# SEED VIGOR MEASUREMENTS AND THEIR USE IN PREDICTING FIELD ESTABLISHMENT OF GRAIN PEARL MILLET (PENNISETUM AMERICANUM)

by

GALLUS JOSEPH MWAGENI

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## INTRODUCTION

Seed vigor is a great problem with pearl millet. Thus, seed vigor is a very important factor for proper field establishment, i.e. proper plant populations. Accordingly, this research was conducted to find out whether some of the vigor tests used to evaluate other crops like grain sorghum could be applicable to pearl millet and to compare those selected vigor tests to get the test that correlates best with field establishment of pearl millet.

Standard laboratory germination is positively correlated to field establishment. However, germination percentage will undoubtedly be higher than field establishment, as seeds are provided with optimum conditions for germination. Thus, these results often over-estimate field establishment (Vanderlip et al. 1973). The field environment is constantly changing, adversely or favorably to the seed sown.

Therefore, the best laboratory test to predict field performance or establishment of any seed lot should be the one which provides stress to the seeds after which these seeds maintain a high germination percentage when optimum conditions are provided. Seeds of low vigor are killed or rendered incapable of normal germination during the harsh or adverse laboratory treatments (Barnes, 1960). On the other hand, some of these laboratory stress tests are so severe that they under-estimate field establishment.

Both laboratory and field trials should always be conducted in order to select the best laboratory stress test that can be used in predicting the actual field performance of seeds (varieties) recommended to farmers especially for a crop like pearl millet which is grown on marginal areas.

Unfortunately, predicting field emergence and establishment of a seed lot is an extremely challenging task. The field is a variable environment, it fluctuates dramatically in temperature, moisture, aeration, bulk density, pH, nutrient status, pathogen level, seed-soil interface and many other factors. These plus those imposed by tillage, planting depth, and seed placement are worthy of consideration. The quality of seed itself, has a direct effect on seedling vigor. Some of the seed factors could include things like its testa permeability to water and oxygen and genotype-environment ineraction. Seed treatment effects are worthy noting also. A vigor test that will predict or prove to be highly correlated with field establishment for a particular crop would be important to both seedmen and farmers to get proper plant population per unit area.

Seedling vigor can be affected by many factors, too voluminous to cover here. To mention a few could include anything that affects seed during its development, maturation, processing and storage (Burris, 1975). Some of these factors are controllable while others are not. Also seedling vigor is influenced by genetic make-up and heterosis of seeds.

## REVIEW OF LITERATURE

Many researchers have published papers that deal with seedling vigor of various crops, each stressing either the importance of seedling vigor, or how to test it, and those factors that govern it. This literature review aims at outlining the numerous vigor test techniques in use today, especially those for cereals. The results of the many experiments performed on seedling vigor show that there is a variable discrepancy between laboratory and field emergence of almost all crops. The worst discrepancy is obtained when field establishment is related to standard germination percentage. This test evaluates germination potential of a seed lot and not its ability to withstand an adverse environment, i.e. vigor.

But, what is "seedling vigor"? For many years no term related to seed quality has been more abused than "seedling vigor" (Burris, 1975). Almost, everyone who deals directly or indirectly with seeds speaks of vigorous seedlings, but no two persons can agree on a definition of vigor or its importance relative to field performance. The main reason vigor has so many definitions is that people don't distinguish between storability and field establishment. These two terms are just the opposite (Vanderlip, 1974). Seed vigor is therefore, the ability of a particular seed to produce a normal healthy plant under field conditions. It is the ability of seed to overcome an adverse environment and still be capable of producing a plant that will complete its life cycle. We want the maximum physiological activity, a rapid uniform seedling emergence and development in its vegetative and reproductive stages. While in storage, we try to

maintain the seed in an environment where there is very little if any physiological activity, so that at the end of the storage period we get viable or vigorous seeds exactly as they were originally. Clearly then, one vigor test may not provide the best information for both seed storability and field establishment capability. For example, artificial or fast aging laboratory test (high temperature and humidity) is best suited for testing seed storability and not for testing seeds for their capability to perform well under field conditions. Treating seeds with NaOH, $NH_4Cl$ or cold test would be ideal for testing field establishment capability of a seed lot. These vigor tests are either direct or indirect.

An example of a direct vigor test is the cold test. Isley (1957) states that cold vigor test has proved worthy for corn in wet and cold regions to differentiate varietal susceptibility to Pithium. These direct vigor tests simultaneously evaluate all vigor factors and bear some resemblance to stresses which the sown seeds encounter. Their disadvantage is that they have high variability. On the other hand, the indirect vigor tests e.g. all biochemical tests, (tetrazolium) growth rate tests, stress tests (unfavorable moisture and temperature, hot water, NaOH, etc.) and physical measurement tests (electrolyte conductivity) can be precisely controlled allowing reproducibility of the results; are quicker, less complex and less expensive (Delouche, 1960). But, they do not simultaneously evaluate all vigor factors especially mechanical injuries and morphological abnormalities. Johnson et al. (1978) concluded that the cold test on soybean seeds consistently had a higher correlation with field emergence and final stand than standard germination, accelerating aging, or tetrazolium tests.

Two seed lots under favorable laboratory test may have equal percentages of germination but may differ in field establishment. Stress vigor tests can identify vigorous seeds from non-vigorous but a vigor test is not a test for field response per se. Vigor tests having little application to field problems are therefore of limited value. Thus, seedling evaluation agronomically should be based on rapidity of germination, growth rate after germination and the integrity and normality of seedlings in the field (Wellington, 1970). The importance of vigor testing was stressed by (Isley, 1958). Certified seeds are becoming more and more expensive. So, it is very important to get a vigorous plant from each seed sown.

Accelerated aging was performed by Abdullahi et al. (1972) on grain sorghum seeds. They got significant correlations between field establishment and this test. Camargo, et al. (1973) artificially aged sorghum seeds (42C 100% RH) for 11 days. Resulting seedlings grew slowly, had reduced height, less tillering, delayed panicle exsertion and anthesis, and yield was reduced up to 18%. Roos et al. (1978) and Camargo et al. (1973) concluded that seeds with higher moisture content at harvest result in lower viability during storage; and that as seed vigor level decreases, the seedling emergence decreases as well. In the laboratory, sorghum seeds that were aged artificially for 3, 5, and 7 days did not differ significantly from the control in germination. In the field, seeds aged for 3 and 5 days again did not differ significantly from the control but were better than seeds aged for 7 and 11 days. Field establishment for seeds aged for 11 days was significantly lower than those aged for 7 days. Yield from control seeds was significantly higher than that obtained

from seeds aged for 7 or 11 days. Therefore, this indicated that the deterioration of seed did affect the field performance of the plants produced from them. Roberts (1972) and Roos et al. (1978) agree in their conclusions that vigor of a seed is at its highest at maturation. From then on it deteriorates inexorably, continuously, and irreversibly. This deterioration rate is largely determined by genetic factors, treatments, and environment before and during storage. Deterioration of four pearl millet lines, they concluded, was twice as fast when they were artificially aged at 32C 90% RH than at 21C 90% RH. They concluded that seed moisture content contributed more to loss of pearl millet seed germination than did storage temperatures because deterioration rate at 32C 70% RH and 21C 70% RH were about the same. Working on barley, wheat, beans, and corn Webster et al. (1961) found that these seeds differed widely in their response to mechanical and artificial aging. There was no close correlation between the germination percentage or rapidity of germination, and size of seedlings.

Many chemicals have been used to stress seeds to evaluate their vigor or to break seed dormancy which is one of the big problems in most pearl millet genotypes. Burton (1969) and Shar et al. (1972) were able to break dormancy by using a 1-hour soak in a water solution of 1% 2-chloroethanol plus 0.5% sodium hypochlorite mixture or thiourea at 100 ppm respectively. Working on the same topic Manohar and Mathur (1965) used succinic acid of various concentrations and osmotic potentials. The results were negative in general although osmotic potential did affect germination and dry weight of the seedlings. The same workers in 1966 reported that treating pearl

millet seeds with 0.09% succinic acid 3 hours before sowing significantly increased plant height, number of tillers per plant and increased grain yield by 74%. Sandhu and Husain (1961) concluded that gibberellic acid did not affect rate of emergence of pearl millet nor the germination percentage; although it increased seedling height significantly at 100, 250 and 500 ppm. Presowing hardening of ragi (Eleusine coracana) seeds with calcium chloride, ascobic acid and benzyl adenine produced higher and more vigorous germination and seedling growth on soils of high exchangeable sodium than untreated seeds. Viswanath et al. (1972) recommended that this technique be used in order to establish better stand in alkali soils.

Various techniques are used to stress seed lots so that their tolerance and expression of vigor can be differentiated among them. Barnes (1960) working in vigor of sorghum seeds concluded that a 5-second soak in 100 C water ranked and correlated the 32 seed lots best with field emergence; and that soaking sorghum seed lots in a 5 percent solution of sodium hydroxide for 2 minutes distinguished the vigorous from non-vigorous. The correlation coefficient between germination following 5% $NH_4Cl$ treatment and field emergence was 0.86. Finally, he concluded that the rank criterion was probably the best index of a vigor test because it provided the most dependable basis for indexing seed lots as they could be expected to perform under adverse field environments. Unfortunately, correlation and average germination criteria were less dependable. Vanderlip et al. (1973) Abdulahi and Vanderlip (1972) and Yayock et al. (1975) consistently got highest correlation coefficients between ammonium chloride treatment and field establishment of grain sorghum. They concluded

that the $NH_4Cl$ concentration should not be more than 4% and the soaking time no longer than 1 or 2 hours at 4OC or 5OC, respectively. Unfortunately none of the modifications of $NH_4Cl$ test greatly improved the correlation with field establishment. Also seed size and tetrazolium tests were not related to field emergence. As a result they concluded that vigor tests should be related to field stand establishment rather than to one another. Johnson (1971) concluded that the best temperature to germinate Panicum maximum was between 15C and 35C. Tetrazolium test results at this temperature range showed that germination was still incomplete after 28 days indicating that most of the seeds were still dormant. On the contrary, Singh, et al. (1971) observed that hybrid pearl millet seeds germinated satisfactorily under 30 and 32C temperatures. Germination was more rapid and uniform in sand than blotter papers or rolled towels in plastic boxes and was complete after 3 to 4 days.

A number of researchers have evaluated seed vigor in terms of seeding depth, drought resistance, biochemical activities of seeds, size, electrolytes leached from seeds and many other procedures. Misra and Kumar (1964) observed that sowing pearl millet seeds at 7.62 cm. in sandy deserts gave higher field establishment than 5.08, 10.16, 12.7 and 15.24 cm. This depth resulted into higher number of tillers, optimum plant height and higher grain yields. Contrary to this, Whalley et al. (1966) and Delouche (1968) found that early seedling emergence was much more dependent on seed quality than sowing depth and that the ultimate yield was better correlated with early emergence than with most other parameters. Experimental results of Alagarswamy

et al. (1977) indicated that genetic differences in seedling vigor among pearl millet genotypes could be distinguished by direct measurements and by visually scoring the plants under field conditions. Criteria found useful for direct measurements were seed weight, plumule and radicle weight after 5 days of laboratory germination, seedling dry weight at emergence, 7, and 15 days after emergence under field conditions. These criteria were significant but weakly intercorrelated, the correlations decreasing as the time interval between two measurements increased. Contrary to this, visual estimation of seedling vigor (1 - 5 score) was able to distinguish the vigor differences among genotypes. As Abdullahi (1968) they found also that seedling vigor estimated by seed size was not related to yield of subsequent crop. Oelke et al. (1969) concluded that seed density of rice was very important in producing larger and more vigorous seedlings but the dry weight levelled off during maturation. Germination percentage, yield, weight per seed and liter weight increased steadily as grain moisture decreased from 43 to 13%. On the other hand, Voigt and Brown (1969) while acknowledging the importance of seed size for seedling vigor reported that they were successful in breeding side-oats Grama for seedling vigor regardless of seed size. Abdullahi and Vanderlip (1972) showed that sorghum seed size and source were both important for germination and field establishment. Larger seeds tended to perform better in laboratory tests than in the field. Whereas, more consistent correlations were obtained between laboratory and field emergence for the medium and small seeds. Protein content of winter wheat was found to be related to seedling vigor (Ries et al. 1976). Alagarswamy et al.

(1977) stated that the preliminary results they had obtained on pearl millet seedling emergence from crusted soils and drought tolerance were encouraging.

Seedling vigor based on genetic make-up of pearl millet was studied by Mahadevappa in 1967 and 1968. Seeds and seedlings of 3 parents and their 6 hybrids revealed that they did not differ significantly in their germinating capacity, but differed significantly in their rates of respiration, seedling height, fresh weight, shoot to root ratio, total root length, leaf area and dry weight especially during the early grand period of growth. Hybrids had better growth during early stages of development and gradually this difference ceased to exist by 50th day. Also he noted that in the diallel cross of inbreds highly significant specific combining ability effects for many characters were present. This indicated that there is an immense practical value of utilizing the same in exploiting heterosis.

Woodstock (1966) observed that corn seeds which were high in germination percentage were not necessarily high in vigor. One seed lot had 91% germination but was evidently low in vigor based on field establishment. Seeds of high vigor had higher respiration rates and the respiration measurements in 100% oxygen were better correlated with seedling growth and field establishment than measurements in air. Therefore, these respiration measurements distinguished seed lots of high, intermediate and low vigor. Also, the ratio of $CO_2$ evolved to $O_2$ absorbed i.e. respiratory quotient (R.Q.) was even more highly correlated with seedling growth than $O_2$ uptake. He suggested this respiration test for seed vigor should prove worthy to those concerned

with testing vigor of seeds. He was also supported by the results of Kittock and Law (1968). They found that there was a significant positive correlation between wheat rate of emergence and vigor, emergence and rate of respiration and finally between vigor and both tetrazolium reduction and the rate of respiration for seeds of different ages. Additionally, seed weight and tetrazolium reduction; shoot weight per plot and tetrazolium reduction both were significantly correlated. Abdul-Baki (1969) listed four biochemical changes associated with reduction in vigor or germinability mostly concerned with respiration, increased total enzymatic activities, and increased membrane permeability and thus greater leakage of sugars, amino acids, inorganic solutes, etc. Results of Grabe (1964) indicated clearly that glutamic acid decarboxylase activity was the most sensitive index of corn and oat seed deterioration and seedling vigor followed by root length, cold performance, and germination. He observed that vigor tests based on germination performance appeared better suited for predicting field emergence while tests based upon enzymatic activity were more adapted for measuring other aspects of vigor. A vigorous evolution of $CO_2$ indicated that the seeds were vigorous. In contrast, Anderson (1970) concluded that $CO_2$ evolution rate from old barley seeds during germination period was twice as high as new seeds. However, accelerated aging (45C 100% RH) caused more rapid drop in germination capacity in the older seeds than young ones.

Roberts (1972) reported that conductivity test has some promising features. Seeds with weaker membrances (testa) release large quantities of electrolytes, giving higher electric conductivity values.

Presley (1958) worked on cotton seedling vigor. He found a good correlation between extent of leaching and cotton field performance. The level of electrical current flowing through the seed indicates the quality of the seed. A low current means a highly vigorous seed and conversely a high current means the seed has poor vigor or is dead.

## MATERIALS AND METHODS

In 1977, 20 pearl millets were selected from materials that had undergone some breeding at Kansas State University or at the University of Nebraska at Lincoln after they were introduced into the United States from Africa. All were from either the 1973 or 1976 crop. Seeds were screened and those retained on 6/64 diameter screen were used for the field experiment and laboratory tests. In both field establishment and laboratory tests four replicates of 50 seeds per seed lot were used. Only one location was selected i.e. Manhattan.

Laboratory and field tests consisted of:

1. Standard germination. This procedure as outlined in the standard rules for laboratory germination of seeds (5) was followed. The temperature setting was 31C and 82% R.H. and germinated for 4 days. Then, percentage germination of normal seedlings was computed.

2. Stress treatment tests.

a) Ammonium chloride treatment test. Seed samples in loosely knit cotton bags were soaked for two hours in two percent w/v aqueous ammonium chloride solution at 40C (Abdullahi, 1968). They were immediately flushed, rinsed several times, and germinated as reported above.

b) Sodium hydroxide treatment test. As outlined by Vanderlip, et al. (1973) a 5% sodium hydroxide solution was used to soak the seed lots for two minutes after which they were flushed and rinsed several times in running tap water. Then laboratory standard germination was performed.

c) Artificial aging test. Artificial aging as reported by Abdullahi and Vanderlip (1972) was performed by placing the seed samples in wide-mouth plastic containers and storing them at 40C and 84% R.H. for 10 days. No fungicide was added to the samples during the study. After that they were germinated under optimum conditions and germination counts recorded.

d) Cold treatment test. Approximately 600g of unsterilized soil from the field establishment site was put in containers and seeds were surface planted and another 250g of soil were added evenly to cover the seeds (Abdullahi, 1968). The soil was kept at field capacity in a cold chamber of 12C for 7 days. At the end of this period the temperature was raised to 30C for another 7 days and the percent emergence, fresh weight and dry weight per pot were recorded.

3. Field establishment studies.

Two planting dates were planned, an early planting and an optimum date. The first planting was May 12 but a heavy storm of about 152 mm of rainfall within 2 hours duration destroyed many seedlings before they were counted 24 days after planting. The second planting was June 7. Unfortunately again on June 17 a 178 mm rain fell within a short period and chinch-bugs (Blissus leucopterus) damaged those plants

remaining. Thus the field stand was severely affected (Table 1). Therefore, a third planting was made on June 27. Better field establishment was obtained although damage by chinch-bugs was obvious.

Seeds were machine planted at depth of 2 - 4 cm. in a split-plot design replicated four times per planting date with planting date as main plots and pearl millet varieties as sub-plots. There were two rows of 6 m each and 75 cm. between rows for each planting date. No yield data were taken. Seedling vigor was evaluated in terms of number of seedlings at 24 days after planting.

In 1978 thirty pearl millet seed lots were obtained from the Fort Hays Branch Experiment Station, mostly from the 1971 breeding program. Seeds obtained were offspring of the plant introductions from Africa, and were very heterogenous in nature. Because pearl millet has high seed dormancy, old seeds were preferred. In addition, no fungicide was added fearing it could have affected germination which was the focal point of the experiment. The seed lots were kept in cool chamber from harvest to the time of the experiment. All seed lots were screened by 4/64 diameter round-hole sieve and those seeds retained were used for the study. Then, 100 seeds per packet per seed lot were machine counted for both field and laboratory tests except for electrolyte conductivity test for which only 50 seeds per seed lot were used. Four replicates of each seed lot for both laboratory and field establishment studies were utilized.

The same procedures as outlined in the first year of study were followed in the second. The cold test was not used because results in the first year were not encouraging and instead a conductivity test was included. Days to germinate them were also increased from 4 to 5. Plastic containers used in accelerated aging were tied with cotton nets and inverted to eliminate condensed water accumulating inside. Relative humidity and temperature setting were changed to 80% and 32C for standard germination and 84% and 41C for fast aging.

The Electrical Conductivity Test. The Seed Germination and Vigor Analyzer*(MSS-110) provided by Agro Science Incorporated of Michigan and commonly used to determine and evaluate cotton-seed germination and vigor was used.

Fifty seeds from each seed lot were soaked in individual tiny plastic chambers for a period ranging from 30 minutes to six hours to select the best soaking time for millet. Each seed was picked up and held by tweezer-electrode while the seed was still immersed in water. The electrical current passing through the seed was registered on the vigor-analyzer. A low current means a vigorous seed and conversely a high current means the seed is non-vigorous or dead.

The vigorous seeds were separated from non-vigorous for each seed lot by using 45 micro-amps as a cut-off point for the 30 minute soaking. These seeds were then germinated separately as outlined in (5). Another procedure used included soaking the seeds overnight after which the electrical conductivity test was done. The cut-off point now was 60 micro-amps. Electrolyte conductivity of each soaked seed was also recorded.

*disclaimer statement

In the field the length of the plots was increased from 6 to 8 m and the establishment counts done 7 and 24 days from the date of planting. Two locations were chosen: St. John and Manhattan. As in the previous year heavy storms affected the seedlings of second and third dates at Manhattan.

In both years, germination percentages from each laboratory test were correlated with field establishment. In addition the ranking procedures Ostle (1963) and Siegel (1956) were used. Finally, the effectiveness of the laboratory tests in ranking the millets in field establishment was evaluated by "rank means" (Barnes 1960). These criteria were used to select the vigor test that best predicted the millet field establishment.

## RESULTS AND DISCUSSION

### VIGOR TESTS 1977

1. Standard Germination

Germination percentages of the 20 varieties are summarized in Table 1. Highly significant differences existed in germination capability among the varieties and these germination percentages were the highest (overall average = 79.3%) among the four laboratory vigor tests performed. This was expected because the seeds were germinated under optimum conditions. LSD values were the least among the laboratory tests.

In general, varieties 6, 7, 9, 10, 15 and 18 gave germination over 89% and were not significantly different from each other at 0.01 level. Variety 20 had the lowest germination percentage (46.5%) followed by variety 19 (53.0%) and variety 13 (58.0%).

2. Stress Treatment Tests

A) Germination after $NH_4Cl$ treatment

The results of germination after treating the seeds with 2% ammonium chloride solution are shown in Table 1. Analysis of variance showed significant differences at 0.01 level among varieties. But, the overall average germination percentage was lower (71.9%) than that of standard germination. This difference was observed by Abdullahi (1968) on sorghum as well. The toxic nature of $NH_4Cl$ must have been the reason for some of the varieties to perform poorly. Varieties 1, 4, 6, 8, 15 and 18 were not significantly different at 0.01 level. Again, varieties 13, 19 and 20 were among the poorest performers.

Table 1. COMPARATIVE GERMINATION OF PEARL MILLET VARIETIES IN LABORATORY AND FIELD ESTABLISHMENT, 1977

| Varieties | May 12 Planting | June 7 Planting | June 29 Planting | Combined over dates (average) | Std. germ. | $NH_4Cl$ | NaOH | Fast Aging | Cold Test (seedling emergence) |
|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | | | | |
| 1 | 38.5 | 50.0 | 56.3 | 47.8 | 87.5 | 84.0 | 66.0 | 52.5 | 13.0 |
| 2 | 34.0 | 37.5 | 47.5 | 39.7 | 81.0 | 56.5 | 45.0 | 24.5 | 10.0 |
| 3 | 31.5 | 29.5 | 62.0 | 41.0 | 81.5 | 71.0 | 73.0 | 28.0 | 16.0 |
| 4 | 37.3 | 41.5 | 52.3 | 43.7 | 83.0 | 90.0 | 68.5 | 38.5 | 11.0 |
| 5 | 36.5 | 34.5 | 42.3 | 37.8 | 61.0 | 57.0 | 32.5 | 31.0 | 9.0 |
| 6 | 36.0 | 35.8 | 49.8 | 40.5 | 90.0 | 89.5 | 77.5 | 58.0 | 15.0 |
| 7 | 34.5 | 43.5 | 54.3 | 44.1 | 92.5 | 74.0 | 64.0 | 23.0 | 12.5 |
| 8 | 34.3 | 43.0 | 57.8 | 45.0 | 85.0 | 86.0 | 59.5 | 28.0 | 10.0 |
| 9 | 35.0 | 48.3 | 55.8 | 46.3 | 90.5 | 69.5 | 57.0 | 36.0 | 49.0 |
| 10 | 32.8 | 42.8 | 67.0 | 47.5 | 91.0 | 79.5 | 59.5 | 23.0 | 21.0 |
| 11 | 35.0 | 28.8 | 40.5 | 34.8 | 69.5 | 58.5 | 31.5 | 13.0 | 17.5 |
| 12 | 38.3 | 34.5 | 46.3 | 39.7 | 82.0 | 74.0 | 47.0 | 20.5 | 18.0 |
| 13 | 15.5 | 14.0 | 31.0 | 20.2 | 58.0 | 34.5 | 18.0 | 1.0 | 6.5 |
| 14 | 28.3 | 30.3 | 45.0 | 34.5 | 81.0 | 73.5 | 56.5 | 16.0 | 23.0 |
| 15 | 41.5 | 39.5 | 56.0 | 46.0 | 92.5 | 87.0 | 80.0 | 69.0 | 34.0 |
| 16 | 33.5 | 34.5 | 52.3 | 40.4 | 86.5 | 79.0 | 47.0 | 16.0 | 23.0 |
| 17 | 28.5 | 28.8 | 45.5 | 33.3 | 85.5 | 73.5 | 58.0 | 33.5 | 24.5 |
| 18 | 39.8 | 42.0 | 64.5 | 48.8 | 89.0 | 90.5 | 76.5 | 56.0 | 17.0 |
| 19 | 25.8 | 18.3 | 49.0 | 31.0 | 53.0 | 57.0 | 4.0 | 22.5 | 4.5 |
| 20 | 7.5 | 9.8 | 33.5 | 16.9 | 46.5 | 53.5 | 18.0 | 26.0 | 7.0 |
| Average | 32.2 | 34.3 | 50.4 | 38.9 | 79.3 | 71.9 | 51.9 | 30.8 | 17.1 |
| LSD (.01) Varieties | 18.6% | 18.6% | 18.6% | 10.8% | 5.6% | 7.9% | 8.1% | 10.3% | 10.2% |

LSD (.01) for difference between two date means = 15.5%

b) Germination following NaOH Treatment

This treatment was more severe than $NH_4Cl$ as can be observed from the results of Table 1. Again, significant differences among varieties to tolerate such a harsh treatment is clearly shown. Varieties 3, 6, 15 and 18 had highest germination percentages and were not statistically different from each other at 0.01 level and the same poor performers (non-vigorous) were the least in this stress test dropping to as low as 4% (var. 19).

c) Germination following accelerated aging.

The high relative humidity and temperature provided a very favorable environment for higher seed respiration rate and fungal growth. Germination of even the best varieties was affected more than in the previous stress tests.

The best performer was variety 15 with 69% germination. Significant differences among varieties at 0.01 level were observed. Non-vigorous seeds were easily killed in the process of aging.

d) Cold Test

This was the most harsh treatment to the seeds. The germination percentage of each variety was the lowest among the laboratory stress tests used. Normally, pearl millet is grown in warm, dry, tropical climates. Therefore, such poor performance in establishment is not uncommon under such cold environments. The best variety was 9 followed by variety 15.

From all the laboratory tests variety 15 was the best performer followed by varieties 6, 18 and 3.

3. Field Establishment Studies.

Field establishment was badly affected by heavy storms. The remaining seedlings were counted and highly significant effects of planting dates and varieties were found (Appendix Table 17). The interaction between dates and varieties was not significant indicating that each variety responded in the same way irrespective of the date of planting. Due to the uncontrollable effect of the storm, error means squares were very high.

Although the third (June 29) planting was damaged by chinch-bugs, field establishment was best among the three dates of planting with an overall average of 50.4% (Table 1). This date was thought to have been more favorable for pearl millet germination from the standpoint of soil temperature and moisture although no soil temperature or moisture data were taken. Highly significant differences in establishment were observed among the 20 varieties (Table 1).

In the first planting date, field establishment ranged from 7.5% for non-vigorous varieties e.g. variety 20 to 41.5% for vigorous varieties e.g. variety 15 with an overall average of 32.2%. The range of field establishment for June 7 planting was between 9.7% to 50.0% and the third planting ranged from 33.5% to 64.5% with an overall mean of 50.4%.

Those varieties which did well in laboratory stress tests performed well in the field and vice versa as indicated in Tables 1 and 2. These differences in vigor may not necessarily be due to genetic variation but could be due to the environmental conditions under which the seed was produced or stored.

Germination following NaOH treatment closely approximated average field establishment from the best (June 7) date of planting.

CRITERIA USED TO SELECT BEST VIGOR TEST

We cannot base our judgement on one criterion alone to select the best vigor test as each has its weakness. For example in Table 3 all correlations for standard germination, $NH_4Cl$, and NaOH treatments are highly significant. The correlations, however, vary in their magnitude of association to field establishment. High correlations may over-estimate or under-estimate field performance and therefore are not totally a reliable method for predicting field establishment of a seed lot per se. A higher correlation is just an indication of consistent behavior of a variety in the two tests compared, but does not take into consideration the gap which exists between the average germination of the two tests.

A variety having comparatively higher performance in both laboratory stress tests and in different dates of planting should be considered the most vigorous variety e.g. variety 15.

i. Ranking of Variety Performances in Laboratory Vigor Tests and in the Field

Ranking the varieties was used to confirm if the performance of a variety in laboratory stress tests was proportional to its performance in the field (Table 2). The most vigorous variety was assigned 1, the next assigned 2, and so on with the least vigorous variety given a rank of 20. The same procedure was also used by Abdullahi (1968) and Barnes (1960). The variety having the lowest numbers in

Table 2. VARIETY RANKS IN FIELD AND LABORATORY, 1977

| Varieties | May 12 Planting | June 7 Planting | June 29 Planting | Combined Over dates (average) | Std. germ. | $NH_4Cl$ | NaOH | Fast Aging | Cold Test | "True Rank" (Avg. of Lab Tests |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 1 | 5 | 3 | 7 | 6 | 6 | 4 | 13 | 7 |
| 2 | 11 | 9 | 12 | 11 | 15 | 15 | 15 | 12 | 16 | 15 |
| 3 | 14 | 13 | 3 | 10 | 13 | 13 | 4 | 10 | 10 | 10 |
| 4 | 5 | 7 | 9 | 7 | 11 | 2 | 5 | 5 | 15 | 8 |
| 5 | 6 | 11 | 15 | 11 | 17 | 17 | 16 | 8 | 17 | 15 |
| 6 | 7 | 10 | 10 | 9 | 5 | 3 | 2 | 2 | 11 | 5 |
| 7 | 9 | 3 | 8 | 8 | 1 | 9 | 7 | 14 | 14 | 9 |
| 8 | 10 | 4 | 4 | 6 | 10 | 5 | 9 | 9 | 12 | 9 |
| 9 | 8 | 2 | 7 | 6 | 4 | 14 | 11 | 6 | 1 | 7 |
| 10 | 13 | 5 | 1 | 6 | 3 | 7 | 8 | 13 | 6 | 7 |
| 11 | 8 | 14 | 17 | 13 | 16 | 16 | 17 | 19 | 8 | 15 |
| 12 | 4 | 11 | 13 | 9 | 12 | 10 | 14 | 16 | 7 | 12 |
| 13 | 18 | 16 | 19 | 18 | 18 | 20 | 19 | 20 | 19 | 19 |
| 14 | 16 | 12 | 14 | 14 | 14 | 12 | 12 | 18 | 5 | 12 |
| 15 | 1 | 8 | 6 | 5 | 2 | 4 | 1 | 1 | 2 | 2 |
| 16 | 12 | 11 | 9 | 11 | 8 | 8 | 13 | 17 | 4 | 10 |
| 17 | 15 | 14 | 16 | 15 | 9 | 11 | 10 | 7 | 3 | 8 |
| 18 | 2 | 6 | 2 | 3 | 6 | 1 | 3 | 3 | 9 | 4 |
| 19 | 17 | 15 | 11 | 14 | 19 | 18 | 20 | 15 | 20 | 18 |
| 20 | 19 | 17 | 18 | 18 | 20 | 19 | 18 | 11 | 18 | 17 |

all tests (Table 2) was the best or most vigorous e.g. varieties 15, 18 and 6. A variety with large numbers in all tests was non-vigorous e.g. varieties 13 and 20.

The combined field establishment percentage (Table 2) is the average percentage field establishment of each variety over the three dates of planting. While the "true rank" is the average of all laboratory tests. Again, the same varieties rated vigorous or non-vigorous and the rest are in between.

ii. Simple Correlations between Field Establishment and Laboratory Vigor Tests.

One of the criteria used to evaluate the various laboratory vigor tests was correlation with field establishment. Standard germination had the highest correlation with field establishment in all dates of planting (Table 3) except June 27 planting. Correlation between germination percentages following $NH_4Cl$ treatment and those of field establishment were second highest and those of NaOH were the third. All three were significant at the 1% level. Correlations between germination following accelerated aging and field establishment were significant (some at 1% and some at 5%) but were much lower than those of standard germination, $NH_4Cl$, and NaOH. As indicated previously the cold test was too harsh for millet; it had the lowest correlation with field establishment.

iii. Effectiveness of Laboratory Vigor Tests in Ranking Millets in Field Establishment.

In addition to comparing germination of laboratory vigor tests to field emergence, analysis of variance, mean separation procedures,

Table 3. SIMPLE CORRELATIONS BETWEEN PEARL MILLET FIELD ESTABLISHMENT AND LABORATORY VIGOR TESTS, 1977

| Laboratory Seed Vigor Test | May 12 Planting | June 7 Planting | June 27 Planting | Combined Over Planting Dates (Average) |
|---|---|---|---|---|
| Standard germination | .75** | .85** | .72** | .85** |
| Germination following $NH_4Cl$ treatment | .69** | .73** | .73** | .77** |
| Germination following NaOH treatment | .67** | .74** | .69** | .76** |
| Germination following accelerated seed aging | .53** | .50* | .47* | .54** |
| Cold test | | | | |
| i) seedling emergence | .37 | .47* | .34 | .44 |
| ii) seedling fresh wt | .40* | .51* | .38 | .48* |
| iii) seedling dry wt | .36 | .45* | .34 | .43 |

*Significant at 5%

**Significant at 1%

ranking, correlations, and rank means were also used to select the laboratory vigor test that best agreed with field establishment. Rank means were determined by subtracting the variety's rank in a particular laboratory test from the field establishment rank, then adding the absolute values of the differences of the 20 varieties and dividing by 20. The lowest rank mean then indicated the laboratory test closest to field establishment. Standard germination, $NH_4Cl$ and NaOH were almost equally correlated to field performance of millets (Table 4). Cold test was the worst and therefore was discarded in the second year of experimentation.

Germination following NaOH treatment overall average was closest (51.9% compared to 50.4%) to field establishment (Table 1) of June 29 planting. This coupled with high correlation and lower rank means seemed to better predict field establishment, although standard germination and $NH_4Cl$ treatments had similar results. These NaOH and $NH_4Cl$ treatment results agree with conclusions of Barnes (1960) and Abdullahi (1968), respectively.

VIGOR TESTS 1978

1. Laboratory Tests

a) The same tests and procedures were repeated in the second year. Very few modifications were made to refine them as outlined in the materials and method section. Results of the four vigor tests are summarized in Table 5. As in the previous year standard germination had the highest germination percentages for almost every variety followed by $NH_4Cl$, accelerated aging and finally NaOH. Their averages were 85.5%, 81.2%, 65.5% and 58.7% respectively.

Table 4. EFFECTIVENESS OF LABORATORY VIGOR TESTS IN RANKING THE 20 MILLETS FOR FIELD ESTABLISHMENT i.e. RANK MEANS, MANHATTAN, 1977

| Planting Dates | Laboratory Vigor Tests | | | | |
|---|---|---|---|---|---|
| | Std. Germ. | $NH_4Cl$ | NaOH | Fast Aging | Cold Test |
| May 12 planting | 4.3 | 3.8 | 3.9 | 3.6 | 5.6 |
| June 7 planting | 3.4 | 3.9 | 4.4 | 5.0 | 5.7 |
| June 29 planting | 3.6 | 3.5 | 3.2 | 4.8 | 5.8 |
| Combined over dates (Average field est.) | 3.5 | 3.3 | 3.4 | 3.8 | 5.0 |
| Overall Average | 3.7 | 3.6 | 3.7 | 4.3 | 5.5 |

Table 5. GERMINATION PERCENTAGES FROM LABORATORY MILLET VIGOR TESTS, 1978

| Varieties | Std. Germ. | Fast Aging | NaOH | $NH_4Cl$ | Average |
|---|---|---|---|---|---|
| 1 | 95 | 81 | 87 | 93 | 89 |
| 2 | 82 | 76 | 77 | 88 | 81 |
| 3 | 83 | 67 | 42 | 88 | 70 |
| 4 | 80 | 77 | 48 | 75 | 70 |
| 5 | 88 | 66 | 55 | 86 | 74 |
| 6 | 88 | 70 | 37 | 72 | 67 |
| 7 | 89 | 62 | 60 | 84 | 74 |
| 8 | 91 | 76 | 56 | 83 | 77 |
| 9 | 80 | 62 | 44 | 67 | 63 |
| 10 | 85 | 46 | 37 | 76 | 61 |
| 11 | 83 | 60 | 51 | 88 | 71 |
| 12 | 77 | 76 | 63 | 88 | 76 |
| 13 | 91 | 77 | 85 | 91 | 86 |
| 14 | 92 | 63 | 88 | 86 | 82 |
| 15 | 75 | 43 | 63 | 76 | 63 |
| 16 | 77 | 56 | 51 | 63 | 62 |
| 17 | 67 | 44 | 40 | 61 | 53 |
| 18 | 89 | 66 | 75 | 88 | 80 |
| 19 | 92 | 81 | 77 | 90 | 85 |
| 20 | 95 | 86 | 79 | 95 | 89 |
| 21 | 88 | 64 | 33 | 82 | 67 |
| 22 | 82 | 81 | 61 | 85 | 77 |
| 23 | 86 | 47 | 50 | 80 | 66 |
| 24 | 94 | 82 | 69 | 94 | 85 |
| 25 | 94 | 72 | 77 | 90 | 83 |
| 26 | 80 | 62 | 47 | 49 | 60 |
| 27 | 93 | 59 | 43 | 83 | 70 |
| 28 | 83 | 41 | 27 | 68 | 55 |
| 29 | 83 | 43 | 60 | 76 | 66 |
| 30 | 93 | 78 | 79 | 92 | 86 |
| Average | 85.8 | 65.5 | 58.7 | 81.2 | |
| LDS (.01) | 6.8 | 14.5 | 14.8 | 28.1 | |

In 1977 the accelerated aging had the lowest average percent germination except for the cold test, while in 1978 it was above the NaOH treatment. This was because of inverting the plastic containers so condensed moisture did not accumulate and also due to reduced duration of aging from 10 to 7 days. Temperature and relative humidity were increased from 32C and 80% in 1977 to 41C and 84% in 1978.

In each vigor test statistically significant differences were observed at both 1% and 5% levels. Among the most vigorous were varieties 1, 2, 13, 14, 18, 19, 20, 25 and 30 and the least vigorous were varieties 17, 26, 28, 23, 16 and 15.

b) Electrical Conductivity Test

i. Germination after soaking for 30 minutes.

After soaking for 30 minutes, seeds were separated into vigorous and non-vigorous and germinated separately. Normal germinated seeds from each of the two groups were counted and expressed as percentage of total seeds (Table 6).

Comparing the results of the "all germinated" seeds irrespective of the cut-off point to the so called "high vigor" seeds according to vigor analyzer, we realize that the electrolyte conductivity method under-estimated the germination capability of most of the 30 varieties. Only five varieties (2, 4, 6, 12 and 17) were over-estimated. Thus not all seeds labelled vigorous were actually vigorous. This point is again repeated when we compare the performance of vigorous (high vigor) seeds to vigorous germinated (high vigor germinated) seeds. No single

Table 6. PERCENTAGES OF VIGOROUS SEEDS (VIGOR ANALYZER) AND PERCENT GERMINATED, 1978

| Variety | Soaking Time: 30 Minutes | | | Soaking Time: Overnight | | |
|---|---|---|---|---|---|---|
| | High Vigor[1] | High Vigor Germinated | All Seeds Germinated[2] | High Vigor[1] | High Vigor Germinated | All Seeds Germinated[2] |
| | % | | | % | | |
| 1 | 40 | 37 | 89 | 88 | 82 | 87 |
| 2 | 91 | 76 | 82 | 99 | 76 | 77 |
| 3 | 55 | 52 | 92 | 81 | 64 | 74 |
| 4 | 78 | 51 | 61 | 85 | 77 | 83 |
| 5 | 65 | 60 | 90 | 90 | 72 | 76 |
| 6 | 79 | 58 | 73 | 88 | 71 | 76 |
| 7 | 49 | 40 | 80 | 78 | 70 | 81 |
| 8 | 76 | 69 | 87 | 92 | 63 | 67 |
| 9 | 78 | 64 | 82 | 84 | 65 | 69 |
| 10 | 55 | 46 | 77 | 81 | 61 | 67 |
| 11 | 62 | 55 | 84 | 85 | 64 | 72 |
| 12 | 81 | 67 | 79 | 93 | 76 | 79 |
| 13 | 62 | 46 | 79 | 88 | 80 | 86 |
| 14 | 79 | 65 | 84 | 95 | 70 | 72 |
| 15 | 50 | 45 | 86 | 89 | 72 | 75 |
| 16 | 75 | 62 | 76 | 82 | 62 | 66 |
| 17 | 70 | 41 | 63 | 74 | 56 | 59 |
| 18 | 67 | 59 | 87 | 81 | 69 | 80 |
| 19 | 48 | 47 | 94 | 86 | 69 | 78 |
| 20 | 46 | 44 | 92 | 90 | 78 | 85 |
| 21 | 76 | 54 | 79 | 90 | 54 | 56 |
| 22 | 73 | 63 | 77 | 90 | 56 | 58 |
| 23 | 47 | 40 | 78 | 84 | 64 | 69 |
| 24 | 57 | 54 | 96 | 91 | 73 | 76 |
| 25 | 68 | 67 | 96 | 91 | 70 | 74 |
| 26 | 57 | 41 | 70 | 81 | 27 | 30 |
| 27 | 76 | 66 | 83 | 90 | 71 | 75 |
| 28 | 34 | 24 | 50 | 59 | 38 | 52 |
| 29 | 49 | 40 | 81 | 70 | 51 | 58 |
| 30 | 72 | 66 | 91 | 87 | 67 | 70 |
| Average | 63.8 | 53.7 | 81.3 | 85.4 | 65.6 | 70.9 |
| LSD (.01) | 5.4 | 8.3 | 9.0 | 8.2 | 8.8 | 6.5 |

1/ According to vigor analyzer (<45 micro amps for 30 min soaking and <60 micro amps for overnight soaking).

2/ From both high and low vigor classes according to vigor analyzer.

seed lot labelled vigorous actually had all its seeds germinated. That is why we have lower germination percentages of the seeds which actually germinated in each variety.

Comparing all seeds germinated to the high vigor germinated seeds, the same trend exists. In general, it is concluded that not all seeds of high vigor germinated.

This method did not prove worthwhile as it under-estimated the germination capability of the seeds no matter if they were vigorous or non-vigorous.

ii. Germination following overnight soaking.

Realizing the 30 minute soaking did not yield good results, soaking the seeds overnight was attempted. The same procedure as outlined in the 30 minute soaking was followed. The germination percentages are indicated in Table 6.

When we compare the germination percentages of vigorous seeds (high vigor) to all seeds germinated (standard germination) the vigorous group has higher germination percentages in each variety except 7. This is contrary to the results of the 30 minute soaking. It means a higher proportion of the seeds labelled vigorous actually had germinated. In this comparison it is surprising to note that the vigorous seed (high vigor) germination percentages are always above those of all germinated seeds. The seeds had already started to germinate at the time of taking electrical conductivity and soluble contents of the seeds should have caused the readings to be higher; meaning non-vigorous seeds. But this was not the case.

The same trend of the lowest germination percentages from the vigorous germinated group continued to exist. The germination percentages of high vigor germinated (overnight soaking) were closer to all seeds germinated (averages 65.6% and 70.9%) than for 30 minute soaking (averages 53.7% and 81.3%). Thus the vigor analyzer was better in predicting non-vigorous seeds than vigorous seeds.

2. Field Establishment, Manhattan, 1978

The unpredictable heavy storms in 1977 forced us to take precautional measures by taking seedling conts at 7 and 24 days for each planting date in 1978. Field establishment was always higher for 7 day counts than for 24 day counts as indicated in Table 7.

Planting pearl millet very early (May 2) had the lowest field establishment percentages ranging from 0 to 7% because soil temperature was too low for the millet. Planting at the end of May had fairly good stands ranging from 41% to 68% for 7 day count and from 24% to 51% for 24 day count. The June 13 planting might have had better field establishment still, but on the 4th day after planting a heavy storm destroyed a proportion of the seedlings before even the 7 day count was made. That is why this third planting date had lower field establishment percentages than those of the second date. Whereas, July 7 planting had the highest field establishment for both 7 day and 24 day counts. Varieties 1, 8, 24, 30, 18, 19, 20 and 22 still had consistently higher field establishment in all dates of planting. Varieties 3, 5, 6, 16, 17, 23 and 26 had poor field establishment as they did in the laboratory stress tests.

Table 7. PERCENTAGES OF FIELD ESTABLISHMENT, MANHATTAN, 1978

| | May 2 | May 30 | | June 13 | | July 7 | | Combined Over Dates | |
|---|---|---|---|---|---|---|---|---|---|
| | 24 days | 7 days | 24 days | 7 days | 24 days | 7 days | 24 days | 7 days | 24 days |
| 1 | 7 | 68 | 51 | 46 | 36 | 88 | 75 | 67 | 42 |
| 2 | 5 | 62 | 29 | 36 | 27 | 88 | 74 | 62 | 34 |
| 3 | 1 | 65 | 35 | 26 | 20 | 63 | 49 | 51 | 26 |
| 4 | 7 | 55 | 40 | 36 | 28 | 70 | 60 | 54 | 34 |
| 5 | 1 | 55 | 30 | 33 | 23 | 72 | 62 | 53 | 29 |
| 6 | 4 | 47 | 32 | 27 | 19 | 55 | 48 | 43 | 26 |
| 7 | 1 | 66 | 44 | 47 | 33 | 75 | 64 | 63 | 36 |
| 8 | 2 | 69 | 42 | 48 | 32 | 78 | 64 | 65 | 35 |
| 9 | 2 | 46 | 30 | 32 | 27 | 72 | 58 | 50 | 29 |
| 10 | 1 | 41 | 29 | 29 | 19 | 70 | 58 | 46 | 27 |
| 11 | 2 | 62 | 37 | 32 | 22 | 72 | 58 | 55 | 28 |
| 12 | 5 | 61 | 33 | 28 | 24 | 70 | 58 | 53 | 30 |
| 13 | 5 | 68 | 42 | 42 | 28 | 79 | 52 | 63 | 32 |
| 14 | 3 | 64 | 31 | 29 | 20 | 81 | 54 | 58 | 27 |
| 15 | 6 | 54 | 32 | 47 | 38 | 65 | 52 | 55 | 32 |
| 16 | 0 | 45 | 32 | 28 | 21 | 64 | 53 | 46 | 27 |
| 17 | 3 | 38 | 24 | 32 | 24 | 59 | 48 | 43 | 25 |
| 18 | 2 | 66 | 41 | 41 | 35 | 75 | 59 | 61 | 34 |
| 19 | 3 | 65 | 42 | 41 | 30 | 76 | 64 | 61 | 35 |
| 20 | 3 | 64 | 34 | 35 | 28 | 84 | 72 | 61 | 34 |
| 21 | 1 | 51 | 33 | 24 | 19 | 68 | 52 | 48 | 26 |
| 22 | 6 | 61 | 38 | 43 | 33 | 77 | 64 | 60 | 35 |
| 23 | 1 | 52 | 41 | 38 | 29 | 63 | 51 | 51 | 31 |
| 24 | 1 | 55 | 50 | 41 | 31 | 78 | 68 | 62 | 38 |
| 25 | 0 | 56 | 34 | 27 | 20 | 81 | 65 | 55 | 30 |
| 26 | 0 | 41 | 31 | 24 | 20 | 62 | 53 | 42 | 26 |
| 27 | 1 | 54 | 37 | 38 | 27 | 72 | 57 | 55 | 31 |
| 28 | 3 | 51 | 29 | 36 | 30 | 72 | 59 | 63 | 31 |
| 29 | 2 | 54 | 29 | 43 | 30 | 71 | 62 | 56 | 31 |
| 30 | 1 | 62 | 41 | 43 | 34 | 81 | 66 | 62 | 36 |
| Avg. | 3 | 57 | 36 | 36 | 27 | 73 | 59 | 55 | 31 |
| $LSD_{.01}$ | 13% | 11.2% | | 13% | 11.2% | 13% | 11.2% | 6.4% | 5.6% |

$LSD_{.01}$ between 2 dates means (7 days) = 6%

$LSD_{.01}$ between 2 dates means (24 days) = 8.8%

$LSD_{.01}$ dates with var. (7 days) = 11.7%

$LSD_{.01}$ dates with var. (24 days) = 11.2%

Results of analysis of variance showed that the dates, varieties and interaction between the two were all significant at 1% level for both 7 and 24 day counts. The F values for 24 day counts were lower than those of 7 day counts although both were significant at 1% (Appendix Table 22). The significant interaction indicates that the varieties responded differently in each planting date.

Excluding the first date of planting, because it had no 7 day count and had the lowest field establishment, from the analysis of variance did not affect the significance of F values for dates, varieties and interaction although their magnitudes were smaller than those when the first date was included.

3. Field Establishment, St. John 1978

St. John is a drier area than Manhattan. Therefore, the pearl millet field establishment for this particular study was not the best one. From the results indicated in Table 11, the first planting date (May 10) had better field establishment than the second planting date (May 30). Although the soil temperature during the first planting was not optimum for millet, the results are comparable to those of May 30 planting in Manhattan for the 24 day counts. Thus, the important stress for this planting date might be soil temperature. The same varieties that had better field establishment in Manhattan showed their superiority at St. John.

May 30 planting was severely affected by a heavy storm on the third day after planting. More than a quarter of the experiment was flooded for two days and both the 7 and 24 day counts were far below the first date. There was no interaction between variety and date of

planting indicating that varieties behaved in the same fashion for both planting dates. The two planting dates were significant at 5% while varieties were significant at 1% for both 7 and 24 day counts.

CRITERIA USED TO SELECT BEST VIGOR TEST

a) Ranking the Performance of Varieties in the Laboratory and Field; Manhattan 1978

Vigorous varieties ranked high in both laboratory stress tests and in the field (Table 8). Among the best performers were varieties 1, 2, 7, 8, 13, 18, 19, 20, 24 and 30. Those with lower germination percentages were 3, 6, 10, 16, 17, 21 and 26. Varieties 7 and 8 had fair performance in the laboratory but did better in the field. On the other hand, variety 20 had a better rank in the laboratory than in the field.

b) Ranking Millet Field Establishment and Laboratory Performance St. John 1978

In general, the same varieties which had better performance in Manhattan showed their superiority in this location as well. Varieties 1, 4, 13, 15, 20, 24, 25 and 30 had better field establishment at this location. Surprisingly variety 4 had far better field establishment here compared to Manhattan and was the only early maturing variety among the 30 tested. Variety 1 maintained its superiority over all varieties in both locations (Table 13).

c) Rank Means, Manhattan 1978

As outlined in the previous year, this method was used to select the laboratory vigor test that had the least amount of deviation from

Table 8. RANKS OF FIELD ESTABLISHMENT AND LABORATORY VIGOR TESTS, MANHATTAN 1978

| Variety | Std. Germ. | Fast Aging | NaOH | $NH_4Cl$ | May 2 Planting 24 Days | May 30 Planting 7 days | May 30 Planting 24 days | June 13 Planting 7 days | June 13 Planting 24 days | July 7 Planting 7 days | July 7 Planting 24 days | Combined Over Dates (Avg.) 7 days | Combined Over Dates (Avg.) 24 days | "True Rank" |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 4 | 2 | 3 | 2 | 3 | 1 | 4 | 2 | 2 | 1 | 3 | 1 | 3 |
| 2 | 23 | 10 | 7 | 10 | 6 | 12 | 28 | 15 | 17 | 2 | 2 | 10 | 10 | 13 |
| 3 | 20 | 14 | 25 | 10 | 23 | 8 | 14 | 28 | 26 | 27 | 27 | 21 | 27 | 17 |
| 4 | 25 | 8 | 21 | 24 | 2 | 18 | 10 | 15 | 14 | 21 | 13 | 18 | 10 | 20 |
| 5 | 14 | 16 | 17 | 14 | 23 | 18 | 25 | 18 | 21 | 16 | 12 | 17 | 21 | 15 |
| 6 | 14 | 13 | 28 | 25 | 8 | 25 | 20 | 27 | 29 | 30 | 29 | 27 | 27 | 20 |
| 7 | 12 | 20 | 15 | 16 | 23 | 5 | 3 | 3 | 6 | 13 | 9 | 7 | 4 | 16 |
| 8 | 10 | 10 | 16 | 18 | 16 | 1 | 5 | 1 | 7 | 9 | 9 | 4 | 6 | 14 |
| 9 | 25 | 20 | 23 | 27 | 16 | 26 | 25 | 20 | 17 | 16 | 18 | 21 | 21 | 24 |
| 10 | 17 | 26 | 28 | 22 | 23 | 29 | 28 | 23 | 29 | 21 | 18 | 24 | 24 | 23 |
| 11 | 20 | 22 | 19 | 10 | 16 | 12 | 13 | 20 | 22 | 16 | 18 | 16 | 22 | 18 |
| 12 | 28 | 10 | 12 | 10 | 6 | 15 | 18 | 25 | 20 | 21 | 18 | 20 | 19 | 15 |
| 13 | 10 | 8 | 3 | 5 | 6 | 3 | 5 | 9 | 14 | 7 | 25 | 6 | 13 | 7 |
| 14 | 8 | 18 | 1 | 14 | 11 | 10 | 23 | 23 | 26 | 5 | 21 | 13 | 24 | 10 |
| 15 | 29 | 29 | 12 | 22 | 4 | 20 | 20 | 3 | 1 | 24 | 25 | 16 | 13 | 23 |
| 16 | 28 | 24 | 19 | 28 | 29 | 27 | 20 | 25 | 23 | 25 | 23 | 26 | 24 | 25 |
| 17 | 30 | 27 | 26 | 29 | 11 | 30 | 30 | 20 | 20 | 29 | 29 | 26 | 29 | 28 |
| 18 | 12 | 16 | 9 | 10 | 16 | 5 | 8 | 9 | 3 | 13 | 15 | 9 | 10 | 12 |
| 19 | 8 | 4 | 7 | 7 | 11 | 8 | 5 | 11 | 10 | 11 | 9 | 10 | 6 | 7 |
| 20 | 2 | 1 | 5 | 1 | 11 | 10 | 16 | 17 | 14 | 3 | 3 | 10 | 10 | 2 |
| 21 | 14 | 17 | 29 | 19 | 23 | 24 | 18 | 30 | 29 | 23 | 25 | 26 | 27 | 20 |
| 22 | 23 | 4 | 13 | 15 | 4 | 15 | 11 | 6 | 6 | 10 | 9 | 10 | 6 | 14 |
| 23 | 16 | 25 | 20 | 20 | 23 | 22 | 8 | 13 | 12 | 27 | 26 | 21 | 16 | 20 |
| 24 | 4 | 2 | 10 | 2 | 23 | 5 | 2 | 9 | 8 | 9 | 4 | 8 | 2 | 5 |
| 25 | 4 | 12 | 7 | 7 | 29 | 16 | 16 | 27 | 26 | 5 | 6 | 16 | 19 | 8 |
| 26 | 25 | 20 | 22 | 30 | 29 | 29 | 23 | 30 | 26 | 28 | 23 | 29 | 27 | 24 |
| 27 | 6 | 23 | 24 | 18 | 23 | 20 | 13 | 13 | 17 | 16 | 20 | 16 | 16 | 18 |
| 28 | 20 | 30 | 30 | 26 | 11 | 24 | 28 | 15 | 10 | 16 | 15 | 18 | 16 | 27 |
| 29 | 20 | 29 | 15 | 22 | 16 | 20 | 28 | 6 | 10 | 19 | 12 | 15 | 16 | 22 |
| 30 | 6 | 6 | 5 | 4 | 23 | 12 | 8 | 6 | 4 | 5 | 5 | 8 | 4 | 5 |

the average field establishment of the varieties per date. Comparing the first date to each laboratory test we find that accelerated aging was better than NaOH followed by $NH_4Cl$ and standard germination (Table 9).

From the results of all planting dates we conclude that NaOH was the closest treatment to field establishment. It had the least deviation from field establishment followed by $NH_4Cl$, accelerated aging and standard germination. Again these results confirm the conclusions reached by Abdullahi (1968), Yayock et al. (1973) and Barnes (1960).

d) Effectiveness of Laboratory Vigor Tests to Rank the Millet Field Establishment, St. John 1978

Table 14 reveals that standard germination test had the largest deviation from field average establishment of the 30 varieties in each planting date, followed by accelerated aging test. The second best was $NH_4Cl$ while NaOH again had the smallest deviation from field establishment. Results are self explanatory that NaOH was the best stress treatment that had its germination percentages very close to field establishment.

e) Correlations Between Laboratory Vigor Tests and Millet Field Establishment, Manhattan 1978

Correlation between field establishment of May 30 planting and standard germination $NH_4Cl$, NaOH, and accelerated aging treatments were all significant at the 1% level for both 7 and 24 day counts. The opposite prevailed for the first planting (May 2) in which no significant correlations existed. The June 13 planting had mixed

Table 9. RANK MEANS OF LABORATORY VIGOR TESTS IN RANKING THE 30 MILLETS FOR FIELD ESTABLISHMENT, MANHATTAN, 1978.

| Planting Dates | Laboratory Vigor Tests | | | |
|---|---|---|---|---|
| | Std. Germ. | $NH_4Cl$ | NaOH | Fast Aging |
| May 2 Planting | 10.4 | 8.8 | 8.0 | 7.8 |
| May 30 Planting | | | | |
| 7 Days | 6.5 | 3.9 | 5.3 | 6.5 |
| 24 Days | 7.0 | 6.1 | 7.7 | 6.0 |
| June 13 Planting | | | | |
| 7 Days | 7.7 | 8.5 | 7.2 | 8.8 |
| 24 Days | 9.0 | 9.0 | 6.9 | 8.7 |
| July 7 Planting | | | | |
| 7 Days | 5.1 | 4.8 | 4.5 | 6.3 |
| 24 Days | 7.0 | 6.3 | 5.7 | 6.2 |
| Combined Over Dates (Average) | | | | |
| 7 Days | 6.1 | 4.8 | 4.4 | 6.3 |
| 24 Days | 6.4 | 6.2 | 5.3 | 5.8 |
| Overall Average | 7.2 | 6.5 | 6.1 | 6.9 |

results but NaOH was the only laboratory treatment which had significant correlation co-efficients (5% level) for the 7 and 24 day counts respectively. $NH_4Cl$ had only one significant correlation. This date of planting was damaged by the storm. The July 7 planting, as expected, had all correlations significant at 1% level for each laboratory treatment.

Each laboratory vigor test was highly correlated to average field establishment combined over the four dates of planting (Table 10). NaOH had the highest number (times) of significant correlations with field establishment followed by the other vigor tests.

The electrical conductivity method (vigor analyzer) gave very disappointing results (Table 10). Soaking the seeds for 30 minutes and sorting based on conductivity had the lowest correlation with field establishment. Insignificant negative correlation coefficients existed between the "high vigor seeds" according to the vigor analyzer and field establishment in five cases. The same trend was observed between high vigor germinated seeds and field stand. Average germination percentage of all seeds germinated irrespective of cut-off point (standard germination) were significantly correlated with May 30 and July 7 plantings and combined over dates for 7 and 24 day counts.

There was a slight difference in correlation coefficients between the standard germination and those for all seeds germinated irrespective of cut-off point. This may be due to sample size differences. In the former a total of 400 seeds were used while in the later case only 200 seeds were used. Secondly, the seeds might have lost viability between the time the standard germination test was conducted and the

Table 10. SIMPLE CORRELATIONS BETWEEN PEARL MILLET FIELD ESTABLIHSMENT AND LABORATORY VIGOR TESTS, MANHATTAN, 1978

| Laboratory Seed Vigor Test | May 2 Planting | May 30 Planting | | June 13 Planting | | July 7 Planting | | Combined Over Planting Dates | |
|---|---|---|---|---|---|---|---|---|---|
| | 24 day count | 7 day count | 24 day count | 7 day count | 24 day count | 7 day count | 24 day count | 7 day count | 24 day count |
| Standard Germination | -.13 | .61** | .61** | .29 | .17 | .60** | .50** | .60** | .54** |
| Germination following $NH_4Cl$ treatment | .20 | .84** | .56** | .39* | .30 | .69** | .55** | .77** | .60** |
| Germination following NaOH treatment | .32 | .69** | .45** | .44* | .39* | .76** | .57** | .76** | .59** |
| Germination after fast aging treatment | .34 | .64** | .57** | .16 | .16 | .57** | .56** | .56** | .55** |
| Germination after ½ hr soaking | | | | | | | | | |
| a) [1]All seeds below cut-off point (45 micro amps) | -.08 | .17 | -.06 | -.20 | -.22 | .22 | .11 | .09 | -.05 |
| b) Only those with high vigor and germinated | .07 | 0.10 | -.27 | -.32 | -.34 | -.02 | -.13 | -.17 | .29 |
| c) [2]All seeds germinated irrespective of cut-off pt. | -.19 | .57** | .42* | .22 | .16 | .46** | .41* | .51** | .42* |
| Germination following overnight soaking | | | | | | | | | |
| a) [1]All seeds below cut-off pt. (60 micro amps) | .42* | .56** | .43* | .31 | .24 | .44* | .34 | .52** | .42* |
| b) Only those with high vigor and germinated | .25 | .39* | .23 | -.01 | -.06 | .39* | .27 | .32 | .20 |
| c) [2]All seeds germinated irrespective of cut-off pt | .39* | .61** | .47** | .35* | .29 | .42* | .34 | .56** | .46** |

* Significant at 5% level
** Significant at 1% level

[1]High vigor according to Vigor analyzer.

[2]From both high and low vigor classes according to vigor analyzer.

time this test was carried out because the seeds were not kept in cold storage room. Another reason may be due to the effect of immersing the seed in water before normal germination was done.

Results obtained from soaking the millet seeds overnight were better than those of 30 minute soaking though not as good as those of the other four laboratory vigor tests. Vigorous seeds i.e. those below 65 micro amps were significantly correlated with field establishments of May 2, May 30, July 7 and combined over dates. Correlations between all seeds germinated irrespective of cut-off point and the various field establishments were not much different from those between standard germination and field establishments. Any minor difference may have been due to the three reasons given above.

Only two correlations were significant at 5% level between high vigor germinated seeds and field establishments (May 30 and July 7).

f) Correlations between Laboratory Vigor Tests and Field Establishment St. John 1978

Standard germination was not significantly correlated with field establishment for either planting date. $NH_4Cl$ treatment had a highly significant correlation with first planting date and with average field establishment of the varieties for 24 day counts. The highest correlations were obtained from the NaOH treatment (all correlations significant at 1%). Accelerated aging had two correlations which were significant at 5% level i.e. first date and average field establishment at 24 days (Table 12).

Table 11. PERCENTAGES OF FIELD ESTABLISHMENT, ST. JOHN, 1978

| Varieties | May 10 Planting 24 Days | May 30 Planting 7 Days | May 30 Planting 24 Days | Combined Over Dates (Average Var.) 24 Days |
|---|---|---|---|---|
| 1 | 45 | 46 | 42 | 44 |
| 2 | 44 | 33 | 24 | 34 |
| 3 | 28 | 24 | 18 | 23 |
| 4 | 44 | 39 | 32 | 38 |
| 5 | 31 | 23 | 19 | 25 |
| 6 | 31 | 20 | 16 | 23 |
| 7 | 35 | 22 | 16 | 26 |
| 8 | 31 | 30 | 21 | 26 |
| 9 | 33 | 31 | 25 | 29 |
| 10 | 29 | 18 | 15 | 22 |
| 11 | 34 | 20 | 18 | 26 |
| 12 | 40 | 28 | 21 | 30 |
| 13 | 37 | 44 | 30 | 33 |
| 14 | 34 | 42 | 30 | 32 |
| 15 | 37 | 37 | 29 | 33 |
| 16 | 25 | 28 | 21 | 23 |
| 17 | 28 | 24 | 20 | 24 |
| 18 | 34 | 34 | 26 | 30 |
| 19 | 32 | 21 | 15 | 24 |
| 20 | 34 | 33 | 28 | 31 |
| 21 | 22 | 20 | 15 | 18 |
| 22 | 34 | 23 | 18 | 26 |
| 23 | 35 | 29 | 23 | 29 |
| 24 | 39 | 26 | 19 | 29 |
| 25 | 36 | 23 | 17 | 26 |
| 26 | 19 | 11 | 9 | 14 |
| 27 | 23 | 18 | 15 | 19 |
| 28 | 34 | 29 | 23 | 29 |
| 29 | 34 | 15 | 12 | 23 |
| 30 | 38 | 33 | 24 | 31 |
| Average Dates | 33 | 28 | 21 | 27 |

LSD .01 for difference between two var. means = 21% (7 day count)
LSD .05 for difference between two date means = 11.7% (24 day count)
LSD .01 for difference between two variety means = 11.3% (24 day count)

Table 12. SIMPLE CORRELATIONS BETWEEN PEARL MILLET FIELD ESTABLISHMENT AND LABORATORY VIGOR TESTS, ST. JOHN, 1978

| Laboratory Seed Vigor Tests | May 10 Planting 24 days count | May 30 Planting 7 Days | May 30 Planting 24 Days | Combined Over Dates (for 24 days |
|---|---|---|---|---|
| Standard Germination | .16 | .17 | .13 | .16 |
| Germination following $NH_4Cl$ treatment | .52** | .36* | .32 | .45** |
| Germination following NaOH treatment | .58** | .57** | .49** | .58** |
| Germination following Fast Aging | .39* | .31 | .27 | .35* |

*Significant at 5% level.

**Significant at 1% level.

Table 13. RANKS OF FIELD ESTABLISHMENT AND LABORATORY VIGOR TESTS, ST. JOHN, 1978

| Variety | Std. Germ. | Fast Aging | NaOH | $NH_4Cl$ | "True Rank" | May 10 Planting 24 days | May 30 Planting 7 days | May 30 Planting 24 days | Combined Over Dates (Average) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 4 | 2 | 3 | 3 | 1 | 1 | 1 | 1 |
| 2 | 23 | 10 | 7 | 10 | 13 | 3 | 8 | 10 | 7 |
| 3 | 19 | 14 | 25 | 10 | 17 | 26 | 18 | 20 | 23 |
| 4 | 25 | 8 | 21 | 24 | 20 | 3 | 4 | 2 | 3 |
| 5 | 14 | 16 | 17 | 14 | 15 | 23 | 20 | 18 | 21 |
| 6 | 14 | 13 | 28 | 25 | 20 | 23 | 25 | 24 | 24 |
| 7 | 12 | 20 | 15 | 16 | 16 | 11 | 22 | 24 | 18 |
| 8 | 10 | 10 | 16 | 18 | 14 | 23 | 11 | 14 | 19 |
| 9 | 25 | 20 | 23 | 27 | 24 | 19 | 10 | 8 | 14 |
| 10 | 17 | 26 | 28 | 22 | 23 | 24 | 28 | 27 | 26 |
| 11 | 20 | 22 | 19 | 10 | 18 | 15 | 25 | 20 | 18 |
| 12 | 28 | 10 | 12 | 10 | 15 | 4 | 15 | 14 | 9 |
| 13 | 10 | 8 | 3 | 5 | 7 | 8 | 2 | 4 | 6 |
| 14 | 8 | 18 | 1 | 14 | 10 | 15 | 3 | 4 | 10 |
| 15 | 29 | 29 | 12 | 22 | 23 | 8 | 5 | 5 | 7 |
| 16 | 28 | 24 | 19 | 28 | 25 | 27 | 15 | 14 | 21 |
| 17 | 30 | 27 | 26 | 29 | 28 | 26 | 18 | 16 | 21 |
| 18 | 12 | 16 | 9 | 10 | 12 | 15 | 6 | 7 | 11 |
| 19 | 8 | 4 | 7 | 7 | 7 | 20 | 23 | 27 | 24 |
| 20 | 2 | 1 | 5 | 1 | 2 | 15 | 8 | 6 | 11 |
| 21 | 14 | 17 | 29 | 19 | 20 | 29 | 25 | 27 | 28 |
| 22 | 23 | 4 | 13 | 15 | 14 | 15 | 20 | 20 | 18 |
| 23 | 16 | 25 | 20 | 20 | 20 | 11 | 13 | 12 | 12 |
| 24 | 4 | 2 | 10 | 2 | 5 | 5 | 16 | 18 | 12 |
| 25 | 4 | 12 | 7 | 7 | 8 | 9 | 20 | 22 | 16 |
| 26 | 25 | 20 | 22 | 30 | 24 | 30 | 30 | 30 | 30 |
| 27 | 6 | 23 | 24 | 18 | 18 | 28 | 28 | 27 | 28 |
| 28 | 20 | 30 | 30 | 26 | 27 | 15 | 13 | 12 | 14 |
| 29 | 20 | 29 | 15 | 22 | 22 | 15 | 29 | 29 | 22 |
| 30 | 6 | 6 | 5 | 4 | 5 | 6 | 8 | 10 | 8 |

Table 14. EFFECTIVENESS OF LABORATORY VIGOR TESTS IN RANKING THE 30 MILLETS FOR FIELD ESTABLISHMENT, ST. JOHN, 1978

| Planting Dates | Laboratory Vigor Tests | | | |
|---|---|---|---|---|
| | Std. Germ. | $NH_4Cl$ | NaOH | Fast Aging |
| May 10 Planting | 8.6 | 6.5 | 5.7 | 7.6 |
| May 30 Planting | | | | |
| a) 7 day count | 9.6 | 8.5 | 6.3 | 8.1 |
| b) 24 day counts | 9.9 | 8.6 | 6.7 | 8.5 |
| Combined over dates (for 24 day count only) | 8.8 | 6.9 | 5.2 | 7.8 |
| Overall Average | 9.2 | 7.6 | 6.0 | 8.0 |

Testing the Agreement Among Vigor Tests in Ranking the Performance of Millet Seeds

To prove whether the millet seeds were ranked differently by the various vigor tests, coefficients of concordance (W) as outlined by Ostle (1963) and Siegel (1956) were calculated from the ranks in Tables 2, 8 and 13 by the following formula:

$$W = \frac{S}{\frac{1}{12} k^2 (N^3 - N)}$$

where S equals the sum of squares of deviations of total ranks assigned to each individual variety from the average value of the totals of the ranks; k is the number of vigor tests and N being the number of varieties ranked. The calculated $X^2$ is approximately distributed as chi-square with (N-1) degrees of freedom.

Cold and electrical conductivity tests were discarded in calculating this W and only the average field establishments in both years were used. In this ranking test, the Kendall coefficients of concordance (W) were significant at 1% level. This shows that the hypothesis that the ranks assigned to each variety are completely random and unrelated in rejected. This means that the various tests used to evaluate the performance of the seeds (vigor) were essentially similar in ranking the millet seeds as vigorous, non-vigorous or between the two. Similarly, highly significant (W) results were obtained by using the average field establishments for 7 and 24 day counts. Therefore, any of the vigor tests used in this study can be used to predict the field establishment of pearl millet except cold test and the 30 minute soaking procedure of the electrolyte conductivity test.

Simple Correlations Between Millet Field Establishment at Manhattan and St. John 1978

Despite the poor field establishment at St. John, one highly significant correlation (June 13 vs May 10) for field establishment of the millet between the two locations was obtained. Correlations between May 30 planting at St. John and the three dates of planting at Manhattan were non-significant. But the correlations between average field establishments were both significant at both 1% and 5% levels as indicated in Table 15. From these results we can conclude that the varieties tested had to some extent a wide range of adaptation. The vigorous varieties showed their ability to establish in the two locations with different environments and the non-vigorous varieties failed to be established well in the two locations. The actual field establishment was not consistent for a given variety either across locations or planting dates.

Table 15. SIMPLE CORRELATIONS BETWEEN MILLET FIELD ESTABLISHMENT AT MANHATTAN AND ST. JOHN, 1978

| | | St. John | | |
|---|---|---|---|---|
| | | May 10 | May 30 | Average |
| Manhattan | May 30 | .44* | .34 | .42* |
| | June 13 | .52** | .31 | .45** |
| | July 7 | .31 | .22 | .29 |
| | Average | .57** | .42* | .53** |

## SUMMARY AND CONCLUSIONS

The aim of the experiment was to measure vigor in grain millet varieties. Seed vigor is very critical for millet field establishment. Also, the purpose of the experiment was to evaluate the several methods used to determine seed vigor in other cereals and select the one most appropriate for pearl millet. Several criteria were used to select the best test e.g. correlations, ranking, rank means, and the Kendall coefficients of concordance.

In the laboratory, standard germination consistently was higher than germination following the stress tests because the non-vigorous seeds were killed during the harsh treatment. It was also noted that the vigorous varieties performed well in both laboratory stress tests and in the field. The opposite was true for non-vigorous seeds. Therefore, highly significant differences in vigor were observed among varieties.

Each vigor test was then evaluated for its ability to predict field establishment of millet. Criteria included:

1. Correlation with field establishment
2. Ability to rank millet varieties according to field performance.

The vigor test having the lowest rank means coupled with high correlations with field establishment was selected as the best to predict field establishment. Based on these criteria the NaOH treatment appeared to be the best vigor test although all vigor tests were similar in ranking the varieties as vigorous, non-vigorous or between the two.

The biggest problem in millet establishment even for vigorous seeds lies in the inability of seedlings to break through the soil crust after it has rained heavily or silting over or wash-out during early stages of field establishment (first week after planting). Any or a combination of the above factors will adversely affect their establishment.

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# APPENDIX

Table 16. PEARL MILLET VARIETIES USED IN VIGOR TESTS, 1977

| Serial No. | Identification No. | Year Grown |
|---|---|---|
| 1 | 2506 1542 | 1973 |
| 2 | K16 1490 | 1973 |
| 3 | 2505 1459 | 1973 |
| 4 | 2503 1551 | 1973 |
| 5 | 2465 1536 | 1973 |
| 6 | 2504 1552 | 1973 |
| 7 | K 15 1420 | 1973 |
| 8 | 2442 1534 | 1973 |
| 9 | 286844 204 | 1976 |
| 10 | 287059 4 | 1973 |
| 11 | 28065 44 | 1976 |
| 12 | K26 164 | 1976 |
| 13 | 287029 258 | 1976 |
| 14 | 286912 17 | 1976 |
| 15 | 286840 62 | 1976 |
| 16 | 286977 261 | 1976 |
| 17 | 287081 93 | 1976 |
| 18 | K15* | 1976 |
| 19 | Tift 23D | 1973 |
| 20 | Tift 239 | 1973 |

Table 17. ANOVA OF MILLET FIELD ESTABLISHMENT, MANHATTAN, 1977

| Source of Variation | d.f. | SS | MS | F |
|---|---|---|---|---|
| Replicates | 3 | 6260.58 | 2086.86 | |
| Dates | 2 | 15585.56 | 7792.78 | 11.18** |
| Error (a) | 6 | 4182.64 | 697.11 | |
| Varieties | 19 | 17010.02 | 895.26 | 8.55** |
| Var. X dates | 38 | 3649.11 | 96.03 | 0.92 |
| Error (b) | 171 | 17899.28 | 104.67 | |
| Total | 239 | 64587.18 | | |

**Significant at 1%.

Table 18. ANOVA OF LABORATORY VIGOR TESTS, 1977

| Source of Variation | Degrees of Freedom | Standard Germination | $NH_4Cl$ | NaOH | Fast Aging | Cold Test: Seedling Emergence | Cold Test: Seedling Fresh Wt. | Cold Test: Seedling Dry Weight |
|---|---|---|---|---|---|---|---|---|
| | | Mean Squares | | | | | | |
| Replicates | 3 | 35.55 | 14.47 | 13.41 | 60.47 | 33.51 | 0.15 | 0.0003 |
| Varieties | 19 | 194.38** | 222.39** | 462.64** | 285.09** | 106.93* | 2.78** | 0.0134** |
| Error | 57 | 7.61 | 15.14 | 15.87 | 26.02 | 25.59 | 0.75 | 0.0038 |

**Denotes significance at the 0.01 level of probability.

Table 19. PEARL MILLET USED IN SEEDLING VIGOR EXPERIMENT, 1978

| Serial No | Sp | Origin | PI No. | Heads/ row | Height (inches) | No tillers | Lodging score | Head diam. (inches) | Head Length (inches) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | Uganda (Serene 3A) | | | 82 | 5 | 2 | 1¼-1½ | 5-12 |
| 2 | typhod | S. Afr. | 307697 | 25 | 54-80 | 4 | 2 | 1½-2 | 6-10 |
| 3 | typhod | A. Afr. | 307710 | 12 | 56-86 | 3 | 2 | 1 - 1½ | 8-16 |
| 4 | | | | 1976 | Bulk dward, | open | pollinated | | |
| 5 | spctum | Nigeria | 286865 | 21 | 80-110 | 2 | 3 | ½-1¼ | 7-16 |
| 6 | spctum | Nigeria | 286959 | 19 | 60-90 | 55 | 2 | 1 - 2 | 7-24 |
| 7 | spctum | Nigeria | 2287041 | 13 | 48-100 | 6 | 2 | ½-1½ | 8-16 |
| 8 | spctum | Nigeria | 286917 | 15 | 70-100 | 6 | 4 | 1 -1¼ | 10-18 |
| 9 | spctum | Rhodesia | 295157 | 19 | 50-84 | 5 | 1 | ½-1 3/4 | 4-12 |
| 10 | spctum | Nigeria | 286955 | 31 | 60-88 | 6 | 3 | 1 - 1¼ | 8-20 |
| 11 | spctum | Nigeria | 286845 | 13 | 80-105 | 4 | 9 | 1 - 1½ | 16 |
| 12 | spctum | Rhodesia | 295160 | 18 | 51-100 | 7 | 3 | 3/4-1½ | 6-12 |
| 13 | | | 286898 | (1972 | selfed) | | | | |
| 14 | spctum | Nigeria | 287016 | 13 | 60-96 | 4 | 1 | 1 - 1½ | 8-18 |
| 15 | | | 286838 | (1972 | open pollinated) | | | | |
| 16 | spctum | Nigeria | 287065 | 21 | 60-100 | 4 | 4 | 1-1 3/4 | 6-20 |
| 17 | spctum | Nigeria | 286894 | | | | | | |
| 18 | spctum | Nigeria | 286864 | 10 | 60-100 | 3 | 3 | 1 - 1¼ | 9-16 |
| 19 | spctum | Nigeria | 286884 | 22 | 60-100 | 5 | 2 | 1 - 1¼ | 9-16 |
| 20 | spctum | Nigeria | 286899 | 21 | 70-98 | 5 | 5 | 1 - 1½ | 8-18 |
| 21 | spctum | Nigeria | 287061 | 2 | 60-100 | 4 | 3 | 1 - 1½ | 10-12 |
| 22 | spctum | Nigeria | 287049 | 16 | 40-96 | 5 | 1 | 1 - 2 | 7-24 |
| 23 | spctum | Nigeria | 286871 | 12 | 60-90 | 3 | 2 | 3/4-1¼ | 12-24 |
| 24 | | | | Ballon | | | | | |
| 25 | spctum | Nigeria | 286867 | 11 | 76-110 | 2 | 3 | ½- 1¼ | 9-16 |
| 26 | spctum | Nigeria | 287062 | 16 | 66-100 | 4 | 2 | 1 - 2 | 12-24 |
| 27 | spctum | Nigeria | 286914 | 12 | 70-94 | 6 | 4 | 1 - 1¼ | 8-16 |
| 28 | spctum | Nigeria | 286889 | 17 | 62-86 | 4 | 7 | ½-1½ | 6-12 |
| 29 | spctum | Nigeria | 286971 | 18 | 70-100 | 4 | 3 | 1-1 3/4 | 8-16 |
| 30 | spctum | Nigeria | 286869 | 1 | 70-110 | 3 | 1 | 1 - 1¼ | 12-24 |

NS spctum = Pennisetum spicatum

typhod = Pennisetum typhoides

lodging score = 0-9; 9 = worst, 0 = no lodging

Table 20. ANOVA OF LABORATORY VIGOR TESTS, 1978

| Source of Variation | Degrees of Freedom | Standard Germination | $NH_4Cl$ | NaOH | Fast Aging |
|---|---|---|---|---|---|
| | | ---------- Mean Squares ---------- | | | |
| Replicates | 3 | 244.2* | 361.2 | 30.4 | 8.6 |
| Varieties | 29 | 190.1** | 484.3** | 1209.7** | 720.6** |
| Error | 87 | 13.0 | 223.4 | 62.4 | 59.7 |

**Denotes significance at the 0.01 level of probability.

Table 21. ANOVA OF SEED ELECTROLYTE CONDUCTIVITY, 1978

| Source of Variation | Degrees of Freedom | 30 Minute Soaking | | | Overnight Soaking | | |
|---|---|---|---|---|---|---|---|
| | | High Vigor and Germinated | All seeds of High Vigor | All Seeds Germinated | High Vigor and Germinated | All seeds of High Vigor | All Seeds Germinated |
| Replicates | 3 | 118.1** | 27.0 | 236.5** | 3055.6** | 308.9** | 2755.0** |
| Varieties | 29 | 149.3** | 204.6** | 109.1** | 141.4** | 63.3** | 140.1** |
| Error | 87 | 23.3 | 20.3 | 12.8 | 21.0 | 8.9 | 24.6 |

Table 22. ANOVA OF MILLET FIELD ESTABLISHMENT, MANHATTAN, 1978

| | 7 Day Counts | | 24 Day Counts | | | |
|---|---|---|---|---|---|---|
| | 2 - 4 Planting dates | | 2 - 4 Planting dates | | 1 - 4 Planting dates | |
| Source of Variation | Degrees of Freedom | Ms | Degrees of Freedom | Ms | Degrees of Freedom | Ms |
| Replicates | 3 | 203.7 | 3 | 1319.5 | 3 | 971.2 |
| Dates | 2 | 41275.3** | 2 | 33736.0** | 3 | 65788.5** |
| Error (a) | 6 | 156.6 | 6 | 478.5 | 9 | 437.7 |
| Varieties | 29 | 582.4** | 29 | 337.5** | 29 | 279.8** |
| Var. X date | 58 | 118.6** | 58 | 91.4** | 87 | 85.3** |
| Error (b) | 261 | 37.5 | 261 | 49.0 | 348 | 37.6 |
| Total | 359 | | 359 | | 479 | |

**Significant at 1%.

Table 23. ANOVA OF MILLET FIELD ESTABLISHMENT, ST. JOHN, 1978.

| | 7 Day Count | | 24 Day Counts | |
|---|---|---|---|---|
| | May 30 Planting | | May 10 and May 30 Planting | |
| Source of Variation | Degrees of Freedom | MS | Degrees of Freedom | MS |
| Replicates | 3 | 1461.2** | 3 | 194.4 |
| Dates | - | - | 1 | 8550.2* |
| Error (a) | - | - | 3 | 817.0 |
| Varieties | 29 | 289.9** | 29 | 286.4** |
| Var. X Date | - | - | 29 | 56.6 |
| Error (b) | 87 | 131.2 | 174 | 76.4 |
| Total | 119 | | 239 | |

*Significant at 5%.

**Significant at 1%.

# SEED VIGOR MEASUREMENTS AND THEIR USE IN PREDICTING FIELD ESTABLISHMENT OF GRAIN PEARL MILLET (PENNISETUM AMERICANUM)

by

GALLUS JOSEPH MWAGENI

B. Sc., North Carolina State University, 1973

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KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Seed vigor is one of the main problems that limit grain millet production because it affects directly the field establishment. This in turn affects yield.

This experiment was carried out to measure vigor in grain millet seeds and secondly to select among vigor tests the one most appropriate for pearl millet.

Laboratory and field tests were conducted in 1977 and 1978 to investigate the degree to which laboratory tests could predict field establishment of pearl millet. Laboratory tests included standard germination, electrical conductivity of soaked seeds and stress tests of soaking the seeds in ammonium chloride solution, soaking seeds in sodium hydroxide solution, artificially aging at high temperature and relative humidity, and soil cold testing. In 1977, 20 varieties were used while in 1978 a different set of 30 varieties were used. In both years the germination percentages from the laboratory tests were compared for their effectiveness to predict field establishment. Field studies included 3 planting dates in 1977 and 4 in 1978 at Manhattan and 2 planting dates at St. John in 1978. Field establishment counts were recorded after 24 days in 1977 and after 7 and 24 days in 1978.

Germination percentages from the stress tests were lower than those from standard germination because seeds of low vigor were killed after being subjected to the adverse treatments while vigorous seeds remained relatively unaffected.

Millet planted between June 13 and July 7 had higher establishment than for May planting, probably because of higher temperatures.

The criteria used to evaluate vigor included:

1. Correlation with field establishment.
2. Ability to rank millet varieties according to field performance.

These criteria suggest that all laboratory tests used except the electrical conductivity following 30 minute soaking were able to some degree, to screen vigorous from non-vigorous seeds. Soaking the millet seeds in 5% sodium hydroxide solution for 2 minutes prior to normal germination seemed to be the best vigor test although $NH_4Cl$, accelerated aging, and standard germination treatments were significantly (at 0.01 level) similar in ranking the seeds vigorous or non-vigorous. Therefore, a variety having comparatively higher performance in both laboratory stress tests and in different dates of planting should be considered the most vigorous variety.