# SEED VIGOR MEASUREMENTS AND THEIR USE IN PREDICTING FIELD ESTABLISHMENT OF GRAIN SORGHUM

by

ANGO ABDULLAHI

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Major Professor

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# INTRODUCTION

The fundamental objective of seed testing is to establish seed quality and provide a basis for consumer discrimination among seed lots.

Total germination as determined by standard germination procedures, though by no means outliving its usefulness, has recently received greater criticism for inadequacy in establishing seed quality. Criticism of the standard laboratory test is usually based on the fact that it is carried out under such highly favorable conditions that it may fail to predict field emergence with sufficient accuracy. This is because of its failure to detect weaknesses which may be present in the seed. Consequently, the standard laboratory test may over-evaluate the value of a seed lot with regard to its actual performance in the field, particularly when soil moisture and temperature conditions are not optimum.

Results of several experiments with many cultivated crops have shown variable degrees of discrepancy between laboratory and field germination. This discrepancy is probably greater for sorghum than most field crops (43). The gap between laboratory test and field test values is to a large extent related to the soil conditions prevailing at planting.

Attempts to predict field performance of seed lots more accurately have involved investigation of many facets of seed or its behavior before and during germination. Hitherto, the critics contended, the present standard laboratory test methods merely evaluate germination potential. The new tests generally referred to as vigor tests are of several kinds.

The cold test for corn which attempts to simulate in the laboratory the adverse field conditions frequently encountered in early spring planting is the most outstanding and the only vigor test now in frequent use in the United States. Other vigor tests include biochemical tests based on enzyme activity, as in tetrazolium tests; the speed of germination and physical measurement of seed or seedlings, as in seed size or the growth rate of seedlings.

Such vigor tests often give a better indication of field performance than the standard germination tests. Some or maybe all of these tests may one day serve as a basis for routine tests of seed quality. When standardized and perfected, the most useful vigor tests should be those most closely related to crop performance in the field. Then, seedmen would be able to control production quality in a way similar to that by which manufacturers control the quality of goods.

The objective of this study was to compare the relative effectiveness of the standard laboratory germination, various laboratory treatments prior to germination and cold test in differentiating vigor in seed lots and in predicting field emergence and yield performance of such seed lots of grain sorghum planted under both favorable and unfavorable field conditions.

# REVIEW OF LITERATURE

Published information on seed vigor has become quite extensive over the past twenty-five years. This review of literature aims to give an outline of the numerous vigor test techniques developed, and investigations pertinent to the present study. In general, vigor tests seek to determine the stand-producing ability of seeds under crop production situations.

Dickson (10) in 1923 first reported cold testing of corn. He planted corn in scab infested soil and studied emergence under varying soil temperatures. He observed a gradual increase in the period of emergence when soil temperatures were lowered from 75 to 70$^{\circ}$ F and more rapid increase in the time of emergence as the temperature went from 75 to 45$^{\circ}$ F. Since Dickson's reports, several workers have used the corn cold-testing procedures with modifications where necessary to test vigor in seeds of corn and other crops.

Tatum (46) reported highly significant correlations between cold test germination of corn and field establishment. Clark (4, 5) using similar methods showed that cold testing provided a better indication of field germination of peas and onions than standard laboratory germination.

The first cold test study with sorghum was undertaken in Israel by Pinthus and Rosenblum in 1959 and 1960 (32). In the study they reported a significant decrease in seedling emergence from cold soils when the seed lots were not treated against seed decay micro-organisms. They also observed a considerable slowing down of emergence when germination temperature was below 18$^{\circ}$ C. However, they found that total germination under low temperatures can equal that at 26° C if the sorghum seeds were treated against seed and soilborne disease organisms. They concluded that the cost test yielded information appropriate for estimating the effect of soilborne and seedborne pathogens on germination of sorghum at low temperatures.

Many other investigators (6, 7, 17, 18) agreed that soil micro-organisms have an adverse effect on seed germination and vigorous growth of seedlings of corn or sorghum when planting is done under cold, wet-soil conditions, and that the cold test is not a test for cold resistance but rather a test for resistance to seed rotting fungi which attack slowly germinating kernels in cold soils.

Hansing (14) reported that Kansas farmers have difficulty in obtaining uniform stands of sorghum even when apparently healthy seeds are planted. He pointed out the importance of seed and soilborne fungi which cause decay and seedling blight particularly when soils remain cold and wet after seeding.

Some workers, however, (20, 45, 44, 13, 24) found other factors beside seed and soil micro-organisms to cause seed to germinate poorly. These factors may either be inherited (44) or have something to do with the physical and/or physiological conditions of the seed at time of testing.

Koehler (22) and Tatum (44, 45) reported decreased germination of corn seeds because of pericarp injuries. Goodsell et al. (12) found that old age of seed adversely affected its germination under cold temperature. Rush (38) and Livingstone (24) and Rossman (37) agreed that immaturity at harvest, poor drying methods and degree of frost damage before harvest, singly or in combinations, would reduce germination of corn under cold testing.

Rosenow et al. (36) studied germination of sorghum, with a moisture content of 34% or higher, at temperatures between 22 and 75° F. They found that germination was greatly reduced under these conditions.

Robbin and Porter (34) observed dormancy in freshly harvested immature sorghum seed and such dormancy was overcome by drying and prechilling before germinating at 20-30° C alternating temperature. They also reported reduced viability when immature sorghum seed was exposed to low temperatures. But mature seed, with a moisture content of 15% or less, was unaffected by exposure to any temperature between 33 and -20° F. Goodsell (12) concluded that temporary seed dormancy was a problem only in seed planted immediately after harvest. Gritton and Atkins (13) showed that such temporary dormancy in sorghum seed existed only 14-30 days after harvest. This dormancy was of no significance 3 months after harvest. They also found no association between seed weight and dormancy.

Isely (19), Svien and Isely (42) and Wernham (49) reviewed the literature concerning the cold test and discussed its tentative merits as a vigor test. They pointed out that the cold test has been difficult to standardize because temperature and soil conditions, especially soil micro-organisms, differ from one geographical area to another.

Numerous field investigations with sorghum have indicated the importance of soil moisture and temperature as they affect establishment and yield.

Stoffer (41) concluded that highest field emergence occurs after soil temperature at sunrise and at the 4 inch depth reaches $65^{\circ}$ F. They, therefore, suggested that soil temperature would be a better criterion for determining the time for planting grain sorghum during spring than specific calendar date, provided soil moisture and other factors are favorable.

Cushing et al. (8) reported a decrease in time from planting to sorghum field emergence with each successive planting date from May 15 to June 1 in Nebraska. Vinall et al. (48) found an increase in yield of grain sorghum with progressively later seeding dates at several locations throughout the Great Central Plains of the United States. In Arizona and California, Martin et al. (25) reported better yield response in plots seeded after June 1 than in earlier plantings. Buchholtz (3), however, reported better yield responses at earlier planting dates, May 18 and May 24, than at later ones in South Dakota. In a study concerning date of planting and yield of early, intermediate and late hybrid sorghums in Manhattan and Powhattan, Kansas, Stickler et al. (40) found that all hybrids under test yielded best at the earliest planting date (May 8) but the late hybrids were especially responsive to early planting averaging 143 bushels per acre. They also noted that early hybrids could be planted later without encountering reduced yield than could be planted later without encountering reduced yield than could medium or late hybrids.

Other kinds of vigor tests which involve measurements of seed or seedling characteristics before and after certain biological, chemical or physical treatments have been widely investigated and reported.

Moore (26, 27) reported that seed staining patterns with tetrazolium revealed weaknesses not detectable in standard germination tests and that both mechanical injuries and physiological deterioration can be detected in this way.

Rice (33) studied the effects of natural aging and mechanical damage on the vigor of hybrid corn seed by use of iodonitrophenyl tetrazolium chloride with other vigor tests. The (INT) test compared favorably with the cold and growth-measurement tests. The intensity of red coloring developed within a specified time interval was an index of seed vigor.

Barnes (2) found that soaking sorghum seeds in 5% sodium hydroxide solution for 5 minutes before standard germination was one of the most effective tests for differentiating vigor among seed lots. Helmer, Delouche and Lienhard (16) soaked crimson clover seeds in 2% ammonium chloride solution for two hours prior to normal germination, and this technique effectively screened vigorous from non-vigorous seed lots. They also measured vigor by artificially aging crimson clover seed at $100^{\circ}$ F and 100% relative humidity for ten days before germination.

Tatum (46) described a water-soak test in which corn seeds from various lots were soaked in water. Turbidity of the steep water was measured and compared with germination under a cold-test situation. A highly significant correlation was found between per cent cold-test germination and turbidity of steep water. It was suggested that very permeable seeds, as indicated by a high concentration of solid material leached out during the soaking period, were more susceptible to cold-test conditions.

Moore (26), working with cotton seed, showed that seed lots of low vigor could be detected by soaking seeds in water under vacuum prior to testing for germination. This treatment either killed seeds of low vigor or caused them to develop abnormal sprouts. Moore further stated that, for acid-delinted cotton seed, the vacuum test gave results comparable to field emergence.

Heise (15) reported a vigor test, used in Holland, based on speed of germination. Seeds were germinated on ruled filter paper on a 'start' or 'zero' line, and after a given period vigor was measured by the length of plumules and the radicles. Throneberry and Smith (47) developed a formula for measuring speed of germination involving summation of the number of normal seedlings per 100 seeds germinated each day and multiplication by the reciprocal of the time in days. Nutile and Hackett (29), in a study of several seed lots differing in speed of germination and percentage germination, found a relationship between vigor as measured by first count in the blotter test and emergence of normal seedlings in laboratory and greenhouse soil tests.

Several workers have studied the effects or influence of seed size on vigor of seeds. Much of the literature on seed size effect on crop development, particularly in perennial grasses, is European. In general, the studies showed that within a seed lot large seeds give the best seedlings, between lots the largest seeded ones have the best vigor and establishment, and among species there is little relationship between size and seedling vigor.

Nadvornick (28) and Davies (9) found higher germination and vigor for large seeds within a species of ryegrass and also showed that this difference was not due to more stored food alone since heavy seeds with part of the endosperm removed still grew better than lighter ones. Peace (31), in the United States, obtained significant phenotypic and genotypic correlation between seed weight and seedling vigor for 20 smooth bromegrass strains. He emphasized that when the seed size was held constant in covariance analysis, the variance among sources was still significant indicating that intensive selection for seedling vigor must be concerned with more than just seed weight.

Rogler (35) studied emergence from various planting depths for strains of crested wheatgrass with seeds of varying sizes. He found high positive correlations between size of seed and emergence at 2 inch or 3 inch depths of planting. He concluded that selection for large seed size was a direct method of increasing seedling vigor in crested wheatgrass.

Kotowoski in Poland (23) distinguished differences due to seed size during the early growth of pea plants, but this difference was no longer evident when flowering began. He also found that seed size does not ultimately affect the number of pods per plant or seed weight within each pod. In a similar study with cabbage he reported that seed size influenced the size of seedlings during a 60-day growth. Effect of seed size disappeared, however, during the time of field growth, and productivity did not depend on the size of seed planted.

Swanson and Hunter (43), in their study at Manhattan in 1931, found that seed size does not appear to be a varietal factor in sorghum germination from the standpoint of reserve food supply, as small seeded sorghums showed a tendency to germinate better than large seeded varieties. However, they found seed size to be an important factor in the mechanical process of planting. Farmers frequently use planting plates with improper perforations or planter speeds and as a result obtain stands too thin, or, more frequently, too thick for best yields. They also studied many samples of sorghum and found that discrepancy between field and laboratory germination was probably greater for sorghum than for any other field crop.

## MATERIALS AND PROCEDURES

Nine lots of RS610 hybrid sorghum seed were procured from Texas, Missouri, Kansas and Nebraska. The seed was from the 1966 sorghum crop and when received all but two lots were treated. Visual examination indicated that the seed treatment chemical was probably Captan. In order to remove seed treatment differentials among the lots all lots were redusted with Ceresan.

Influence of seed size on the laboratory and field tests was one of the important aspects of this study. Seeds of each lots were separated into three size groups--large, medium, small with the original sample making up a fourth group. The large, medium and small seeds were screened with graduated round holes of varying diameter. The large seeds were retained by holes 10/64 inch in diameter and the medium and small size seeds by holes 9/64 and 8/64 inch diameter, respectively. The composite group was simply taken from the original lots. Two random replicates of 250 seeds from each size group of each lot were sampled at random and weighed to determine the relationship between seed size and seed weight. The tests to be described in the following paragraphs involved 36 treatments, combinations of 9 seed sources and 4 seed sizes.

Laboratory Method. Two methods were employed to measure seed vigor in the laboratory as follows:

1. Standard Laboratory Germination. Four random replications of 50 seeds from the thirty-six treatment combinations were germinated as provided in the standard rules for laboratory germination of seeds (1). Temperature in the germinator, however, fluctuated between 25 and 27$^{\circ}$ C.

Counts were taken after two days and when germination was complete. In each case only normal seedlings which had developed according to standard rules were counted.

2. Stress Treatment Tests.

a. Artificial aging of seeds. Approximately 60 gm of seed from each source seed size group were placed in small, wide-topped open bottles and all were placed in a growth chamber in which a temperature of 100° F and a relative humidity between 95 and 100% were maintained for ten days. Immediately after the treatment, four random replicates of 50 seeds each were germinated as in the standard method. Again germination counts were taken at two days and at the termination of the test.

b. Ammonium Chloride Treatment Test. Two per cent ammonium chloride solution was warmed to 40° C, and seed samples in loosely knit cotton bags were soaked in the warm solution for two hours. The seeds were then flushed and rinsed for about 30 seconds, and blotted dry prior to immediate germination. Four random replicates of 50 seeds each were germinated and counts were recorded at two days and at the end of the test.

c. Cold test. Six-hundred grams of unsterilized soil from adjacent to field plots were weighed into plastic quarter containers. Three replicates of 50 seeds from the subgroups were surface planted in the pots and another 250 gm of soil were added to cover the seeds. This gave an approximate planting depth of 3/4 to 1 inch. The field capacity of the soil was determined and, together with the known weight of the soil per each pot and the moisture already present, field capacity was maintained throughout the cold treatment by weighing the pots after every 48 hours and adding water to make up any loss of weight. As a safeguard against water saturation, the pots were perforated for drainage.

The cold treatment consisted of growth chamber temperature of 55-56° F for seven days after which it was raised to between 79 and 80° F until the completion of seedling emergence. Dry matter weight per seedling was determined by cutting the seedlings at the soil surface and drying at 100° C for 24 hours.

3. Field Emergence Studies

a. "Early" planting. This was on May 19, 1967, at Manhattan Agronomy Farm. This period was considered early spring when soil was both cold and wet and generally less than optimum for good germination of sorghum seeds.

b. "Optimum" date of planting. This was eighteen days later than the first on the same site at Manhattan. Conditions were then dryer and warmer and generally in the optimum range for good seedling emergence.

Machine planting was used in each case and seeding rate was obtained by duplicating the plant operations but instead of dropping the seeds in the soil catching them in bags attached to the planting tubes. The number of seeds dropped over a distance of 120 ft. were counted and the planting rate for each seed size was determined for the 15 ft. plot. A split plot design was used with the two planting dates as the main plots while the nine seed lots and their component seed sizes were completely randomized within the sub-plots.

Emergence counts were taken about fourteen days after planting. Dates of half-bloom were recorded when more than half the number of plants in each row plot showed bloom. Harvest was by hand. Sorghum heads were harvested from 15 foot plots, counted and dried. All replications were threshed and moisture was determined on the threshed grain. Yields were adjusted to 12.5% moisture.

# RESULTS AND DISCUSSIONS

## LABORATORY TESTS

### 1. Standard Germination

Data on the influence of seed source, seed size and date of germination count are summarized in Tables 1 and 2. Analysis of variance of data revealed differences, significant at the 1% level, among seed sources, among seed sizes and between the two-day and total germination counts. Also highly significant source x seed size interaction effects were indicated in the analysis.

As expected the two-day count was lower than the total germination in all the seed sources. Total germination showed an over-all average of 88.6% while the two-day count averaged over the seed sources gave a percent germination of 78.5.

In general, sources 1, 2, 3, 4 and 6 gave total germinations over 90% each and were not significantly different from each other. Source 5 had the lowest total germination (81.8%) and was significantly lower in germination than any of the other lots except 6, 7, and 8.

Table 1 shows the influence of seed size on germination. In general germination was higher with increase in seed size in all the seed sources tested with a few exceptions, when large, medium and composite seeds showed inconsistency to that trend. The small seeds however gave significantly lower germination than other seed sizes and showed an average total germination of 75.6%. The large, medium and composite seeds on the other hand were not significantly different from each other with average germinations of 94.1, 92.8 and 91.8 respectively.

TABLE 1

Effect of Seed Size on Total and Two-Day Germinations of Seed Lots in the Standard Germination Test

| Size / Sources | Composite | | Large | | Medium | | Small | |
|---|---|---|---|---|---|---|---|---|
| | Two-day | Total | Two-day | Total | Two-day | Total | Two-day | Total |
| 1 | 89.0 | 95.0 | 85.6 | 98.0 | 87.6 | 95.6 | 78.6 | 87.6 |
| 2 | 87.6 | 92.6 | 92.0 | 95.0 | 87.0 | 94.0 | 77.0 | 83.0 |
| 3 | 84.6 | 95.0 | 93.0 | 96.6 | 95.0 | 97.0 | 74.0 | 81.6 |
| 4 | 83.6 | 92.6 | 83.6 | 90.0 | 88.0 | 91.0 | 86.6 | 88.0 |
| 5 | 74.0 | 85.6 | 85.0 | 90.0 | 86.0 | 89.6 | 42.0 | 61.6 |
| 6 | 78.0 | 95.0 | 74.6 | 94.0 | 86.6 | 96.0 | 55.0 | 77.6 |
| 7 | 80.6 | 92.6 | 81.6 | 95.0 | 74.0 | 88.0 | 45.6 | 62.0 |
| 8 | 81.6 | 88.6 | 79.0 | 94.6 | 76.0 | 93.0 | 43.0 | 62.0 |
| 9 | 85.6 | 89.0 | 82.6 | 93.6 | 86.0 | 91.6 | 63.6 | 76.0 |
| Avg. | 83.0 | 91.8 | 84.2 | 94.1 | 85.0 | 92.8 | 62.8 | 75.6 |

L.S.D. Bet sizes within two-day = 14.2%**

L.S.D. Bet sizes within total = 9.8%**

** Significance at 1%

TABLE 2

Two-Day and Total Germination Percentages of the Nine Seed Lots in the Standard Germination Test

| Date / Sources | Two-day Germination | Total Germination |
|---|---|---|
| 1 | 83.2 | 94.0 |
| 2 | 85.8 | 91.2 |
| 3 | 86.6 | 92.6 |
| 4 | 85.8 | 90.4 |
| 5 | 71.8 | 81.8 |
| 6 | 73.6 | 90.6 |
| 7 | 70.4 | 84.4 |
| 8 | 69.8 | 84.6 |
| 9 | 79.4 | 87.6 |
| Avg. | 78.5 | 88.6 |
| L.S.D. | 7.0%** | 5.0%** |

**Significance at 1%

The seed size x seed source interaction might be due to the behavior of the different seed sizes within the various seed sources--Table 1. The general trend that germination had increased with increase in seed size was not found to be totally true and consistent in the 9 seed lots. For example the composite seed of source 1, Table 1 showed 95.0% average germination while large seeds and medium seeds in the same source gave 98.0 and 95.6% average germinations, respectively. In sources 4, 5, and 6 the medium seed size was consistently better than the large seed in its total germination.

It is interesting to note that the four seed sizes behaved in generally the same pattern in their two-day germinations as they did in their total germination except that as expected, the two-day counts were lower than the final counts. The large, medium and mixed seeds did not differ significantly in their two-day germination showing 84.2, 85.0 and 83.0 per cents, respectively, Table 1. The small seeds however, indicated only 62.8% average two-day germination. This was singificantly lower than the germination of any of the other seed sizes.

Germination After Accelerated Aging

Data for germination after seeds were subjected to unfavorable temperature and relative humidity are shown in Tables 3 and 4. Analysis of variance indicated highly significant differences among seed sources and seed sizes. There was also a highly significant source x seed size interaction.

Average two-day germination was 77.5% while the total germination average was 84.1%. It is interesting to compare these two averages with

TABLE 3

Two-Day and Total Germination Percentages of
Nine Seed Sources After Seeds Were Artificially Aged

| Date / Sources | Two-Day Germination | Total Germination |
|---|---|---|
| 1 | 86.0 | 88.8 |
| 2 | 83.6 | 87.0 |
| 3 | 81.4 | 89.0 |
| 4 | 74.8 | 81.8 |
| 5 | 67.8 | 77.0 |
| 6 | 77.8 | 85.6 |
| 7 | 75.2 | 83.2 |
| 8 | 79.0 | 87.2 |
| 9 | 71.8 | 77.6 |
| Avg. | 77.5 | 84.1 |
| L.S.D. | 7.4%* | 5.2%** |

* Significance at 5%
** Significance at 1%

TABLE 4

Seed Sizes and Their Percent Germinations After Artificial Aging

| Sizes / Sources | Composite | | Large | | Medium | | Small | |
|---|---|---|---|---|---|---|---|---|
| | Two-day | Total | Two-day | Total | Two-day | Total | Two-day | Total |
| 1 | 87.6 | 91.6 | 90.0 | 91.6 | 91.0 | 92.0 | 75.6 | 80.0 |
| 2 | 86.6 | 88.6 | 90.0 | 93.0 | 85.0 | 90.0 | 72.6 | 76.0 |
| 3 | 87.0 | 92.0 | 73.6 | 95.0 | 85.6 | 86.6 | 79.6 | 82.6 |
| 4 | 63.0 | 81.0 | 67.6 | 75.0 | 85.6 | 86.6 | 83.0 | 84.6 |
| 5 | 69.0 | 82.0 | 73.0 | 81.0 | 80.6 | 84.6 | 49.0 | 60.0 |
| 6 | 83.0 | 88.0 | 66.6 | 86.0 | 92.0 | 93.0 | 69.6 | 75.0 |
| 7 | 75.0 | 85.6 | 86.6 | 92.0 | 84.6 | 91.6 | 54.6 | 63.6 |
| 8 | 81.0 | 83.0 | 90.6 | 96.0 | 80.0 | 84.0 | 64.0 | 86.0 |
| 9 | 73.6 | 79.0 | 82.0 | 83.0 | 77.0 | 78.6 | 55.0 | 70.0 |
| Avg. | 78.4 | 85.6 | 80.0 | 88.1 | 84.6 | 87.5 | 67.0 | 75.3 |

L.S.D. size within two-day = 19.8%**

L.S.D. size within total = 10.6%**

*** Significance at 1%

the corresponding averages in the standard test which were 78.5 and 88.6% respectively. One could note the lack of difference between the two-day germinations in the two tests while the total germination in the standard test stood higher than that in the aging treatment. This means that the rate of germination did not seem to differ in the two tests inspite of the pretreatment. The total germination, however, were different as expected because some of the seeds, presumably the non-vigorous ones, must have been killed in the process of aging.

Total germination among seed sources ranged from 77.0 to 89.0%.

The influence of seed size as in the standard test remained important in this test. The four seed sizes showed relatively similar differences to those in the standard test except that germinations were generally lower. Large seeds showed a total germination average of 88.1% while the medium and composite seeds gave 87.5 and 85.6% respectively. These figures are obviously close to each other and are not different statistically at 0.01 level of significance. The small seeds, on the other hand, showed an average germination of 75.3%. This was significantly lower than any of the other seed size groups in the same test. It is interesting to note that the germination average of the small seeds in the standard germination was 75.6%. These are almost identical and one wonders whether the aging treatment only affected the germination of larger seeds and had no effect on the small seeds at all.

The seed source x seed size interaction effect was due, as in the case of standard germination, to the fact that the 4 seed size groups, particularly the large, medium and composite, were not consistent in their germination differences even though the general trend was that germination had increased with increase in seed size.

Germination After Ammonium Chloride Treatment

Tables 5 and 6 show the results of germination of the seed sources and sizes after treatment with 2% ammonium chloride solution. Analysis of variance of the data showed significant differences at 0.01 level among sources and sizes and an interaction effect between seed source and seed size.

Two-day and total germination averages were 77.0 and 81.2%, respectively. Comparing these averages with corresponding averages in the standard and aging germination, it again becomes evident that the two-day germination was not different from two-day germination in other tests. But the total germination from the $NH_4Cl$ treatment (81.2%) is lower than that of standard germination (88.6%) and similar to that of the aging treatment (79.0%). The difference between standard and the $NH_4Cl$ treatment in their total germination must have been due to the toxic nature of treatment for some of the seeds which came into contact with it.

The influence of seed size on germination is similar to what was reported for standard germination and the accelerated aging treatment, except like the aging treatment, the germinations were lower than the standard. Large, medium and composite seed showed germination averages of 88.1, 84.9 and 85.1%, respectively--Table 6. The small seeds showed an average of 66.2% germination. Comparing this with the germination of small seeds in the standard test, the $NH_4Cl$ treatment seemed to have been equally depressive on the germination of all seeds irrespective of size. This, it is recalled, was not true for small seeds in the accelerated aging treatment.

Source x size interaction effect can be explained as in other cases by inspecting the performances of the seed sizes in the different lots

TABLE 5

Effect of Ammonium Chloride Treatment on the Two-Day and Total Percent Germinations of Seed Sources

| Date / Source | Two-day Germination | Total Germination |
|---|---|---|
| 1 | 85.8 | 88.6 |
| 2 | 83.0 | 85.4 |
| 3 | 88.8 | 91.0 |
| 4 | 78.8 | 82.2 |
| 5 | 64.2 | 70.4 |
| 6 | 78.6 | 82.4 |
| 7 | 69.8 | 78.6 |
| 8 | 74.2 | 77.8 |
| 9 | 70.0 | 74.6 |
| Avg. | 77.0 | 81.2 |
| L.S.D. | 5.6%** | 5.6%** |

** Significance at 1%

TABLE 6

Effect of Ammonium Chloride Treatment and Seed Size on Total and Two-day Germination Percentages of the Seed Lots

| Sizes / Source | Composite | | Large | | Medium | | Small | |
|---|---|---|---|---|---|---|---|---|
| | Two-day | Total | Two-day | Total | Two-day | Total | Two-day | Total |
| 1 | 91.6 | 93.6 | 92.6 | 94.6 | 91.6 | 91.6 | 67.0 | 74.6 |
| 2 | 88.6 | 89.0 | 87.6 | 90.0 | 83.0 | 85.0 | 73.0 | 77.6 |
| 3 | 92.6 | 95.0 | 93.0 | 95.0 | 92.6 | 93.0 | 77.0 | 81.0 |
| 4 | 82.0 | 87.0 | 76.6 | 81.6 | 83.6 | 85.0 | 72.6 | 75.0 |
| 5 | 73.0 | 79.6 | 73.0 | 80.6 | 70.6 | 76.0 | 40.0 | 45.0 |
| 6 | 85.6 | 88.0 | 85.0 | 88.0 | 83.0 | 85.6 | 60.6 | 68.0 |
| 7 | 72.6 | 83.6 | 84.0 | 89.0 | 67.0 | 78.6 | 56.0 | 61.0 |
| 8 | 75.6 | 78.6 | 87.0 | 91.0 | 82.6 | 85.6 | 51.6 | 55.6 |
| 9 | 68.0 | 71.6 | 82.0 | 83.0 | 77.6 | 83.6 | 52.6 | 58.0 |
| Avg. | 81.1 | 85.1 | 84.5 | 88.1 | 81.3 | 84.9 | 61.1 | 66.2 |

L.S.D. Bet. sizes within two-day = 11.2%**

L.S.D. Bet. sizes within total = 10.8%**

** Significance at 1%

in Table 5. There was lack of trueness to the trend of increased germination due to increase seed size in the large, medium and composite seeds of several seed lots.

Cold Testing and Seedling Vigor

Information on the effects of seed sources and seed size on total seedling emergence through soil in the growth chamber after cold treatment is given in Table 7. Analysis of variance of the data indicated significant differences among seed sources and seed sizes in the way they affected total seedling emergence in this test. Total emergence of seedlings increased with increase in seed size with large seeds giving an average emergence of 84.2%. The small seeds showed an average emergence of 65.6%. The composite and medium seeds were not significantly different from each other.

The influence of seed source on total seedling emergence also given in Table 7 showed that some seed sources gave high emergence up to an average of 87.4% while others such as source 5 were low with only 46.4% average seedling emergence after cold treatment.

The interaction effect between seed source and seed size can be explained by data in Table 7. There was general lack of consistency as to which seed size was better in seedling emergence among the different seed lots, even though on the average the trend showed increased seedling emergence with increased seed size.

The influence of seed sources and seed size on seedling growth rate, seedling vigor, measured as dry weight per seedling 4 days after emergence from the soil is given in Table 8. With an L.S.D. of 0.9 milligrams, all sources except source 5, which showed a seedling dry

TABLE 7

Seedling Emergence from Different Seed Sizes Following Exposure to Cold Treated Soil

| Seed Lots \ Seed Sizes | Composite | Large | Medium | Small | Source Average |
|---|---|---|---|---|---|
| 1 | 80.6 | 92.6 | 91.2 | 75.2 | 83.0 |
| 2 | 83.2 | 87.2 | 86.0 | 71.2 | 81.8 |
| 3 | 89.2 | 95.2 | 90.0 | 75.2 | 87.4 |
| 4 | 78.6 | 83.2 | 76.6 | 82.0 | 80.6 |
| 5 | 34.6 | 52.0 | 48.6 | 50.6 | 46.4 |
| 6 | 86.0 | 94.6 | 86.0 | 64.6 | 82.8 |
| 7 | 83.2 | 88.0 | 83.2 | 62.0 | 79.2 |
| 8 | 68.6 | 83.2 | 73.2 | 65.2 | 72.6 |
| 9 | 58.6 | 82.0 | 66.0 | 45.0 | 63.0 |
| Size Avg. | 73.6 | 84.2 | 77.8 | 65.6 | |

L.S.D. source avg. = 9.8% at 1%.

L.S.D. seed size avg. = 7.7% at 1%.

TABLE 8

Seedling Growth Rate As Affected by Seed Source and Seed Size--
Figures Expressed as Dry Weight Per Seedling in mg.

| Seed Sizes / Seed Lots | Composite | Large | Medium | Small | Source Average |
|---|---|---|---|---|---|
| 1 | 6.6 | 7.5 | 7.7 | 5.6 | 6.9 |
| 2 | 7.0 | 7.7 | 6.6 | 5.8 | 6.8 |
| 3 | 6.9 | 7.9 | 7.1 | 5.5 | 6.9 |
| 4 | 6.3 | 7.9 | 6.9 | 5.5 | 6.7 |
| 5 | 4.9 | 8.2 | 5.6 | 4.5 | 5.8 |
| 6 | 7.1 | 7.5 | 6.9 | 4.7 | 6.6 |
| 7 | 6.5 | 7.3 | 7.2 | 5.9 | 6.8 |
| 8 | 6.5 | 7.1 | 6.6 | 4.6 | 6.2 |
| 9 | 6.2 | 6.9 | 6.1 | 6.1 | 6.3 |
| Size Avg. | 6.4 | 7.5 | 6.7 | 5.4 | |

L.S.D. source avg. = 1.00 mg. at 1%.

L.S.D. seed size avg. = 0.95 mg. at 1%.

weight of 6.0 milligrams were not significantly different from each other. Even source 5 with an average seedling dry weight of 5.8 mg. was not significantly different from sources 6, 8 and 9. This apparently is an indication of the weakness of this test in differentiating vigorous seed lots from non-vigorous ones.

The influence of seed size on seedling vigor is immediately apparent in Table 8. The large seeds showed an average dry weight per seedling of 7.5 mg. While the small seeds gave only 5.4 mg. the medium and composite seeds with 6.7 mg. and 6.4 mg., respectively were not statistically different at 0.01 level.

## Field Establishment

Seed source and seed size averages for field establishment for May 19 and June 6 plantings are given in Tables 9 and 10. Highly significant differences (at 1% level) among seed lots and seed sizes was indicated by analysis of variance of the data. Difference between the two dates of planting was significant at 5% level.

As expected the June 6 seeding showed higher field establishment than May 19 seeding with average emergence percentages of 68.9 and 60.4% respectively (Table 10). Since the seed lots tested were of the same chemical and storage treatment after they were received, then the difference in establishment showed by the two dates of planting must have been due to differences in environmental conditions. June 6 planting, which showed superior establishment, was thought to be more suitable from the standpoint that soil temperature and moisture were more favorable for sorghum germination than the soil temperature and moisture during the seeding in May 19. It must be emphasized at this

TABLE 9

Effect of Seed Size on Field Emergence in the Two Dates of Planting

| Seed Lots / Seed Sizes | Composite | | Large | | Medium | | Small | |
|---|---|---|---|---|---|---|---|---|
| | May Planting | June Planting | May Planting | June Planting | May Planting | June Planting | May Planting | June Planting |
| 1 | 73.8 | 80.9 | 70.5 | 81.9 | 76.6 | 81.4 | 53.8 | 67.7 |
| 2 | 66.6 | 68.9 | 69.8 | 72.9 | 64.5 | 81.4 | 54.1 | 60.4 |
| 3 | 63.9 | 74.1 | 70.6 | 75.8 | 74.2 | 80.6 | 54.5 | 68.0 |
| 4 | 70.6 | 76.5 | 51.6 | 61.8 | 54.4 | 75.4 | 59.0 | 68.7 |
| 5 | 40.4 | 44.4 | 51.6 | 58.2 | 62.8 | 70.5 | 36.4 | 38.2 |
| 6 | 66.6 | 75.9 | 69.6 | 66.4 | 54.8 | 79.8 | 52.0 | 59.7 |
| 7 | 71.8 | 75.8 | 59.5 | 77.8 | 69.3 | 78.6 | 48.9 | 56.9 |
| 8 | 64.7 | 70.6 | 68.4 | 69.6 | 68.1 | 72.1 | 39.0 | 52.4 |
| 9 | 53.1 | 67.4 | 64.3 | 68.0 | 62.1 | 71.7 | 41.9 | 49.9 |
| Avg. | 63.5 | 70.5 | 63.9 | 70.3 | 65.2 | 76.8 | 48.8 | 57.9 |

L.S.D. Seed size at 0.01 = 6.1%
L.S.D. Date at 0.05 = 7.9%

TABLE 10

Effect of Seed Sources and Planting Date on Field Establishment Figures Given in Percentages

| Sources \ Date | May 19 | June 6 |
|---|---|---|
| 1 | 68.7 | 77.9 |
| 2 | 68.8 | 70.9 |
| 3 | 65.8 | 74.6 |
| 4 | 58.9 | 70.6 |
| 5 | 47.8 | 52.8 |
| 6 | 60.8 | 70.4 |
| 7 | 62.4 | 72.3 |
| 8 | 60.1 | 66.2 |
| 9 | 55.3 | 64.3 |
| Avg. | 60.4 | 68.9 |

L.S.D. sources = 9.1% at 1%

L.S.D. date = 8.2% at 5%

point that no soil temperature or moisture readings were taken to support the above, rather subjective, evaluation of the planting situations.

Highly significant source differences occurred in both dates of planting as shown in Table 10. In May 19 planted plots individual seed lots ranged from an emergence percentage of 47.8 to 68.7, with a range of 20.9%. All but three seed lots gave per cent emergence over 60. In June 6 planting the germination percentages of the individual seed lots were higher than what they were for the May planting. The emergence ranged from 52.8 to 77.9% with only three lots showing per cent establishment below 60. In general the seed lots which did well in their germination under the May 19 conditions maintained the same standard for the June planting. The reasons for the differences between seed lots of the same genetic stock, the same age and the same treatment germinating under the similar conditions are not very easy to determine. Differences may be due to the vigor or vitality of the seed lots. These differences in vitality may not necessarily be due to some genetic factor but could as well be due to the environmental conditions under which the seed was produced and the different handling processes before they were received for this study. Soil variations in the field and the effectiveness of the seed treatment are other factors that might contribute to differences among seed lots of different seed sources.

The influence of seed sizes on field emergence is shown in Table 9. Analysis of variance showed highly significant differences among the four seed sizes in their ability to germinate and produce viable seedlings in the field. Looking at effect of seed size on establishment in May 19 one could see that the composite, large and medium seeds, with average gerination of 63.5, 63.9 and 65.2% respectively, were not significantly different from each other. The small seeds, however, with average establishment of 48.8%, were quite low in germination and were significantly inferior to other seed sizes. The same seed sizes showed similar trends in the June 6 plots except that they showed correspondingly higher germinations due to better growing conditions. Large, composite and medium seeds were not statistically different (at 1% level) with average emergence of 70.3, 70.5, and 76.8, respectively. Unlike in most other tests the medium seeds tended to show superior field germination to large seeds. The reasons for this are purely speculative and will not be discussed here. The small seeds, however, showed significantly inferior germination (57.9%) to the other seed sizes. Most investigations concerned with seed size and its influence on germination and field establishment reported that the superiority of large seeds over relatively small ones in producing strong vigorous seedlings due to the fact that the large seeds have more food reserve to start with than do small seeds. Other workers reported that other factors associated with smallness in seeds may be indirectly responsible for the comparatively poor germination and field establishment of small seeds. Small seeds are associated with immaturity and immaturity could have ill consequences on the normality of the embryo. Immaturity of seeds at harvest also would mean higher moisture content and such seeds are more likely to suffer from pericarp injuries than mature seeds. Pericarp injuries were found to have adverse effect on the germination of corn (46) especially under unfavorable conditions such as cold, wet and microorganism-infested soil. This was even true when such seeds had been treated against seed decay organisms.

Analysis of variance also revealed highly significant source x seed size interaction effect at 0.01 level. This interaction is partially explained by Table 9. The large and medium seed sizes are conspicuous in the manner in which they interchange positions in their field germination performances in both dates of planting. The composite seeds, to a lesser degree, also were inconsistent in germination in different lots.

Grain Yields

Data on grain yield as influenced by seed source and date of planting are presented in Table 11. The average difference between the yields of plots in the two dates was 13 bushels per acre. This difference, however, is not statistically significant at 0.05 level. This lack of significance even though the average yield difference between May and June planting was 13 bushels per acre might be due to one of the disadvantages associated with split plot design, where the effect of the main plot treatment, though large, is not significant, whereas the effect of the sub-plots which are too small to be of practical interest, are statistically significant. Seed sources were highly inconsistent in their yield difference in the two dates of planting. For example, source 9 showed a yield difference of 24.7 bushels per acre while source 3 showed a difference of only 8.5 bushels to the acre. Source 4 provided the only case in which yield from June planted plots was higher (0.8 bushel per acre) than that from May plots. This difference is obviously nonsignificant. This trend of yield pattern was, however, not surprising because the analysis of variance of the data had indicated a significant date x source interaction at 5% level.

TABLE 11

Effect of Planting Date and Seed Source on Sorghum Yields in Bushels Per Acre

| Seed Lots \ Planting Date | May 18 | June 6 |
|---|---|---|
| 1 | 121.8 | 107.8 |
| 2 | 113.1 | 100.3 |
| 3 | 119.6 | 111.1 |
| 4 | 109.0 | 109.8 |
| 5 | 123.6 | 107.4 |
| 6 | 117.4 | 107.5 |
| 7 | 123.6 | 103.2 |
| 8 | 117.6 | 108.4 |
| 9 | 129.7 | 105.0 |
| Avg. | 119.5 | 106.5 |

The increase in yield with earlier planting obtained in this study contradicts with the findings of many workers in the Great Central Plains of the United States (48, 41). But it is also in support of other workers such as Buchholtz (3) and Stickler et al. (40) in the State of Kansas. The workers who reported increased yield with successively later planting found that such superior yield was due to better stand establishment and more heads harvested per unit area of land. The field establishment results in this study also showed better establishment in the later (June) planting than the early (May) planting resulting in more heads per unit area of land in the June planted plots than in the earlier seeded plots. Another yield component, weight of grain per head, was analyzed and it was found that differences in weight of grain per head were highly significant. The weight of grains per head in the May 19 plots was significantly higher than that from June plots. This would mean that the weight of grain per head in the plots seeded in May had more than offset the advantage of more heads per unit land area gained by the June planting due to better establishment. In fact, the study had shown that high field establishment could be a disadvantage to yield if factors other than population are limiting. The reason for the shift in yield advantage from June to May is probably related to environmental factors which might affect grain filling and weight (also assuming that the weight of grain-per-head differential was not due to the number of grains per head--which was not evaluated in this study). Sources 5 and 9, which gave the poorest field stands in the field, provided the highest yield in the group. This would probably suggest that the plant population in the June plots may have been above optimum for the moisture regime available during the growing season. A mild drought effect was further observed especially in one of the June planted blocks at a time immediately after full bloom. This might have aggrevated the moisture-plant population balance. The May plots were not visably affected by lack of moisture.

The effect of seed size on yield was not significant in this study. This is in spite of the superior field establishment of large over small seeds. Table 12 shows the seed size influence on yield of grain. The mean averages of the four seed sizes showed grain yields which are obviously similar with the smallest seeds giving 115.3 bushels per acre while the large, medium, and composite seeds had 110.3, 113.9 and 112.3 bushels per acre, respectively. This yield trend tends to support an earlier suggestion that the yield at least during this season was to a large degree dependent on the plant population--soil moisture balance. Since the small seeds with the poorest field stand gave higher yields than large seeds which had a more superior field establishment. It was also noted that the plots showed the same degree of tillering in spite of lower plant population in the May 19 planted plots.

Tables 13 and 14 show the response of the different seed sources and seed size to maturity measured by time of half bloom. Analysis of variance showed highly significant differences in time of half bloom between seed sources, between dates of planting, and among seed sizes. Significant date x source and date x size interaction effects were also indicated. The average half bloom date for the seed sources in the May and June plantings were 72.0 and 63.2 days, respectively. This indicated that all the seed sources required less time from planting to half bloom (they developed faster) as planting time was delayed. Thus

TABLE 12

Data Showing the Effects of Date of Planting Seed Source and Seed Size on Grain Yield Expressed in Bushels Per Acre

| Seed Lots \ Seed Size | Composite | | Large | | Medium | | Small | |
|---|---|---|---|---|---|---|---|---|
| | May Planting | June Planting | May Planting | June Planting | May Planting | June Planting | May Planting | June Planting |
| 1 | 131.9 | 106.1 | 110.8 | 109.2 | 117.5 | 109.3 | 127.1 | 106.6 |
| 2 | 118.4 | 98.9 | 98.7 | 100.6 | 115.8 | 99.0 | 119.4 | 102.5 |
| 3 | 121.3 | 109.2 | 127.4 | 106.9 | 119.4 | 114.0 | 110.1 | 114.4 |
| 4 | 107.3 | 104.4 | 104.0 | 110.2 | 117.5 | 115.2 | 107.3 | 119.8 |
| 5 | 123.6 | 102.9 | 115.8 | 101.9 | 117.0 | 123.5 | 137.8 | 101.1 |
| 6 | 125.6 | 103.3 | 118.5 | 99.0 | 113.8 | 104.6 | 111.5 | 123.2 |
| 7 | 116.6 | 101.5 | 116.2 | 107.1 | 123.6 | 102.0 | 137.9 | 102.3 |
| 8 | 122.0 | 103.9 | 115.2 | 105.2 | 119.5 | 101.1 | 113.7 | 104.9 |
| 9 | 122.6 | 102.1 | 131.9 | 106.4 | 135.3 | 102.6 | 129.1 | 108.9 |
| Avg. | 121.0 | 103.6 | 115.4 | 105.2 | 119.9 | 107.9 | 121.3 | 109.2 |
| Mean Avg. | 112.3 | | 110.3 | | 113.9 | | 115.3 | |

TABLE 13

Effect of Seed Sources and Date of Planting on Time of Half Bloom (Figures in days)

| Sources \ Date of Planting | May 19 | June 6 |
|---|---|---|
| 1 | 71.3 | 63.2 |
| 2 | 72.1 | 62.9 |
| 3 | 71.4 | 63.2 |
| 4 | 72.2 | 63.4 |
| 5 | 72.7 | 63.4 |
| 6 | 72.9 | 63.4 |
| 7 | 72.3 | 63.2 |
| 8 | 72.4 | 63.4 |
| 9 | 71.9 | 63.1 |
| Avg. | 72.0 | 63.2 |

TABLE 14

INFLUENCE OF SEED SIZE AND DATE OF PLANTING ON TIME OF HALF BLOOM

| | Composite | | Large | | Medium | | Small | |
|---|---|---|---|---|---|---|---|---|
| | May | June | May | June | May | June | May | June |
| 1 | 71.0 | 63.3 | 70.5 | 62.8 | 71.0 | 62.8 | 72.8 | 63.8 |
| 2 | 72.5 | 62.8 | 71.3 | 63.3 | 71.8 | 62.5 | 72.8 | 63.3 |
| 3 | 71.5 | 63.3 | 70.8 | 62.8 | 71.0 | 63.3 | 72.3 | 63.5 |
| 4 | 72.5 | 63.3 | 72.0 | 63.0 | 72.3 | 63.8 | 72.0 | 63.5 |
| 5 | 72.5 | 63.3 | 72.5 | 63.0 | 72.5 | 63.3 | 73.5 | 64.0 |
| 6 | 72.5 | 63.5 | 72.3 | 63.0 | 72.5 | 62.8 | 74.3 | 63.5 |
| 7 | 71.5 | 62.8 | 71.3 | 62.8 | 72.8 | 63.0 | 73.5 | 64.0 |
| 8 | 72.5 | 63.0 | 71.5 | 63.3 | 72.3 | 63.3 | 73.3 | 64.0 |
| 9 | 72.3 | 62.8 | 70.8 | 63.3 | 72.0 | 62.8 | 72.5 | 63.5 |
| Avg. | 72.1 | 63.1 | 71.4 | 63.0 | 72.0 | 63.1 | 73.0 | 63.6 |

from the 18-day delay in seeding, the half bloom period was hastened by 8.8 days. Reasons for this may be related to warmer temperatures and shorter days which encourage maturity in sorghum and both associated with delayed planting.

Seed source variation within a planting date, though statistically significant did not seem to have practical importance as differences were usually less than one day. Seed size influence (Table 14) indicated that the large seeds showed earlier bloom dates suggesting that plants from large seeds developed faster than those from small seeds. Difference in maturity between seed sizes was more pronounced in the early planting in which plants from small seeds showed 73.0 days to half bloom while those from large seeds required 71.4 days. In the June planting, the difference was less than half a day. The reason for interactions was probably due to the inconsistent manner in which the seed sources and the seed sizes reached half bloom in the two dates of planting as shown in Tables 13 and 14.

Evaluation of Vigor

Vigor has remained a very difficult term to define precisely. The effects of low vigor are hard to specify--one cannot, for example, look at the leaf or root of a growing plant for signs of low vigor problems as one could in the case of insects or disease causing damage. However, the bad effects of low vigor still exist and hurt just as those caused by visible agents. The fact that it is difficult to associate vigor with a single physiological, biological or even physical phenomenon of seed has led to the multiplicity of definitions of vigor and even more numerous methods for its measurement. It is therefore obvious that there must be a common denominator of understanding as to what vigor is before a realistic measurement of it could be devised.

Isely (20) reviewed several points of view concerning vigor and arrived at two generally accepted definitions:

1. The usual mechanism of vigor in the field is the differential susceptibility of seeds and seedlings to unfavorable conditions. Vigor in other words, could be defined as the sum of all seed and seedling attributes which favor establishment under unfavorable field conditions. Unfavorable conditions are used to measure such differentials because seed lots with approximately the same per cent germination under ideal or favorable situations in the field or laboratory may differ markedly in their ability to establish under adverse environmental conditions.

2. Vigor as reflected by speed of germination and rapidity of growth of seedlings.

Both of these concepts have their merits and demerits. The concept of differential susceptibility of seeds and seedlings to unfavorable field conditions had great appeal because of its recognition of the importance of the environment in establishment. The concept gave birth to so-called direct vigor tests, the most popular of which, in the United States, is the soil cold test. This method tries to simulate in the laboratory the most common unfavorable growing conditions encounted by farmers seeding in early spring. One of the greatest limitations of this method is that unfavorable field conditions are so numerous and varied that it probably would be impractical to include all of them in tests conducted in laboratories. On the other hand any simplification of field realities would often lead to underscoring of the actual situations seeds usually contend with when they are germinating in the field--and particularly when growing conditions are obviously sub-optimum. Another difficulty in the successful use of cold tests is the selection of a field situation for comparison with laboratory tests since field conditions are constantly changing day by day and year by year.

Tests which bypass the environmental variables and try to indirectly evaluate vigor on certain physiological, biological or physical facets of seeds before, during or after germination have shown great promise for a more practical and accurate determination of vigor. They are usually simple to perform and their results can easily be repeated or duplicated within the laboratory and between laboratories. These tests, however, remain sensitive to the constant variability of conditions in the field and their accuracy in determining vigor based on field results would still be dictated by conditions which influence field establishment in any particular location.

The present study utilized both concepts of vigor determinations outlined by Isely with one basic assumption. It was conceived that at some stage during a harsh treatment a non-vigorous seed would be killed or rendered incapable of normal germination while vigorous seed would remain relatively unaffected.

Several criteria have been used to evaluate vigor in the multitude of tests developed. In this study the following three criteria for evaluating vigor in the tests were used.

1. The ability of a test to correlate closely with field establishment. That is the degree of association between a test result with the results of field emergence.

2. Ability of a test's germination average to approximate the average field establishment percentage.

3. The ability of a test to rank seed lots in the laboratory according to how they would perform in the field.

The ability of a test's average to approximate the average field emergence of large groups of seed lots can be used to definite advantage when the average field germinations of the groups tested is what is required. The test's average approximation has limited usefulness in situations where two seed lots are being compared or an information on a specific seed lot is required. The main concern in the average germination percentage for a large group of seed lots is that it does not take into account the fluctuation widely reported between field and laboratory germination for an individual seed lot. Most germination tests are not interested in average germination for groups of lots per se but more concerned with individual seed lots. For this reason the ability of a test to approximate average field emergence alone is not enough and should not be used as the only criterion in the evaluation of vigor in a test.

Numerous workers (4) used vigor tests which have shown high correlation coefficients when compared with field establishment as a good index to field performance under adverse conditions. A close association between results of a vigor test in the laboratory and field establishment indicated by a high correlation coefficient means that there are consistent differences in the germination percentages of all the lots tested but does not of necessity mean a superior test. More reliable information can be obtained by running a regression analysis to see if a high correlation also means a close approximation of field emergence. It is possible to have a high correlation coefficient and still not have a close approximation of the field establishment from some tests. This situation is commonly found in standard laboratory tests when compared with field emergence. It is possible to have consistency of differences between results in the laboratory and in the field thus giving rise to high correlation. This would even arise in situations where the laboratory test had an average germination of 90% while the field establishment has less than 50%. A high correlation coefficient coupled with close approximation of means between a laboratory test and field establishment are complimentary for a more accurate and reliable prediction of field emergence than either one of them used alone.

A laboratory test which ranks seed lots according to their performance in a field situation, is probably the best available tool for seedmen to discriminate between good and better or between poor and good seed lots. This test criterion, however, is criticized because of lack of emphasis on the actual numerical field emergence itself. Ranking seed lots by the use of an adverse treatment on seed is not an attempt to predict actual field stand itself but is a method of determining how a seed lot would perform under unfavorable field conditions when compared to others. The utility of the rank criterion is especially evident when two seed lots germinate with approximately the same percentage in the standard laboratory test while one of them fails when planted in the field under adverse situations. This criterion can be made more efficient as a means of predicting field emergence, or what seeding rate to use for getting a desired plant population, by a complimentary close approximation of its means and those of field establishment.

In this study results of the various laboratory tests had been evaluated in the light of the above discussion for the purpose of reflecting primarily field establishment and secondly, the yield of hybrid grain sorghum RS610 when planted under optimum and sub-optimum field conditions.

Field Establishment Approximation

The comparative average laboratory germinations and field emergence percentages of the nine seed sources tested are given in Table 15. The mean average of each test and the range within each are also included at the bottom of Table 15. The highest mean average percent germination and the smallest range in germination between the seed sources was obtained in the total standard germination. The next highest germination average and the next smallest range in germination was in the total germination of the seeds which were treated with 2% ammonium chloride solution for two hours prior to standard germination. The lowest emergence average among the laboratory test was obtained in the cold test.

Looking at field establishment mean average percentages for the two dates of planting one would see that May 19 establishment average was 60.4% with a spread of 21.1% among individual seed lots. The June 6 emergence average was 68.9% with the lowest individual lot emergence of 52.8% and the highest 77.9%.

TABLE 15

Comparative Germination Percentages of Sorghum Lots in Laboratory and Field Test

| Seed Size / Source | Field Emerg. May | Field Emerg. June | Stand. Germ. Two-day | Stand. Germ. Total | $NH_4Cl$ Treat. Two-day | $NH_4Cl$ Treat. Total | Aged Seed Two-day | Aged Seed Total | Cold Test |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 68.7 | 77.9 | 83.2 | 94.0 | 85.8 | 88.6 | 86.0 | 88.8 | 83.0 |
| 2 | 63.8 | 70.9 | 85.8 | 91.2 | 83.0 | 85.4 | 83.6 | 87.0 | 81.8 |
| 3 | 65.8 | 74.6 | 86.6 | 92.6 | 88.8 | 91.0 | 81.4 | 89.0 | 87.4 |
| 4 | 58.9 | 70.6 | 85.8 | 90.4 | 78.8 | 82.2 | 74.8 | 81.8 | 80.6 |
| 5 | 47.8 | 52.8 | 71.8 | 81.8 | 64.2 | 70.4 | 67.8 | 77.0 | 46.4 |
| 6 | 60.8 | 70.4 | 73.6 | 90.6 | 78.6 | 82.4 | 77.8 | 85.6 | 82.8 |
| 7 | 62.4 | 72.3 | 70.4 | 84.4 | 69.8 | 78.6 | 75.2 | 83.2 | 79.2 |
| 8 | 60.1 | 66.2 | 69.8 | 84.6 | 74.2 | 77.8 | 79.0 | 87.2 | 72.6 |
| 9 | 55.3 | 64.3 | 79.4 | 87.6 | 70.0 | 74.6 | 71.8 | 77.6 | 63.0 |
| Avg. | 60.4 | 68.9 | 78.5 | 88.9 | 76.9 | 81.2 | 77.5 | 84.1 | 75.2 |
| Range | 47.8 to 68.7 | 52.8 to 77.9 | 69.8 to 86.6 | 81.8 to 94.0 | 64.2 to 85.8 | 70.4 to 88.6 | 67.8 to 86.0 | 67.8 to 88.8 | 46.4 to 87.4 |

The cold test provided the best approximation of average field establishment (75.2%) and on that basis alone, it is the best vigor index of all the tests. The average germination percentages of the two-day and total germinations of all other laboratory tests especially those from the standard test were considerably higher than average field emergence in either the May and June plantings. The big differential between standard germination test averages and those of the field was expected since laboratory germination, having been in artificial suitable conditions or even in what might be considered as favorable field planting conditions. The fact that the standard germination averages including the two-day averages are still higher than the average establishment in June 6, when field conditions were considered optimum goes to support the criticism of the standard germination as being too artificial and disregarding of the numerous factors seeds actually contend with in order to germinate in the field even when soil temperatures and moistures are practically optimum. However, the better establishment shown by the June planted plots over those planted in May is an indicator that soil temperature and moisture are quite important factors to reckon with when planning experiments which try to simulate unfavorable field conditions in the laboratory, keeping in mind, however, other factors singly and especially in combination could be just as important.

The average percentages from the aging and ammonium chloride treatments, though lower than the averages of the standard germination, still showed relatively higher germinations than those obtained from the two planting dates. Since there was no reason to believe that the seeds deteriorated between the time when the standard germination and the adverse treatments were conducted, then the relatively lower germination averages shown by the adversely treated seeds must have been due to the treatment. This substantiates the assumption that at some point during a harsh treatment a non-vigorous seed would be killed or rendered abnormal but a vigorous seed would be relatively unaffected. It would also seem from comparing these average percentages that the stress treatments meted to the seeds in an attempt to screen vigorous from non-vigorous seeds in this study were not individually enough to represent or equal the cumulative unfavorable effects which came to bear on the seeds in either date of planting, especially in May.

Even though the cold test mean average percentage was closest to the emergence averages in the two dates of planting, it also, showed superior emergence. This goes to support an earlier statement that the cold treatment plus the moisture conditions in this test are only an important part of the stress effects which exist in the field.

Examination of the germination percentages of individual seed sources under each test in Table 15 shows marked individual differences in response to variations in germination conditions. For example, source 3 germinated 87.4% under the cold test while source 5 showed a germination of only 46.4% under the same treatment. Most of the other sources showed an intermediate response between these two extremes.

Thus on the basis of using percent average germination of a laboratory test to provide a close approximation of average field establishment of the nine sources as one group, the cold test was the best index of all the tests used for measuring seed vigor. This method as mentioned earlier is weak in that it did not take into account the rather very important factor of variation among individual seed lots as seen in the behavior of sources 3 and 5 in the cold test. This could even be more serious in situations where wide variations in vigor among differerent seed lots is expected as often is the case when different hybrids or varieties are being tested.

Coefficient of Correlation Criterion

The correlation coefficients between the various laboratory tests and field establishment in the two different planting dates and the combined planting dates are presented in Table 15. This table also includes an item which was not included in Table 15, that is the dry matter weight of seedlings harvested at the end of the cold test. The dry matter weight per seedling represented the growth rate of seedlings from the various seed sources and seed sizes. This rate of growth is itself a measure of vigor.

All vigor correlations in Table 15 were positive and highly significant at 0.01 level. These correlations, however, vary in their magnitude of association. Looking at the individual tests of correlation with establishment in the May 19 planting, it is noted that the two-day standard germination, the ammonium chloride and the aging treatments in each case, showed lower correlation values than their respective total germinations. This means that the total germinations were more highly related to field emergence when seeds were planted in May 19, than their two-day germinations. The tests separately showed ammonium chloride treatment to give the best indication of relative field germination and field establishment in the May planting. The total standard germination gave the second best measure of association showing a correlation

TABLE 15

Simple Correlations Between Field Establishment and Laboratory Tests

| Laboratory Test | Field Establishment | | |
|---|---|---|---|
| | May 19 | June 6 | Combined Date |
| Standard Lab Test | | | |
| (a) Two-day count | .682 | .735 | .657 |
| (b) Total count | .779 | .790 | .728 |
| Accelerated Seed Aging | | | |
| (a) Two-day count | .657 | .793 | .673 |
| (b) Total count | .679 | .752 | .664 |
| Ammonium Chloride Treatment | | | |
| (a) Two-day count | .796 | .784 | .732 |
| (b) Total count | .819 | .798 | .749 |
| Cold Test | .739 | .770 | .699 |
| Seedling Growth Rate | .628 | .595 | .567 |

** All correlations are significant at 0.01.

coefficient of 0.77. This significant correlation between standard germination and field establishment is rarely reported for sorghum and suggests that the standard germination was essentially similar, for evaluating vigor in the seed lots, as the other vigor tests in this study.

The corresponding correlation values for June 6 emergence showed that the tests had maintained essentially the same pattern except that the values are generally higher than those under May 19 date of planting. A notable exception was the ammonium chloride treatment. Even though it showed the highest precision of association, its values were lower than those shown for May 19 seeding suggesting that the ammonium chloride test is especially better for predicting emergence when seeds are planted under unfavorable field conditions.

Correlation values for combined date of planting to show which test gave the best prediction of field emergence irrespective of date of planting between May 19 and June 6 indicated that the accuracy for prediction was lower for combined date of planting when compared with correlations for specific date of planting. In general the tests maintained the same relative positions of accuracy in their prediction of field emergence irrespective of date of seeding between May 19 and June 6 as they did for the two specific dates.

Information obtained from correlation criteria and average approximation comparisons support the criticism that high correlation is not totally a reliable method for predicting performance of a seed lot under field conditions. The high correlation (0.77) shown by standard germination with its high average percentage germination of 88.6 compared to 60.4 for establishment in May revealed a germination gap of

28.4%. This means that the high correlation is just an indication of consistency in the behavior of the lots in the two tests but does not take into account the gap which exists between the average germination in the two tests.

Ranking of Seed Lots Criterion

In this test criterion the nine seed lots were ranked from 1 to 9 according to how well they germinated or emerged in each of the laboratory tests as shown in Table 17. The seedling growth rate test was dropped from the list of tests used in the ranking evaluation because of its relatively poor correlation with field establishment. In this ranking criterion three questions were answered.

1. Whether the seed lots were ranked differently by the various tests.

2. Which of the tests ranked the seed lots closest to their "true" rankings assuming that field establishment data was not available for comparison, or the field establishment has an assigned value of zero.

3. Which tests actually ranked the seed lots according to the ranks shown in the field data since in an earlier statement it was said that the ultimate objective of any seed test should be evaluation of its field performance.

To answer the first question a coefficient of concordance, W, proposed by Kendell and Smith (30, 39) was calculated by using the following formula

$$W = \frac{12S}{m^2(n^3 - n)} ,$$

TABLE 16

Comparison of Field Rankings Calculated Rankings and Rankings from the Different Laboratory Tests of the Nine Seed Lots

| Tests / Lots | May Plots | June 6 Plots | "True" Ranks | $NH_4Cl$ Rank | Stand. Germ. | Aging Test | Cold Test |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| 2 | 3 | 4 | 3 | 3 | 3 | 2 | 4 |
| 3 | 2 | 2 | 2 | 2 | 2 | 3 | 1 |
| 4 | 7 | 5 | 5 | 5 | 5 | 7 | 5 |
| 5 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 6 | 5 | 6 | 4 | 4 | 4 | 5 | 3 |
| 7 | 4 | 3 | 7 | 6 | 8 | 6 | 6 |
| 8 | 6 | 7 | 6 | 7 | 7 | 4 | 7 |
| 9 | 8 | 8 | 8 | 8 | 6 | 8 | 8 |

where S equals the sum of squares of the deviations of the total ranks assigned to each individual lot from the average value of the totals of the ranks, hence S is the usual sum of squares of the deviations from the mean. A test of significance for W for r = 8 degress of freedom was calculated as follows:

$$X^2 = n(n - 1)W = \frac{12S}{mn\ (n + 1)} ,$$

where m represents the number of tests and n the number of individual seed lots ranked. The calculated $X^2$ is approximately distributed as chi-square with 8 degrees of freedom.

In this ranking test W was found to be significant at 1% level. This means that the hypothesis that the ranks assigned to each seed lot are completely random and unrelated was rejected. In other words the high significance for value of W in this test means that various tests used to rank the seed lots applied essentially similar standards in ranking the seed lots. It also means, however, that some tests ranked the seed lots more accurately than others according to their true ranks. Assuming, as implied in question 2 that there was no relevant external criterion for ordering the seed lots their pooled or "true" ranking may serve as a "standard" to test how each test ranking compared with the standard.

In the absence of field emergence data the pooled or standard ranking shown in Table 17 could be used as a basis for selecting seed lots according to how they are expected to perform in the field. As mentioned earlier in the discussion for evaluating vigor, this method has a shortcoming in that it does not emphasize the numerical field germination of a seed lot along with the rank index.

Comparing the individual test's ranking with the calculated standard one could see that the $NH_4Cl$ pretreatment ranked the seed lots closest to their true calculated ranking with only a slight switch in the positions of seed lots 6 and 7. The standard germination ranking was next to the best ranking six of the nine lots according to the calculated true ranking. The cold test and the aging treatment ranked four and three seed lots out of the nine correctly.

Since field emergence rankings are the ultimate test for ranking the seed lots, they are compared with those of the tests and the calculated rankings in Table 17. The field establishment thus served as the "objective" test for the validity of the calculated rankings and those from the individual laboratory tests. Both the calculated ranking and the ammonium chloride test ranking showed about 70% accuracy in the way they ranked the seed lots according to their field performance.

## SUMMARY AND CONCLUSIONS

Experiments in this study were conducted to measure vigor in nine seed lots of hybrid sorghum RS610 procured from different seed companies at different locations--from Texas, Missouri, Kansas and Nebraska. Various laboratory tests were used and their results evaluated for predicting field establishment and grain yields of sorghum. The influence of seed size on the measurements of vigor was also part of the study.

### Method

#### Laboratory Tests

1. Standard germination as prescribed in the rules for testing seeds (1).

2. Unfavorable laboratory treatments prior to normal germination which included:

a) Soaking seeds in 2% ammonium chloride solution at 40° C for 2 hours.

b) Artificially aging the test seeds in 100° F atmosphere and a relative humidity of 95-100% for ten days.

c) Planting seeds in cold (54° F) and wet (field capacity) soil for seven days before raising the temperature to 80° F for the emergence to complete. This test procedure is generally referred to as cold test.

3. Seedling growth rate: four-day old seedlings from the cold test were harvested at soil surface level and the dry matter weight per seedling determined.

Two-day germination counts were taken in addition to total germination for the standard test, ammonium chloride and the aging treatments.

Field Studies

A split plot design was used for the field study which involved two planting dates--May 19 and June 6--as the main plots, and the nine seed lots and the four seed sizes within each lot were completely randomized within sub-plots.

Results

Results of adverse treatments when compared with those of standard germination substantiated the assumption that seeds of low vigor are killed or rendered incapable of normal germination during the harsh treatment while vigorous seeds are left relatively unaffected. This is because the average germinations after adverse treatment were lower than those obtained in the standard germination.

The results of tests conducted in this study suggested that seed sources can be a highly important factor not only in seed vigor research but also in the selection of seed for planting. The result also suggests that a single seed lot could not be expected to truly represent a hybrid.

Germinations in laboratory and field studies generally increased with increase in seed size though there was no significant difference between the performances of large, medium and composite seed lots in all the tests performed. The small seeds, however, were consistently and significantly inferior in performance to the other sizes.

The cold test average seedling emergence gave the closest approximation of field establishment averages for both date of planting. The standard germination averages showed greater discrepancy from average field emergence than any of the other tests. The relatively superior germination averages of the adverse treatment tests over field emergence suggest that the field variables which depress germination and establishment are more severe on seed germination than the individual adverse treatments the seeds were subjected to in the laboratory.

June planted plots showed higher per cent establishment than May plots. Since the seeds used were of the same hybrid, the same age and had received the same treatment against seed decay organisms, the differences in the establishment must have been due to the differences in the field conditions under which the seeds germinated in the two dates of planting.

Grain yield was lower in the June plots than from May plots. Yield differential was found to be due to the weight of seeds per head rather than the number of heads harvested per unit area of land. The high plant establishment from June planting seemed to have resulted in an imbalance between plant population and moisture regime for the growing season. The effect of planting large seeds for the purpose of better establishment seemed to have been masked by the fact that yield differences were not related to high field establishment in this study.

The three criteria used to evaluate vigor measurements in the tests are:

1. Ability to rank seed lots according to their performance in the field.

2. Ability to correlate closely with field establishment.

3. Agreement of average germination or emergence with average field establishment.

The ranking criterion, which is probably the most effective way to differentiate seed lots according to their field expectation, showed that the 2% ammonium chloride pretreatment ranked the nine seed lots best on the basis of their field performance. The standard germination was the next most effective test to rank seed lots according to their expected field emergence. This perhaps would help explain why the standard test also showed the second best correlation with field establishment.

Significant positive correlations were found between laboratory tests and field establishment. Again the $NH_4Cl$ treatment showed the highest correlation with field establishment for both and combined dates of planting. The standard germination correlation with field establishment was the next highest but showed average percent germination discrepancies of 28.4 and 19.7% between its total average germination and the May and June average per cent establishments respectively.

The cold test seedling emergence average was the closest to those of field. But this test showed a relatively low correlation with field establishment probably because of its inability to rank the seed tests in the laboratory according to how they performed in the field.

It would appear that a high correlation complimented by close approximation of means of field establishment by means of a laboratory test together would provide a better field establishment prediction than either one used alone.

Vigor measurements and criteria used to evaluate vigor in this study suggest that all the tests used were, to different degrees, able to screen vigorous from non-vigorous seed lots. It seemed, however, that soaking sorghum seeds in 2% ammonium chloride solution at 40$^{o}$ C for two hours prior to germination was the best vigor test on the basis of the criteria used to evaluate vigor in this study.

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APPENDIX

TWO-DAY STANDARD GERMINATION

| Source of Variation | Degree of freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Replicates | 3 | 30.13 | 10.04 | |
| Sources | 8 | 1720.12 | 215.01 | 14.70** |
| Sizes | 3 | 3067.63 | 1022.54 | 69.91** |
| Source x size | 24 | 1383.43 | 57.64 | 3.94** |
| Error | 105 | 1535.61 | 14.62 | |

TOTAL STANDARD GERMINATION

| Source of Variation | Degree of Freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Replicates | 3 | 28.85 | 9.61 | |
| Sources | 8 | 574.75 | 71.84 | 10.13** |
| Size | 3 | 2126.85 | 708.95 | 100.00** |
| Source x size | 24 | 606.58 | 25.27 | 3.18** |
| Error | 105 | 744.39 | 7.08 | |

TWO-DAY GERMINATION AFTER AGING TREATMENT

| Source of Variation | Degree of Freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Replicates | 3 | 7.29 | 2.43 | |
| Sources | 8 | 1220.63 | 152.57 | 5.39** |
| Sizes | 3 | 1089.35 | 363.11 | 12.84* |
| Source x size | 24 | 1825.08 | 76.04 | 2.69** |
| Error | 105 | 2970.45 | 28.29 | |

TOTAL GERMINATION AFTER AGING TREATMENT

| Source of Variation | Degree of Freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Replicates | 3 | 49.24 | 16.41 | |
| Sources | 8 | 629.50 | 78.68 | 9.55** |
| Size | 3 | 1397.63 | 465.87 | 56.52** |
| Source x size | 24 | 766.55 | 31.93 | 3.87** |
| Error | 105 | 865.50 | 8.24 | |

TWO-DAY GERMINATION AFTER AMMONIUM CHLORIDE TREATMENT

| Source of Variation | Degrees of freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Replicates | 3 | 39.68 | 13.22 | |
| Sources | 8 | 2108.50 | 263.56 | 29.08** |
| Size | 3 | 3082.74 | 1027.58 | 111.30** |
| Source x size | 24 | 675.44 | 28.14 | 3.11** |
| Error | 105 | 951.56 | 9.06 | |

TOTAL GERMINATION AFTER AMMONIUM CHLORIDE TREATMENT

| Source of Variation | Degrees of freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Replicates | 3 | 22.80 | 7.60 | |
| Sources | 8 | 1415.30 | 176.91 | 20.52** |
| Sizes | 3 | 2753.19 | 917.73 | 106.45** |
| Source x size | 24 | 638.80 | 26.61 | 3.09** |
| Error | 105 | 905.19 | 8.62 | |

TABLE 4

Seedling Emergence After Cold Soil Treatment

| Source of Variation | D.F. | S.S. | M.S. | F |
|---|---|---|---|---|
| Replication | 2 | 122.72 | 61.36 | |
| Seed source | 8 | ·3749.83 | 468.72 | 33.84** |
| Seed size | 3 | 1178.47 | 392.82 | 28.36** |
| Source x size | 24 | 826.52 | 34.85 | 2.51** |
| Error | 70 | 969.38 | 13.84 | |

** Significance at 1% level.

TABLE 5

Seedling Vigor--Growth Rate

| Source of Variation | Degrees of Freedom | Sums of Square | Mean Square | F |
|---|---|---|---|---|
| Replicates | 2 | 22.55 | 11.27 | |
| Seed source | 8 | 22.21 | 2.77 | 2.94** |
| Seed size | 3 | 78.68 | 26.22 | 27.79** |
| Seed x source | 24 | 17.50 | 0.72 | 0.77 N.S. |
| Error | 70 | 66.06 | 0.94 | |

** Significance at 1% level

TABLE 6

Field Establishment

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Replicates | 3 | 797.08 | 265.69 | 0.62 |
| Time of planting | 1 | 5219.00 | 5219.00 | 12.35** |
| Error (A) | 3 | 1266.89 | 422.29 | |
| Source | 8 | 11268.67 | 1408.58 | 14.52** |
| Seed size | 3 | 12814.83 | 4271.60 | 44.03** |
| Time x source | 8 | 273.73 | 34.21 | 0.35 |
| Time x size | 3 | 315.71 | 105.23 | 1.08 |
| Source x size | 24 | 5492.12 | 228.83 | 2.35** |
| Time x source x size | 24 | 1743.49 | 72.64 | 0.74 |
| Error (B) | 210 | 20372.01 | 97.00 | |

** Significance at 1% level.

TABLE 7

Date of Half Bloom

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Replicates | 3 | 4.04 | 1.34 | 4.97 |
| Date of planting | 1 | 5760.21 | 5760.21 | 21334.14** |
| Error (A) | 3 | 0.81 | 0.27 | |
| Seed source | 8 | 25.02 | 3.12 | 4.89** |
| Seed size | 3 | 46.40 | 15.46 | 24.17** |
| Time x source | 8 | 16.77 | 2.09 | 3.28** |
| Time x size | 3 | 7.97 | 2.65 | 4.15** |
| Source x size | 24 | 15.22 | 0.63 | 0.98 |
| Time x source x size | 24 | 11.02 | 0.45 | 0.71 |
| Error | 210 | 135.14 | 0.64 | |

** Significance at 1% level.

TABLE 8

Heads Harvested Per 15 Ft. Row Plots

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Replicates | 3 | 305.01 | 101.67 | 3.48 |
| Date of planting | 1 | 2261.28 | 2261.28 | 77.32** |
| Error (A) | 3 | 87.73 | 29.24 | |
| Seed source | 8 | 4859.83 | 607.47 | 14.39** |
| Seed size | 3 | 1173.78 | 391.26 | 9.27** |
| Date x source | 8 | 111.43 | 13.92 | 0.33 |
| Date x size | 3 | 127.95 | 42.65 | 1.01 |
| Source x size | 24 | 2418.28 | 100.75 | 2.39** |
| Date x source x size | 24 | 708.70 | 29.52 | 0.70 |
| Error | 210 | 8861.97 | 42.19 | |

** Significance at 1% level.

TABLE 9

Grain Yield--Bushels Per Acre

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Replicates | 3 | 193802.12 | 64600.70 | 30.89 |
| Date of planting | 1 | 12142.01 | 12142.01 | 5.81 |
| Error (A) | 3 | 6272.12 | 2090.70 | |
| Seed source | 8 | 2700.99 | 337.62 | 1.33 |
| Seed size | 3 | 1040.09 | 346.69 | 1.94 |
| Date x source | 8 | 4051.28 | 506.41 | 0.67 |
| Date x size | 3 | 522.00 | 174.00 | 0.42 |
| Source x size | 24 | 2619.83 | 109.15 | 1.00 |
| Date x source x size | 24 | 6290.30 | 262.09 | |
| Error | 210 | 54797.55 | 260.94 | |

TABLE 10

Grain Moisture Content

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Replicates | 3 | 725.11 | 241.70 | 3.31 |
| Date of planting | 1 | 1989.75 | 1989.75 | 27.25** |
| Error (A) | 3 | 219.03 | 73.01 | |
| Seed source | 8 | 17.53 | 2.19 | 0.61 |
| Seed size | 3 | 2.00 | 0.66 | 0.19 |
| Date x source | 8 | 21.06 | 2.63 | 0.73 |
| Date x size | 3 | 2.56 | 0.85 | 0.24 |
| Source x size | 24 | 67.58 | 2.81 | 0.78 |
| Date x source x size | 24 | 65.46 | 2.72 | 0.76 |
| Error | 210 | 753.48 | 3.58 | |

** Significance at 1% level.

WEIGHT OF GRAIN PER HEAD

| Source of Variation | Degrees of Freedom | Sums of Squares | Mean Squares | F |
|---|---|---|---|---|
| Replicates | 3 | 0.725 | 0.241 | |
| Date of planting | 1 | 0.268 | 0.268 | 3.13 |
| Error (date) | 3 | 0.257 | 0.085 | |
| Sources | 8 | 4.201 | 0.525 | 6.90** |
| Size | 3 | 1.258 | 0.419 | 5.51* |
| Date x source | 8 | 0.476 | 0.059 | 0.78 |
| Date x size | 3 | 0.148 | 0.049 | 0.65 |
| Source x size | 24 | 3.437 | 0.143 | 1.88* |
| Source x size x date | 24 | 1.211 | 0.046 | 0.61 |
| Error | 210 | 15.976 | 0.076 | |

Seedlot Identification

| Numberals Used in the Study | Seed Dealers |
|---|---|
| 1 | Anderson Seed Company, Texas |
| 2 | Dorman and Company, Texas |
| 3 | W. R. Grace & Company, Missouri |
| 4 | Henry and John Bunk, Kansas |
| 5 | NC + Hybrids, Kansas |
| 6 | Prairie Valley, Inc., Kansas |
| 7 | Prairie Valley, Inc., Nebraska |
| 8 | Richardson Seed Farms, Texas |
| 9 | Star Seed & Produce Company, Texas |

# SEED VIGOR MEASUREMENTS AND THEIR USE IN PREDICTING FIELD ESTABLISHMENT OF GRAIN SORGHUM

by

ANGO ABDULLAHI

B. Sc., University of London, 1964

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AN ABSTRACT OF A MASTER'S THESIS

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Laboratory and field tests were conducted in 1967 to investigate the degree to which the laboratory tests can be used to predict field establishment using nine seed lots of hybrid sorghum RS610. The influence of seed size on the germination and vigor measurements taken was also studied.

Seed lots came from the 1966 sorghum crop and were procured directly from commercial seed dealers in Texas, Missouri, Kansas, and Nebraska. All the seed lots were dusted with Cerasan against seed decay organisms.

Laboratory tests included standard germination and adverse seed treatments--vigor tests--which involved artificial aging of seed, soaking seeds in 2% ammonium chloride solution, soil cold testing and seedling growth rate. Two-day and total germinations from some of the laboratory tests were also compared in their effectiveness to predict field establishment. Field studies included two dates of field planting; 1) May 19, when soil temperature and moisture were considered unfavorable for good sorghum germination, 2) June 6, when conditions were generally improved over those of May 19.

A split plot design was used for the field study while completely random design was adopted for the laboratory tests.

Total germination results in the laboratory substantiated an assumption that seeds of low vigor are killed or rendered incapable of normal germination after being subjected to adverse treatment while vigorous seeds remained relatively unaffected. This is because the average germination after adverse treatment were lower than that obtained in standard germination.

Results of tests suggested that seed sources can be a highly influential factor not only in seed vigor research but also in the selection of seed for planting. The results also suggested that a single seed lot could not be expected to truly represent a hybrid.

The influence of seed size was significant in all aspects of the study except yield. Laboratory germination and cold soil and field emergence generally increased with increase in seed size. However, there was no significant difference between large, medium and composite seeds in all tests performed. But small seeds were consistently and significantly lower in performance than the other sizes.

June planted plots showed higher per cent establishment than May plots. This difference was attributed to improved weather in June. Grain yield was lower in the June plots than in May plots. Yield differential was due to weight of seeds per head rather than the number of heads harvested from unit area of land.

Three criteria used to evaluate vigor measurements taken in the tests conducted were:

1) Ability to rank seed lots according to their performance in the field.
2) Ability to correlate closely with field establishment.
3) Agreement of average germination or emergence with average field emergence.

All the above criteria suggested that all the laboratory tests used were, to different degrees, able to screen vigorous from non-vigorous seed lots. It seemed, however, that soaking sorghum seeds in

2% ammonium chloride solution at 40$^{o}$ C for 2 hours prior to germination was the best vigor test in this study, based on the three criteria of evaluation of vigor.