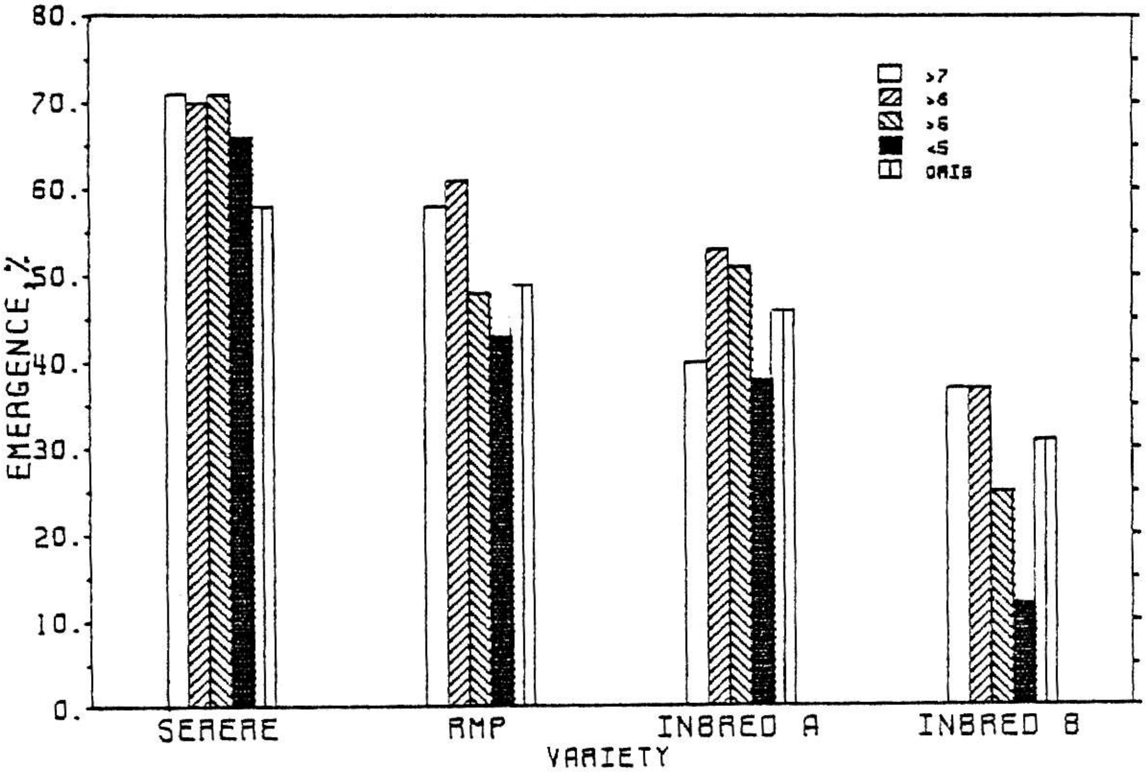

Figure 8. Emergence percentage at St. John in 1979 for the size treatments by variety.

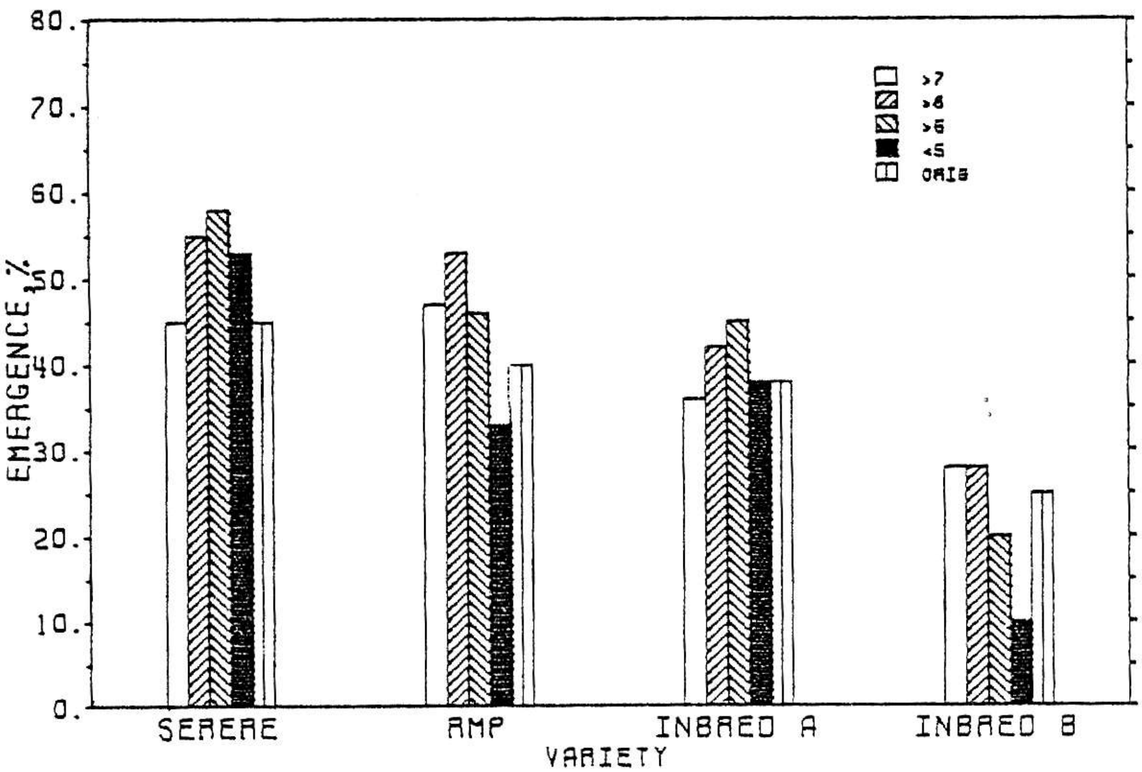

Figure 9. Emergence percentage at Manhattan in 1979 for the size treatments by variety.

The ability of seed size to be related to seedling vigor is affected by the seedlot which has been sieved. Serere 3A and RMP had the two largest size categories produce the most seedlings. The largest seed of Inbred A performed almost as poorly as the smallest seed. Inbred B, the seedlot lowest in vigor, had size directly related to emergence performance. Even with the significant interaction the smallest seeds were lowest in vigor.

Head production reflects both the influence of the number of plants established and the tillering ability of the plants. Treatments influencing head number were similarly between dates. Head number was affected by a variety_treatment interaction only at Manhattan in both years (Fig. 10 and 11, Tables 4 and 6).

In 1978 for all but one case, the smallest seeds averaged the lowest heads/ha at harvest. Though seed size influences stand establishment, it still

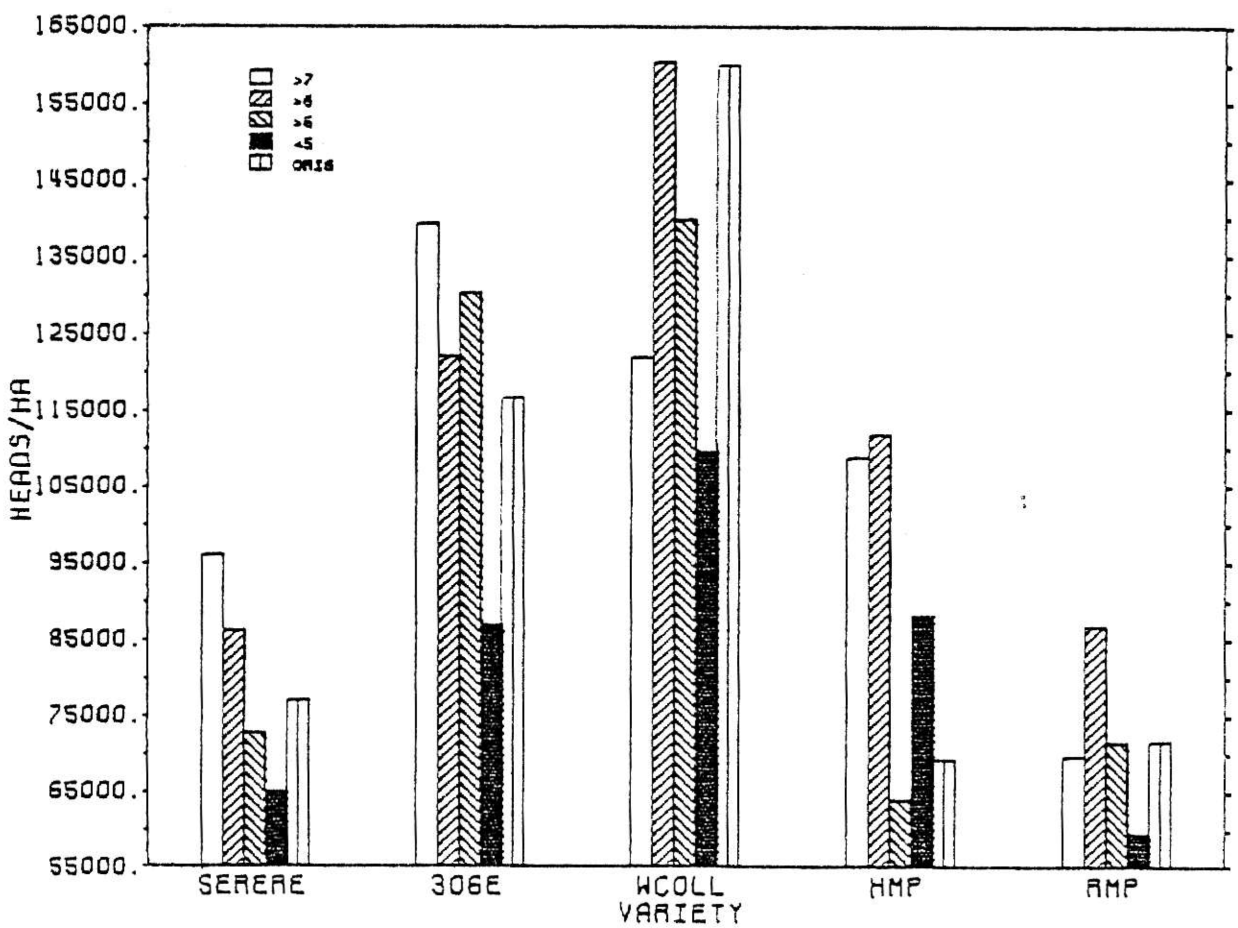

Figure 10. Head number per hectare at Manhattan in 1978 for the size treatments by variety.

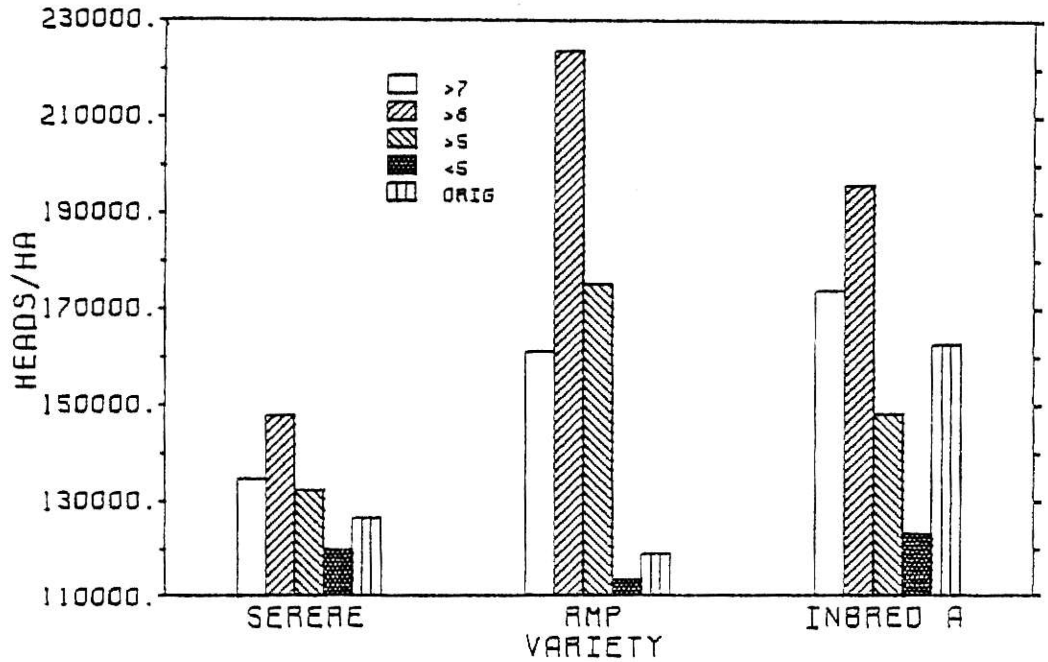

Figure 11. Head number per hectare at Manhattan in 1979 for the size treatments by variety.

seems to be a determining factor affecting the plant to maturity.

Grain yield was significantly affected by seed size (Tables 5 and 7). At St. John in both years there was a positive relationship between size and grain yield as shown by significant linear size effects (Fig. 12). At Manhattan in 1978 a significant variety-treatment effect was found (Fig. 13, Table 4). In 1979 a significant date-treatment effect was also found (Fig. 14, Table 6). The Manhattan location in both years was infested with chinchbugs. Visually, varietal preferences by the insects were apparent in the field for the dwarf millets (RMP, HMP1700 A and B). Stress upon the plants at Manhattan from the seedling stage on was more biological than at St. John because of the chinchbugs and by its very nature capable of being variety or perhaps even treatment selective.

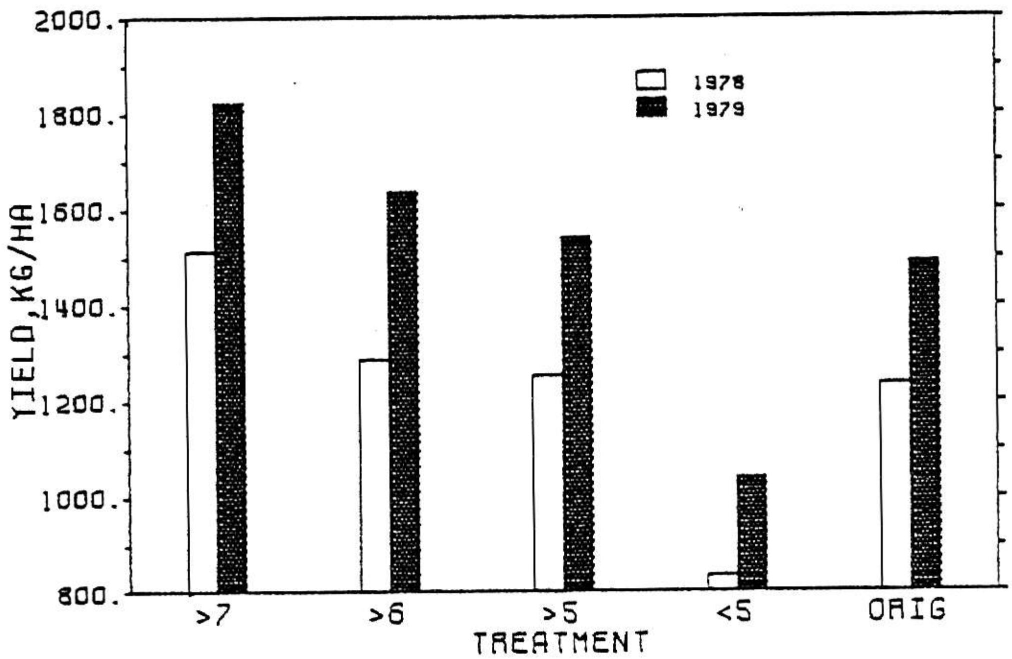

Figure 12. Grain yield at St. John for the size treatments averaged over all varieties in 1978 and 1979.

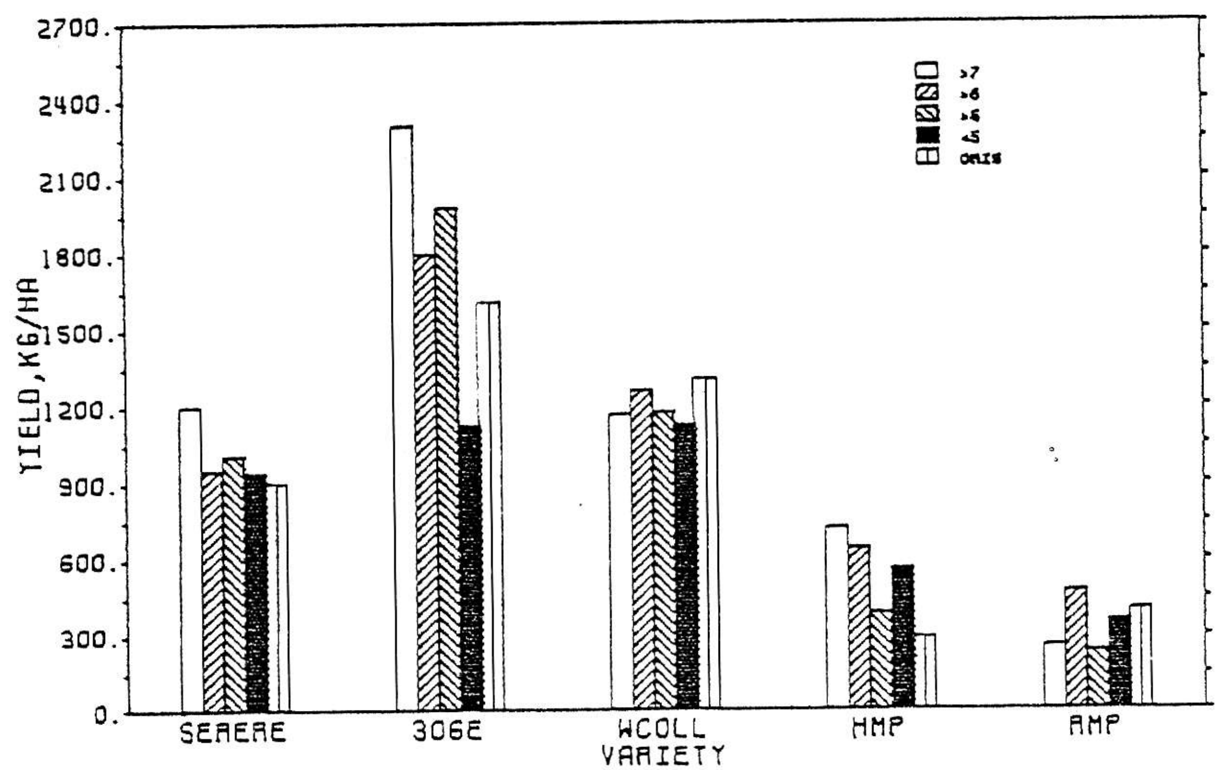

Figure 13. Grain yield at Manhattan in 1978 for the size treatments by variety.

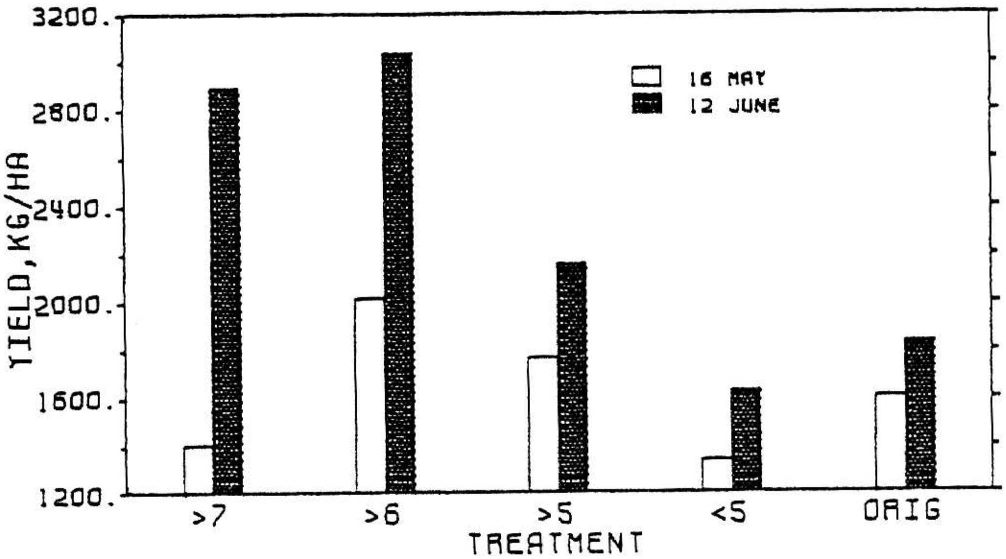

Figure 14. Grain yield at Manhattan in 1979 for the size treatments by planting date.

Seed Density

Density separations were made regardless of seed size. In 1978 only two fractions were tested; seeds from the original seedlot were classified as either high or low in density. In 1979 three fractions were made and classified high, medium, or low density seeds.

The effect of high density seeds upon emergence was positive. In 1978 variety-treatment interactions were significant at both locations (Fig. 15 and 16, Tables 4 and 5). In every case except RMP at St. John, however, the high density seeds emerged better than the low density seeds. Results were variable though with differences between the check and original seedlot often of the same magnitude as differences between densities. The interest in selection of seeds by density was heightened by visual observation of the plants from the 3 to 10 leaf stages. Seedlings from high density seeds seemed more vigorous, taller, and generally more leafy than plants from low density seed. Yield advantage of high density seed was seen in 1978 but

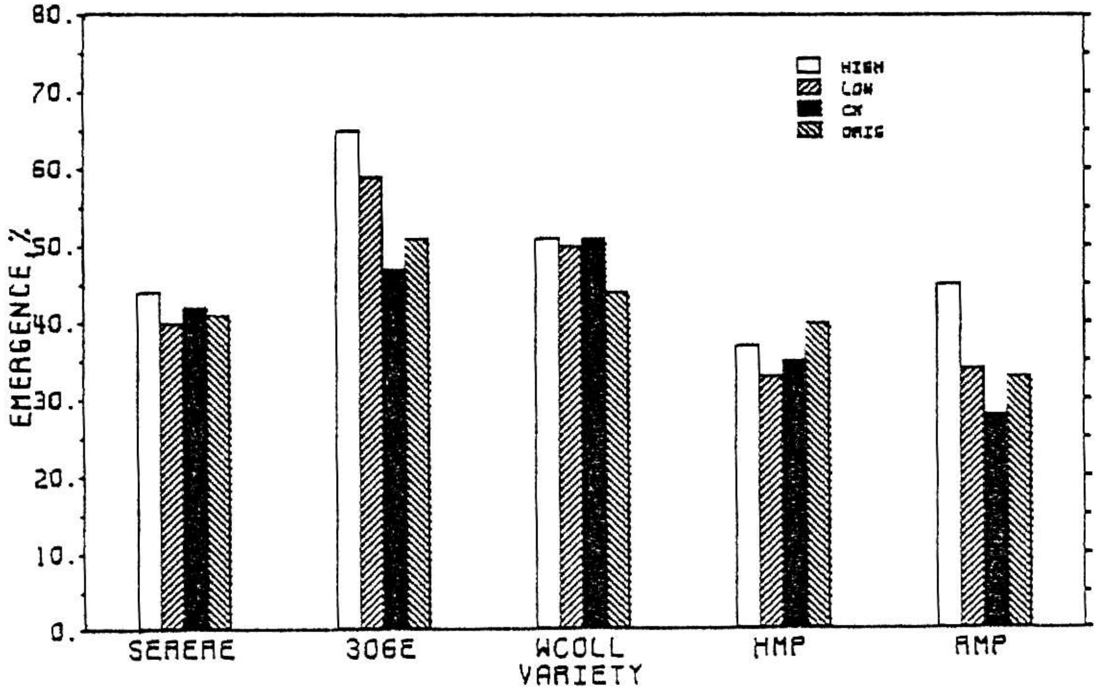

Figure 15. Emergence percentage at Manhattan in 1978 for the density treatments by variety.

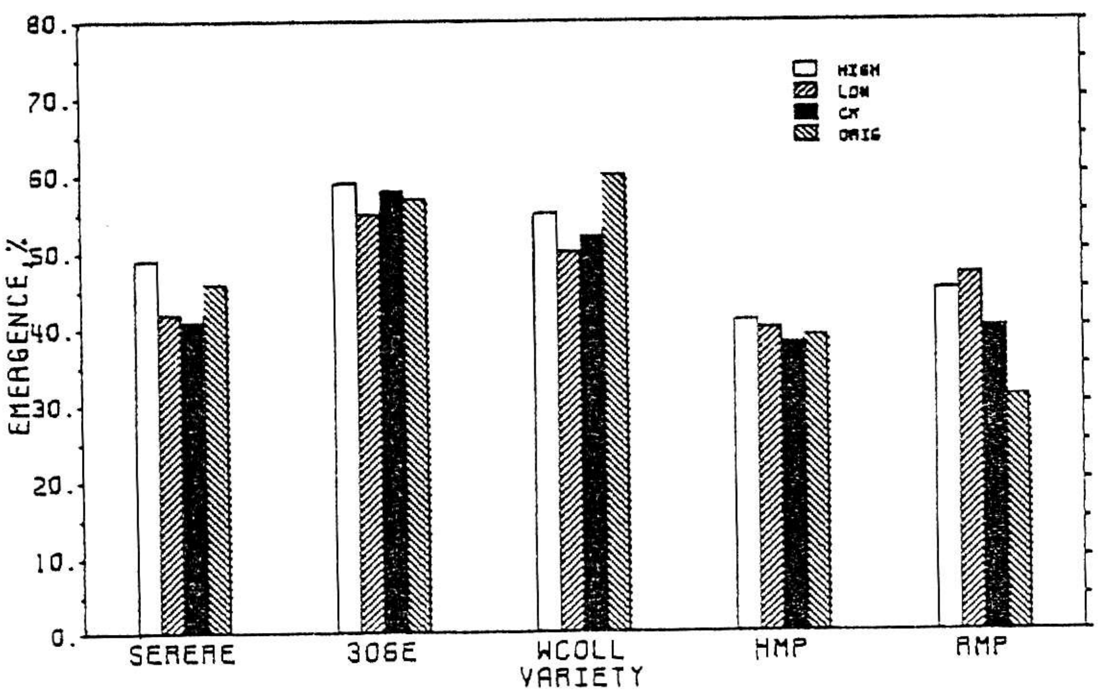

Figure 16. Emergence percentage at St. John in 1978 for the density treatments by variety.

because of the variability between the check and original treatments could have been due to the separation technique. Yield response to density was similar between years, however. At Manhattan, vigor in the seedling stage was important because of the chinchbug preference for plants in thin stands. Thus yield responded to density at Manhattan while at St. John no density effect was seen. The low density plots were able to tiller and yield equal to the high density plots (Fig. 17).

In 1979 at Manhattan despite a significant variety-treatment interaction was found, the effect of density was consistent in both varieties and inbreds (Fig. 18). In the analysis of variance with Inbred B removed, the linear density effect was the largest contributor to the treatment sums of squares for emergence. (Table 5). At St. John the same relationships were found. The variety-treatment interaction was not a result of inconsistent density performance (Fig. 19). Seed density has a strong effect upon the initial vigor of the pearl millet plant.

The relationship between seed density and yield seems to be different than that of seed size and yield. With seed size we have seen that the effect at emergence influenced grain yield. Seed density does not appear to remain as effective at harvest.

At St. John in 1979 the average emergence rate for the smallest seed size was 56.6% while the lowest density was 46.5%. Head production for the same two treatments however was 91,454/ha and 103,289/ha, respectively. The low density treatment went on to yield an average of 408 kg/ha more grain than the small seed size, and not significantly different from the high density treatments. Examination of the yield components heads/plant and weight/head show an increase in both with decreasing seed density. The variety-treatment interaction for heads/plant did not seem to apply to

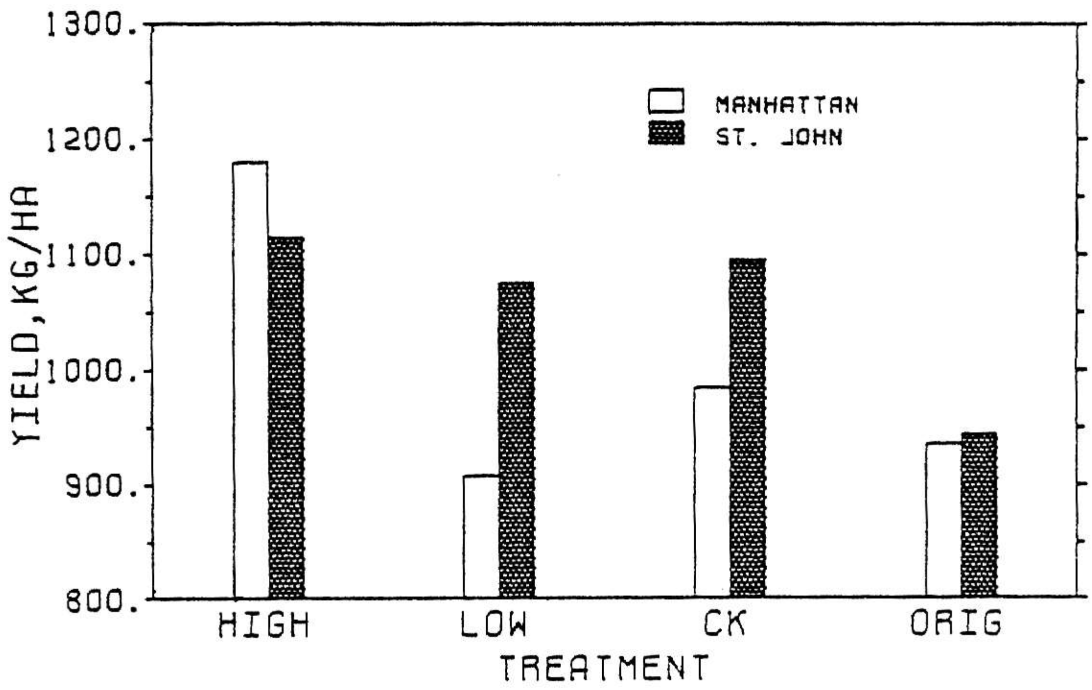

Figure 17. Grain yield in 1978 for the density treatments at both locations.

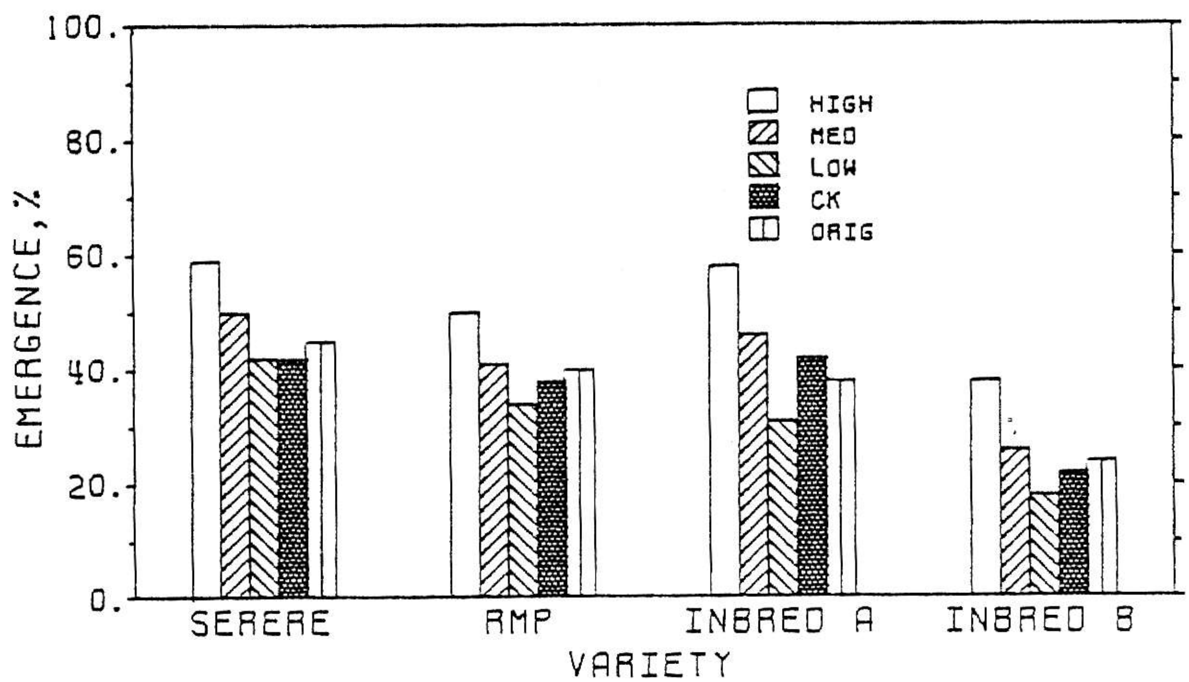

Figure 18. Emergence percentage at Manhattan in 1979 for the density treatments by variety.

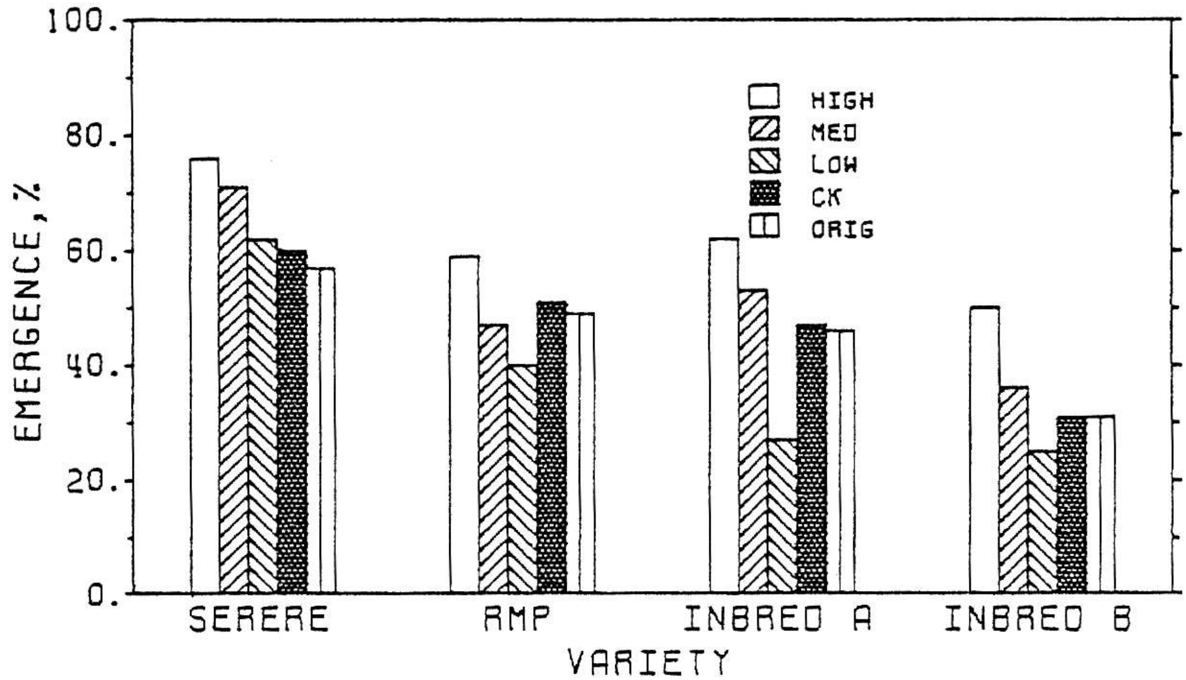

Figure 19. Emergence percentage at St. John in 1979 for the density treatments by variety.

density treatments as their effect was fairly consistent (Fig. 20 and 21).

Weight/head was significant for the density linear effect (Table 11), but the relationship is the inverse; the denser the seed, the lighter the head (Fig. 20), probably because of the plants compensation for stand.

At Manhattan the density effect did not influence heads/plant but, as at St. John, the size linear effect did. (Table 10). Heads/ha was affected by a variety-treatment interaction which shows a general trend different from that at St. John with higher densities producing more heads/ha (Fig. 22). Yield was affected by a date-treatment interaction in which density was a factor (Fig. 23). Again yield and heads were affected by stress from migrating chinchbugs which could be at least partially responsible for the yield and yield component variability between locations.

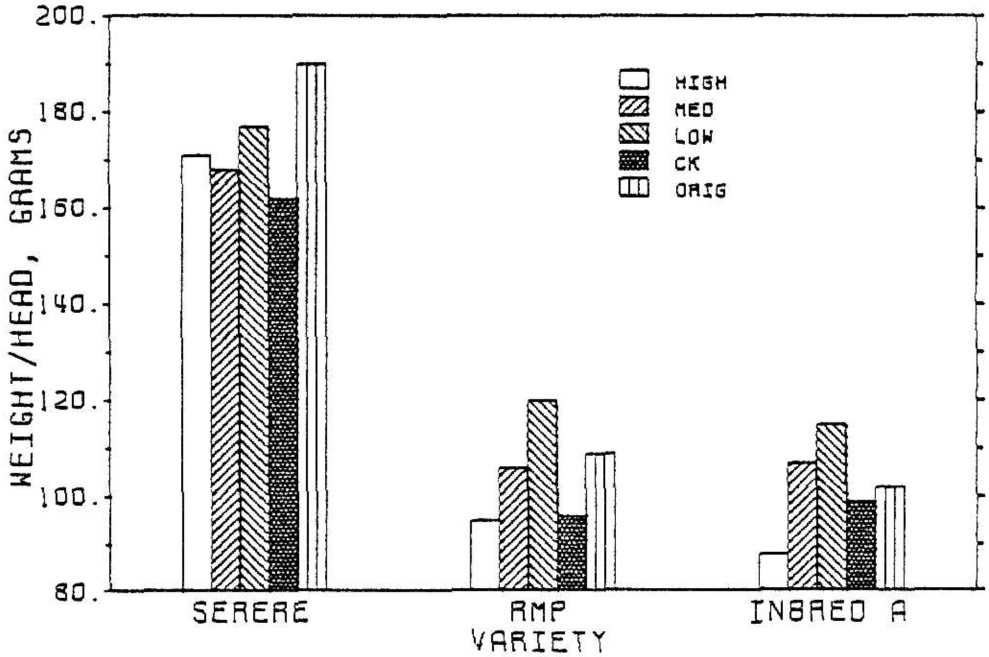

Figure 20. Weight per head at St. John in 1979 for the density treatments by variety.

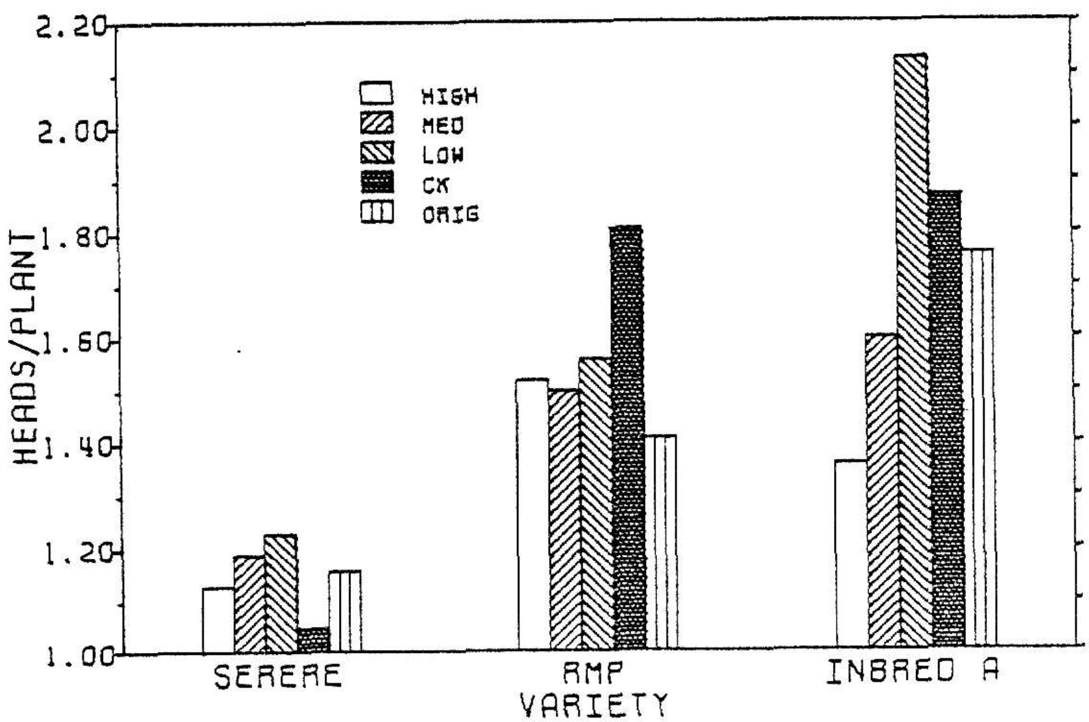

Figure 21. Heads per plant at St. John in 1979 for the density treatments by variety.

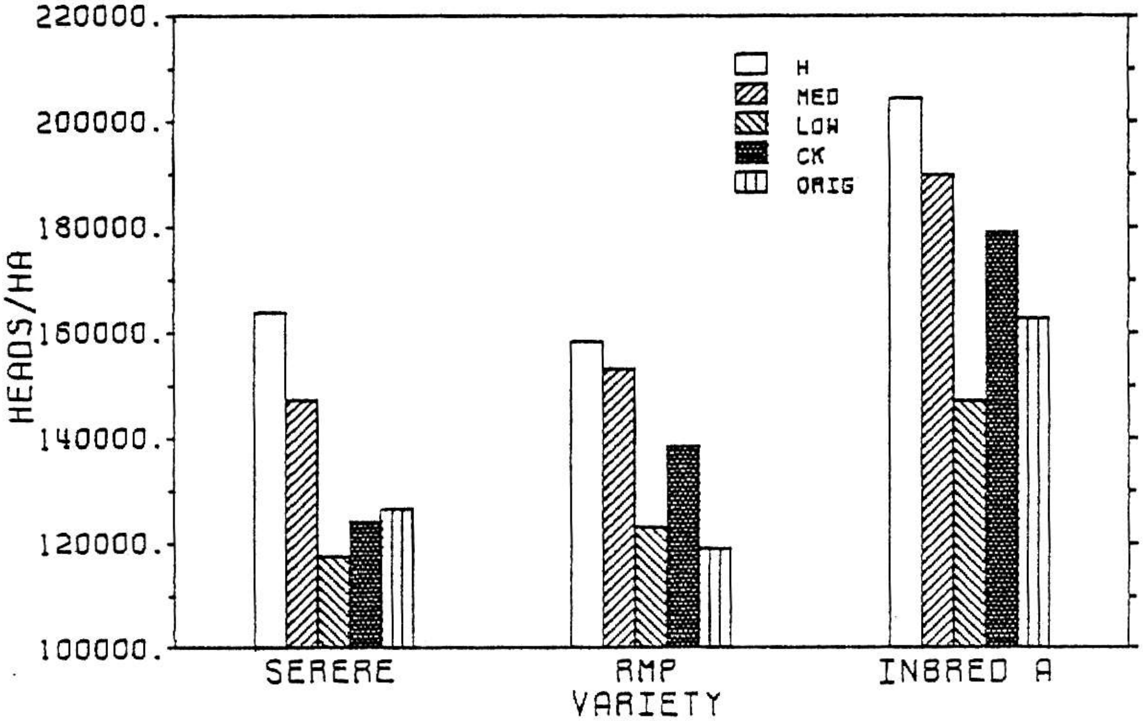

Figure 22. Heads per hectare at Manhattan in 1979 for the density treatments by variety.

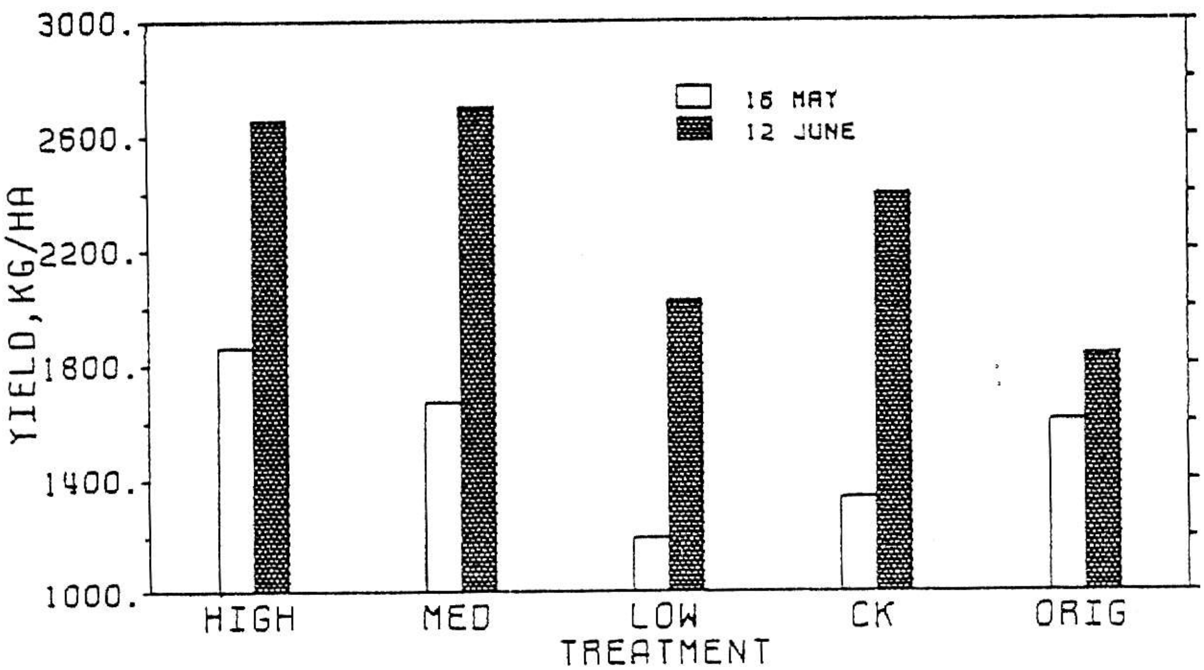

Figure 23. Grain yield at Manhattan in 1979 for the planting dates by density treatments.

Seed density was shown to be a consistent and effective criterion for improving seedling vigor, but it does not discriminate against plants able to tiller and produce grain under varied plant populations. Small seeds, however, do seem associated not only with poor seed quality but also with a plant lacking the capability to adjust yield components for efficient grain production.

Source-Sink Depletions

The production of seedlots with enough variability in size to exhibit the effects shown with sieving was unsuccessful. The data point out that the technique may have been responsible. The two millets treated, Serere 3A and Inbred B, were poor choices. Serere 3A was too tall to be thorough in the source depletion method of leaf areas trimming. Inbred B is a dwarf millet and the treatments were applied successfully, but it also is a low vigor, low yielding inbred resulting in little harvest data.

Emergence results at Manhattan and St. John show the variability of response between varieties and treatments (Table 2).

Table 2. Source-sink treatment emergence percentages.

Variety	Treatment	EMERGENCE %	
		St. John	Manhattan
Serere 3A	defoliated	65	57
	decapitated	64	44
	control	59	43
Inbred B	defoliated	18	17
	decapitated	31	21
	control	29	25

The defoliation treatment did seem to be most effective on the dwarf millet as seen by lower emergence rates of that treatment. Another problem with the sink depletion method of decapitation was the ability of pearl millet to compensate for the reduction by tillering, branching and head splitting to effectively increase sink size.

Seed Protein

Protein content has been reported to be positively related to both seed size and seed vigor. Protein percentages for the 1979 seedlot treatments were determined and correlated with emergence rates for each date at both locations (Table 3).

Table 3. Correlation of emergence and percent protein, 1979.

Location and Date	Variety				Combined overall
	Serere 3A	RMP	Inbred A	Inbred B	
St. John-1	-.189	.472	-.553	-.773*	0.538**
St. John-2	-.242	.615	-.585	-.697*	0.546**
Manhattan-1	-.776*	.614	-.468	-.696*	0.416*
Manhattan-2	-.671*	.329	-.758*	-.769*	0.382*

Seedlots differed in protein content, but there were similarities between inbreds and between populations. In both populations the largest seed contained a higher percentage of protein than any other fraction. The smallest seed contained the most protein percentage in the inbreds (Fig. 24).

Protein concentration has been found to decrease in cereal grains as physiological maturity approaches. Protein is laid down first in the developing seed followed by starch translocation and deposition. The response of protein to seed sieving in the inbreds, that is for small seeds to contain the most protein, seems to agree with this theory of kernel development. The smaller seeds, those not able to completely fill, were the highest in protein. The emergence results from these same treatments, however, were inconsistent with the literature. The highest protein seeds in the inbreds were the lowest in vigor. The populations followed somewhat the same tendency as the largest seeds, which were the highest in protein, were also associated with a drop in vigor.

The relationship between density and protein was less variable among seedlots. The lower the density of the seed, the higher the percentage of protein was found. Density has been reported to be a measure of maturity

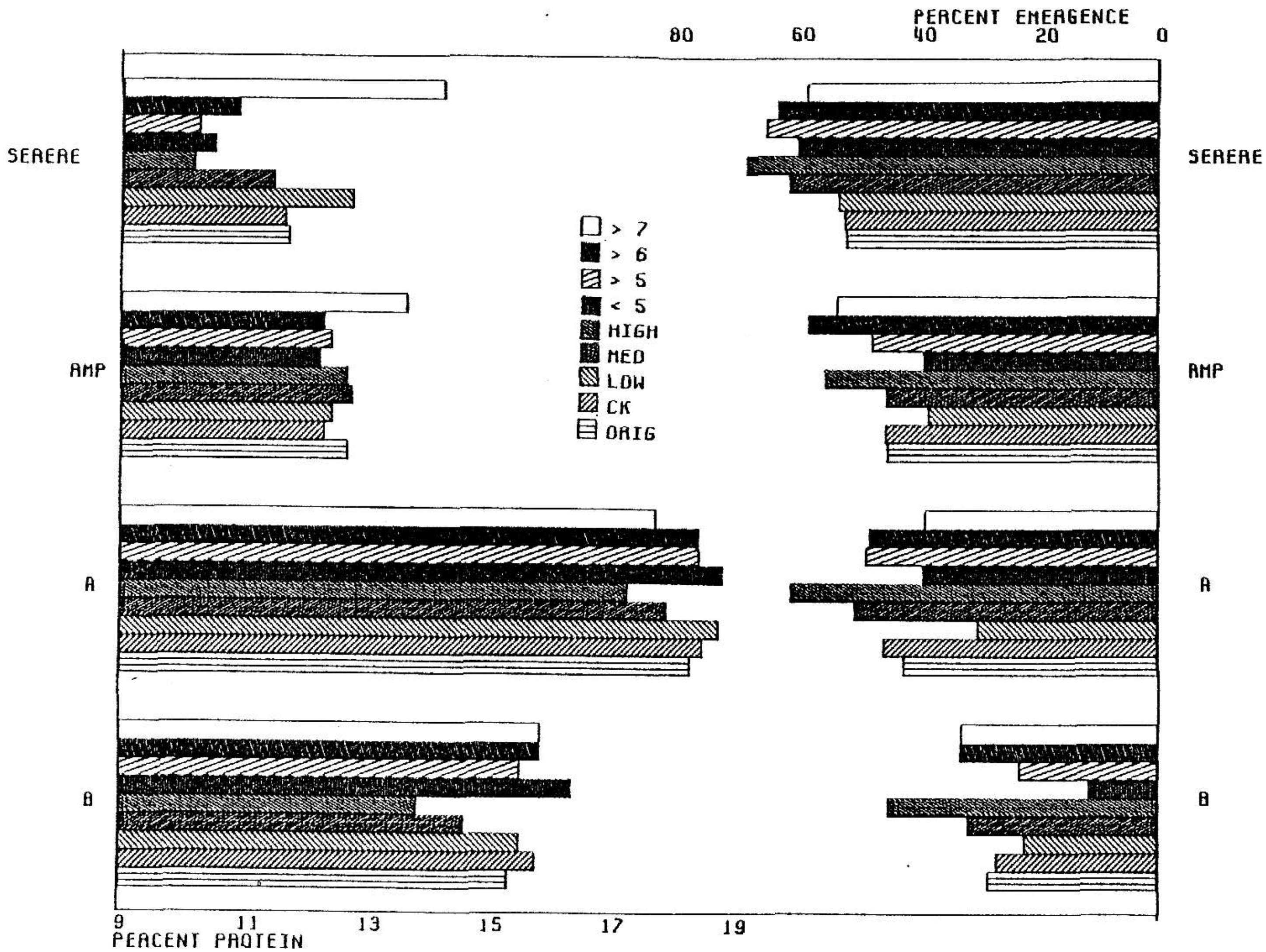

Figure 24. Percent protein and percent emergence for all treatments in 1979 by variety.

and efficiency of packaging nutrients for the embryonic plant. The emergence results substantiate this claim with seeds classified low in density to be high in protein percent.

The largest seeds often were associated with a drop in vigor. If density is assumed to be inversely related to protein, then in the populations it may be possible that the largest seeds, if they are to be vigorous, must also be high in density. The largest seeds may not be fully filled with nutrients but rather void space, thus be lower in density. These are only possibilities. What does seem certain is that the relationship between size, density, protein, and vigor is not fully understood and may be different in pearl millet than in other cereals.

CONCLUSIONS

Seed characteristics of size and density were found effective for selecting the most vigorous seeds in a seedlot. Small seeds were closely related to poor seedling vigor and low yield. The best seeds were often not the largest, but were the larger half of the size range. Seed density was positively related to seedling vigor. The higher the density of the seed, the greater chance it had of survival. Low density seed did not have the low yield characteristic the small seed had unless the environment discriminated against thin stands by a selective stress such as chinchbug damage. Low density seeds were able to compensate in other yield components to produce yields comparable to those plants from high density seeds. Seed protein does not have a clear relationship with seedling vigor but does appear to be inversely related.

The effects of seed characteristics were most apparent during the early stages of growth. As the plant develops, the environment plays a larger role in determining whether a characteristic of the embryonic plant will influence yield.

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Table 4. Analysis of variance of emergence, heads/ha, and grain yields at Manhattan in 1978.

		Mean Squares for		
SOURCES	D.F.	EMERGENCE	HEADS/HA	YIELD, KG/HA
REPLICATES	3	607.7	9368962740.	680527.1
date	1	107309.6 **	121003980105. **	39773090.0 **
error (a)	3	188.7	2728169352.	358441.
variety	4	2954.6 **	65172586902. **	22377012. **
treatment	7	625.8 **	4432220724. **	520760.7 **
size linear	(1)	1882.9 **	16462156738. **	1492049.8 **
size quadratic	(1)	531.9 **	4954489992. *	83910.1
hi vs lo den.	(1)	495.2 **	7376428444. **	1385411.0 **
orig vs ck	(1)	78.8	29008258.	87075.0
residual	(3)	463.9 **	734487212.	198959.7
date x variety	4	40.8	9026410776. **	2937748.3 **
date x treatment	7	46.7	980589476.	112112.6
variety x treatment	28	121.1 **	2054113508. *	371045.8 **
date x var x trmt.	28	74.4 *	1458539433.	232126.3
error (b)	234	45.6	1203534699.	175328.9
total	319			

* $P < .05$
** $P < .01$

Table 5. Analysis of variance for emergence, heads/ha, and Kg/ha at St. John in 1978

		Mean Squares for		
SOURCES	D.F.	EMERGENCE	HEADS/HA	YIELD, KG/HA
REPLICATES	3	38.1	11854495913.	2878415.
date	1	11.7	128403641954. **	384095.
error (a)	3	111.4	4558047404.	1728803.
variety	4	3521.4 **	53130698910. **	507888. **
treatment	7	283.4 **	12543830051. **	727636. **
size linear	(1)	1161.2 **	75159261268. **	3058057. **
size quadratic	(1)	406.6 *	2987489493.	661232.
hi vs lo den.	(1)	174.0	86539419.	29815.
orig vs ck	(1)	17.7	2055800.	426496.
residual	(3)	74.8	3190488126.	305951.
date x variety	4	459.4 **	9438808391. **	200823.
date x treatment	7	122.9	3654061798.	34631.
variety x treatment	28	156.8 *	2441849431.	261548.
date x var x trmt.	28	128.1	1505992846.	261826.
error (b)	234	89.5	2050714416.	190745.
total	319			

* $P \leq .05$
** $P < .01$

Table 6. Analysis of variance for emergence, heads/ha, and Kg/ha with Inbred B removed at Manhattan in 1979

		Mean Squares for		
SOURCES	D.F.	EMERGENCE	HEADS/HA	YIELD, KG/HA
REPLICATES	3	538.3	36234720400.	12561749.3
date	1	11.6	1680706052.	33852150.1 **
error (a)	3	340.5	659148087.	434552.8
variety	2	1376.7 **	21415582916. **	55676316.9 **
treatment	8	860.0 **	11906430402. **	2723247.4 **
size linear	(1)	18.4	27033312069. **	7850711.8 **
size quadratic	(1)	1441.5 **	25798184741. **	4380149.9 **
density linear	(1)	4543.5 **	25619156052. **	5009891.7 **
orig vs ck	(1)	1.3	1499301005.	261600.4
residual	(4)	219.0 **	3825372337. **	1070906. *
date^{x}variety	2	61.9	2052893089.	2571191.3 **
date^{x}treatment	8	61.8	1512850224.	1045655.8 **
variety^{x}treatment	16	154.9 **	2459443239. *	378510.6
date^{x}var^{x}trmt.	16	74.3	1436775393.	440522.0
error (b)	156	46.5	1315041254.	384803.2
total	215			

* $P < .05$
** $P < .01$

Table 7. Analysis of variance for emergence, heads/ha and Kg/ha with Inbred B removed for the first date at St. John in 1979.

		Mean Squares for		
SOURCES	D.F.	EMERGENCE	HEADS/HA	YIELD, KG/HA
REPLICATES	3	28.8	1319640242.	150835.4
variety	2	3636.6 **	1485784381.	4268976.5 **
treatment	8	462.1 **	2774698923. **	526791.2 *
size linear	(1)	290.4 **	15191189265. **	3590361.1 **
size quadratic	(1)	280.3 **	1981904868.	299024.7
density linear	(1)	2688.2 **	3674317013. **	5608.9
orig vs ck	(1)	5.0	634208571.	32136.9
residual	(4)	108.0 *	178992916.7	71799.5
variety x treatment	16	171.3 **	793610180.	188726.5
error	78	36.1	598189924.	199369.5
TOTAL	107			

* P<.05
** P<.01

Table 8. Analysis of variance for emergence at St. John in 1979

SOURCE	D.F.	Mean Squares for EMERGENCE
replicates	3	795.6
date	1	1296.2
error (a)	3	779.8
variety	3	15370.0 **
treatment	8	1675.4 **
size linear	(1)	2701.9 **
size quad.	(1)	1243.7 **
density lin.	(1)	8487.0 **
orig vs ck	(1)	47.3
residual	(4)	230.8 **
date x variety	3	109.4
date x trmt.	8	41.7
var x trmt.	24	251.5 **
date x var x trmt.	24	61.2
error (b)	210	53.5
total	287	

Table 9. Analysis of variance for emergence for source-sink depletions at St. John in 1979

SOURCE	D.F.	Mean Squares for EMERGENCE
replicates	3	126.9
date	1	143.5
error (a)	3	31.9
variety	1	16096.7 **
treatment	2	149.3
date x variety	1	63.0
date x trmt.	2	29.0
variety x trmt.	2	291.1 *
date x var x trmt.	2	93.7
error (b)	30	71.9
total	47	

* P<.05
** P<.01

Table 10. Analysis of variance for emergence, heads/ha, and Kg/ha for the source-sink depletions at Manhattan in 1979

		Mean Squares for		
SOURCE	D.F.	EMERGENCE	HEADS/HA	YIELD, KG/HA
replicates	3	138.0	1369775207.	859930.0
date	1	48.0	1515830695.	1177074.5
error (a)	3	31.5	352719438.	271562.6
variety	1	8748.0 **	200779882079. **	133697047.7 **
treatment	2	93.7	1734429189. *	1049482.5 *
date x variety	1	4.1	38587512.	1550588.2 *
date x trmt.	2	24.9	117606487.	4613.2
variety x trmt.	2	514.3 **	3062359941. **	992425.2 *
date x var x trmt.	2	0.6	104572257.	19210.6
error (b)	30	43.8	361392073.	262715.6
total	47			

Table 11. Analysis of variance for heads/ha and Kg/ha for source-sink depletions at St. Johns in 1979

replicates	3		45504858.	110234.2
variety	1		2903162520.	10899577.7 **
treatment	2		441014047.	39216.6
variety x trmt.	2		98869856.	66080.4
error	15		756752081.	277465.4
total	23			

* P<.05
** P<.01

Table 12. Analysis of variance for heads/plant and weight/head at Manhattan in 1979.

SOURCE	D.F.	Mean Squares for HEAD/PLT.		Mean Squares for WT/HEAD	
replicates	3	4.91		.000134	
date	1	.035		.0012009	**
error (a)	3	1.38		.000002113	
variety	2	15.95	**	.004157	**
treatment	8	1.249	**	.00000911	
size lin.	(1)	6.89	**	.00003081	*
size quad.	(1)	.10		.00001344	
density lin.	(1)	1.45		.00000120	
orig vs ck	(1)	.32		.00000291	
residual	(4)	.305		.00000613	
date^{x}var	2	1.01		.00009575	**
date^{x}trmt.	8	.24		.00001654	*
var^{x}trmt.	16	.63		.00000918	
date^{x}var^{x}trmt.	16	.53		.000006077	
error (b)	156	.395		.00000759	
total	215				

Table 13. Analysis of variance for heads/plant and weight/head for the first date at St. John in 1979.

replicates	3	.3318		.000006163	
variety	2	3.9666	**	.0004808	**
treatment	8	.3204	**	.00000842	
size lin.	(1)	1.5979	**	.00001544	
size quad.	(1)	.0031		.00000197	
density lin.	(1)	.5736	**	.00002306	*
orig vs ck	(1)	.1008		.00001291	
residual	(4)	.0718		.000003495	
variety^{x}trmt.	16	.1378	*	.000002844	
error	78	.07626		.00000426	
total	107				

THE EFFECT OF SEED SIZE AND DENSITY
ON
FIELD EMERGENCE AND YIELD OF PEARL MILLET
[*Pennisetum americanum* (L.) K. Schum.]

by

JOHN C. GARDNER

B.S., Kansas State University, 1978

AN ABSTRACT OF A MASTERS THESIS

submitted in partial fulfillment of the

requirements for the degree

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KANSAS STATE UNIVERSITY
Manhattan, Kansas

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ABSTRACT

Pearl millet [*Pennisetum americanum* (L.) K. Schum.] has poor stand establishment as a result of inherently low seedling vigor and small seed size. The physical characteristics of seed size and density were evaluated for their influence upon stand establishment and grain yield.

During 1978 and 1979 seedlots of five varieties and two inbred lines were separated on the basis of seed size and density. Four seed sizes were sieved from a portion of each original seedlot in both years. In 1978 two density fractions were determined from the original seedlots by immersion in sucrose solution. In 1979 three fractions were made. Sizes and densities were compared to the original seedlot and a portion of the original seedlot which were soaked in a sucrose solution. Evaluation of size and density was based on field emergence percentage and grain yield at Manhattan and St. John with two planting dates per location.

Size and density were found to effectively select the most vigorous seeds in a seedlot. Small seeds were not only low in emergence percentages but also produced mature plants with lower grain yields and head numbers. The best seeds were often not the largest, but, the larger half of the size range. Seed density was directly related to emergence percentages with low density seeds being lowest in vigor. Low density seeds, however, were not associated with low grain yields unless the environment placed increased importance upon stand establishment by a selective stress such as insect damage. Density did not seem to discriminate against yield component adjustment for different plant populations as did size.

Contrary to the literature, percent protein of the 1979 seedlot treatments was found to be negatively correlated to emergence percentages.