Maintaining Soybean Seed Quality

The more than threefold increase in soybean acreage in the U.S. since the early 1950's combined with the release of many new varieties and a diminishing number of farmers who "save" seed provided ample incentives for substantial commercialization of soybean seed production and supply. The large-scale, widespread, and increasingly professional soybean seed industry established during this period has no parallel among other nonhybrid grain crops.

In 1972 over 900,000 acres of soybeans with estimated production of 27 million bu of seed passed genetic and field standards of the various state seed certification agencies (41). Assuming that as much as 30% of the field-approved certified seed were diverted to the grain trade for various reasons—e.g., low germination (a serious problem in 1972)—about 19 million bu of certified seed were available for marketing, enough to plant more than one-third of the 1973 soybean crop. The market value of this seed was at least $150 million (approximately $8/bu). The other two-thirds of the 1973 soybean crop was planted with noncertified seed purchased from dealers, neighbors, or "saved." The value of this noncertified and the certified seed used to plant the 1973 soybean crop totaled more than $300 million.

SEED BUSINESS GROWING

The soybean seed industry is expanding rapidly under the stimuli of strong demand, excellent prices, and the many advantages derived from the Plant Variety Protection Act. The potential soybean seed market is huge—as many bushels of seed as there are acres planted.
During the period of very rapid growth of the soybean seed industry, and until fairly recently, major efforts and resources were focused on expanding capacity of production and processing operations to keep abreast of the rising demand for seed. Established seed operations were reorganized and modified to handle soybean seed; many new companies were launched and new facilities constructed, many of which already are inadequate; and even more modern, high capacity facilities are under construction or on the drawing board. Therefore, the industry has been largely concerned with establishing its physical base.

The over-riding but necessary preoccupation with quantity and capacity—bushels of seed bagged per year—has, unfortunately, mitigated against any substantial advance in the quality of seed marketed, exclusive of the genetic (varietal) component. The general quality of soybean seed has improved only slightly during the past 15 years. Quality is usually moderately good, and periodically poor.

Moderately good quality soybean seed, however, are not satisfying the expectations of farmers, who are becoming increasingly aware of the importance of high quality seed. The gap between the quality of soybean seed offered in the trade and expectations of soybean growers will widen unless major quality problems are resolved.

**ATTRIBUTES OF QUALITY**

Seed quality in soybeans encompasses several important attributes:

1. **Genetic purity**—Varietal purity is important from the standpoint of both total performance and uniformity, especially uniformity of maturity.
2. **Physical purity**—Seed should contain a minimum of inert material and should not be contaminated with seed of objectionable weeds and other crops.
3. **Germination**—High quality seed should germinate 90% or better.
4. **Vigor**—The germinable seed in a lot should be vigorous enough to emerge rapidly and uniformly under a broad spectrum of seedbed conditions and to develop into rapidly growing, productive plants.

The most chronic seed quality problems in soybeans relate to germinability and vigor. Sources of these problems and their possible resolution are discussed in the following section. Problems involving varietal purity and weed seed contaminants—less frequent but not less serious—will be considered in later sections.

**FACTORS IN GERMINATION, VIGOR**

Sources of germination and vigor problems that plague the soybean seed industry are diverse: inexperienced of “new” producers in the industry; compromises between quantity and quality that are tipped in favor of quantity; over-extension of production beyond harvesting, bulk storage and processing capacity; unfavorable weather during harvest period; etc. The basic and most important seed quality problems in soybeans, however, and the one which directly or indirectly influences the occurrence and severity of nearly all other problems, resides within the soybean seed. The “modern” soybean seed is a marvelous packet of valuable chemical constituents, but as a reproductive unit it borders on being a flop.

**Seed Development and Morphology**

The structural and physiological delicacy of the soybean seed contributes in a major way to many germination and vigor problems. Thus, some knowledge of seed development and morphology is essential to understand the complexity of factors involved in loss of germinability and vigor and possible means of minimizing these losses.

Development of the soybean seed begins with fertilization (sexual). The two cotyledons and growing points are fully differentiated within 2 weeks. Dry weight of the developing seed increases slowly until about 20 (late blooms) to 30 days (early blooms) after flowering (3), while moisture content (w.b.) slowly decreases from about 90% to 80% (figure 1, Lee variety). Beginning about 25 to 35 days after flowering, dry matter begins to accumulate rapidly in the seed, reaching a maximum at 65 to 75 days. Thereafter, dry weight tends to remain constant or decrease slightly (sometimes substantially when the seed are severely weathered prior to harvest). During the period of rapid dry matter accumulation, seed moisture content decreases rather slowly to 40%-50% at the time maximum dry weight is attained. Under good field drying conditions seed moisture content further decreases to 15%-18% in about 1 week.

Soybean seed are physiologically mature at the time maximum dry weight is reached (40%-50% moisture content). At this stage, germinability and vigor are highest even though the seed first become capable of germination when about one-third of the dry weight has been accumulated.

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1 Date of flowering (fertilization) has a pronounced effect on rate of seed development in a determinate variety such as Lee. Seed from late season flowers develop much more rapidly than those from early season blooms. Seed set late in the season, therefore, "catch up" to those set earlier as the season progresses.
The mature soybean seed is generally spherical in shape and has a relatively thin seed coat (figure 2). The hilum, point of attachment of the seed in the pod, is linear to elliptic in shape and located on the ventral face of the seed coat. It may be variously pigmented. The endosperm is represented only by a thin layer of cells immediately beneath the seed coat. The remainder of the interior of the seed is occupied by the embryo, which consists of a short radicle-hypocotyl axis, two fleshly cotyledons (lateral organs) and a well developed plumule-growing point with two leaves, which is terminal on the radicle-hypocotyl axis and between the cotyledons.

The short radicle-hypocotyl axis is curved so that it lies against the basal margins of the cotyledons with tip pointed in same direction as apices of the cotyledons. The position of the radicle-hypocotyl axis and the delicacy of the seed covering, which is its only protection, makes the seed especially vulnerable to injury by mechanical abuse from any source—harvesting, conveying, processing, etc. Since the radicle-hypocotyl axis is essential for normal germination, any substantial damage to it can be disastrous to seed quality.

Figure 1. Moisture content and dry weight changes in soybean seed during maturation. (MC—moisture content; DW—dry weight; G—50% seed capable of germination; M-1—physiological maturity of seed set from July 17 flowers; M-2—physiological maturity of seed set from August 6 flowers) (3)

Figure 2. Seed and seedling structure in soybeans. A—seed; B—seedling; C—embryo; a—seed coat; b—hilum; c—hypocotyl; d—plumule; e—cotyledon; f—primary root)
Field Environment

Quality is very much affected by climatic conditions from the time the beans first drop below 25% in moisture, during the post-maturation drying phase, until they are harvested. Since the seed are physiologically mature, they are in effect “stored” in the field during this period (23, 32).

Frequent and/or prolonged precipitation during the post-maturation, preharvest period results in alternate wetting and drying of the seed in the pod and severe deterioration. The dates in table 1 illustrate the effects of adverse climatic conditions on moisture content and germination of soybean seed while they are still on the plant. After reaching “field maturity” i.e., harvestable stage, on about September 20, moisture content of Hill soybean seed fluctuated from 11% to 20% depending on rainfall and germination dropped to below 80% by October 6 and to 37% by November 3. The Bragg variety, which reached field maturity around October 23 or approximately 1 month later than Hill, also fluctuated widely in moisture content under influence of rainfall but loss of germinability was not nearly so severe. Bragg seed harvested on December 12 still germinated above 80%.

The much greater reduction in germination of the Hill variety, even though subjected to fewer rains than Bragg, is due to the warmer temperatures during the Hill weathering period. The effects of weathering on seed quality increase in severity as temperature increases. For this reason, germination problems of early maturing varieties are more frequent and severe than for late maturing varieties (26, 64).

The soybean seed producer cannot control climatic conditions during the harvest period but he can take steps to limit the extent and severity of weathering. Soybean seed should be harvested when they reach field maturity (14%-15% moisture) unless rainfall interferes. Harvest should not be delayed until the cotton is in and/or the corn gathered. When rains delay harvest, seed producers equipped with adequate drying facilities can take advantage of any “break” in the weather. They do not need to delay harvest until moisture content drops back down to 13% or less.

Reduced seed quality has been associated with environmental conditions just opposite those discussed above. Hot, dry weather during harvest adversely affects both the physical and physiological quality of soybean seed (49, 50, 54).

Some efforts are being made to improve seed quality in soybeans through development of lines resistant to weathering and other environmental stresses during the maturation period (50, 51, 52, 89).

Harvesting

In terms of seed quality, harvesting is probably the most critical phase of the overall soybean seed production-processing operation. First, improper cleaning of the combine and incautious operation are major sources of varietal contamination. Second, timeliness of harvest is most important in minimizing field deterioration, as pointed out above. Finally, mechanical abuse during the harvesting operation is the most important cause of injury to soybean seed, commonly referred to as mechanical damage.

Although “bad” weather at harvest creates quality problems, it does not follow that “good” drying weather eliminates all problems. The opposite is all too frequently the case. Seed moisture content decreases rapidly when good drying weather prevails. Soybeans become very brittle and susceptible to injury from mechanical forces when moisture content drops below 13%-14% (table 2). If seed moisture drops to 10% or less before the harvest operation can begin or is completed, substantial seed injury may occur even though harvest is done as carefully as possible. Germination of soybean seed at 10% moisture or less can be immediately reduced as much as 10% by force of impact resulting from a 5-foot drop onto a metal surface. The mechanical forces generated in the threshing section of a combine and in certain types

<table>
<thead>
<tr>
<th>Date of harvest</th>
<th>Hill M.C.</th>
<th>Hill Germination</th>
<th>Bragg M.C.</th>
<th>Bragg Germination</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/15</td>
<td>26</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/22</td>
<td>13</td>
<td>97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/29b</td>
<td>17</td>
<td>90</td>
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<td></td>
</tr>
<tr>
<td>10/6b</td>
<td>20</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/13</td>
<td>11</td>
<td>76</td>
<td>26</td>
<td>98</td>
</tr>
<tr>
<td>10/20b</td>
<td>19</td>
<td>71</td>
<td>18</td>
<td>98</td>
</tr>
<tr>
<td>10/27</td>
<td>12</td>
<td>53</td>
<td>13</td>
<td>93</td>
</tr>
<tr>
<td>11/3b</td>
<td>14</td>
<td>37</td>
<td>14</td>
<td>92</td>
</tr>
<tr>
<td>11/10</td>
<td>12</td>
<td>92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/17b</td>
<td>20</td>
<td>89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/24b</td>
<td>13</td>
<td>86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/1</td>
<td>15</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/8</td>
<td>11</td>
<td>84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/15b</td>
<td>14</td>
<td>84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Seed hand harvested and threshed, then cleaned with hand screens and aspirator before germination test.

*One or more rains during preceding week.
of conveyors are much greater than those resulting from a 5- or even 10-foot drop (60, 63, 86). On the other hand, a 20-foot drop has no effect on seed with 14% moisture.

The most favorable seed moisture content for harvest of soybeans is controversial. Available evidence (14, 26, 49, 60, 63, 65, 72, 77), however, suggests that the optimal range is rather narrow, between about 12.5% and 14.5%. Seed cracking and splitting increase sharply as moisture content decreases below 12.5%; seed bruising and other less visible, but not less detrimental, injuries increase at moisture contents above 14.0%.

Moisture content of seed in the field can exceed both the upper and lower limits of the optimal harvest range within a single day—for example, 15% moisture in early morning (foggy or heavy dew), and 11% moisture on a sunny afternoon. Nevertheless, the general recommendation for harvesting soybean seed is to start harvesting as soon as moisture content drops to 14% and continue—weather permitting—until harvest is completed.

Although the harvest operation is discussed in detail elsewhere in these proceedings, a few “rules of thumb” for harvesting as related to maintenance of seed quality are advanced below.

1. Weed-free, uniform stands facilitate adjustments of combine to minimize seed damage.
2. Commence harvesting when seed moisture content first drops below about 14.5%.
3. Combine at uniform ground speed.
4. Adjust clearance and cylinder speed so that complete threshing is achieved—but not higher.
5. Readjust cylinder speed in afternoon—usually to slower rpm.
6. Check threshed seed periodically to determine extent of seed damage.
7. Weathering reduces resistance of seed to cracking and splitting; therefore, combine weathered seed at higher moisture contents (13%-15%) and slower cylinder speeds.

### Table 2. Relation of seed moisture content and force of impact (height of drop) to loss of germinability of soybean seed dropped onto a hard surface (27)

<table>
<thead>
<tr>
<th>Seed moisture content (%)</th>
<th>Height of drop (ft)</th>
<th>% germination</th>
<th>Height of drop (ft)</th>
<th>% germination</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0</td>
<td>98</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>98</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>98</td>
<td>12</td>
<td>88</td>
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<tr>
<td>12</td>
<td>10(2X)</td>
<td>98</td>
<td>10</td>
<td>88</td>
</tr>
<tr>
<td>14</td>
<td>20</td>
<td>98</td>
<td>10</td>
<td>88</td>
</tr>
</tbody>
</table>

*Seed dropped twice from height of 10 ft.*

Handling, Bulk Storage, Aeration, and Drying

Handling and conveying—All handling and conveying operations must be accomplished as gently as possible to minimize seed damage. For this reason, use of inclined augers for loading seed into bulk storage bins is not recommended. Loading of bins is best accomplished by “belt-conveyors” or via the typical vibro-dump pit, belt-bucket or continuous bucket elevator, horizontal drag flight or belt conveyor, gravity spouting system (figure 3) (65, 86). The use of “dead
viability in bulk storage (7, 26). Natural air dryers confronted with harvested beans containing up to 24% moisture in fall 1972 resorted to all sorts of seed drying indicates that air flow rates of 3 to 6 cfm/bu are adequate for drying seed up to about 16% moisture. Supplemental heat is usually necessary for effectively drying seed with more than 16% moisture.

Aeration is usually adequate for conditioning and maintenance of viability of seed at 14% moisture or less. Aeration equalizes temperature within the seed mass, prevents moisture migration, cools the seed as ambient temperature drops with the advance of the fall season, and can reduce seed moisture content by 1% to 1.5% with higher air flow rates. Reducing the temperature of the seed to 5°-10°C and seed moisture content below 13% just about eliminates seed deterioration from storage molds, especially for the relatively short period involved.

Air flow rates of 0.1 to 1.0 cfm/bu are used for aeration. An air flow rate of near 1.0 cfm/bu is necessary to reduce seed moisture content by the 1.0% to 1.5% mentioned above. Aeration is best controlled with a humidistat set to cut off the fan whenever ambient relative humidity rises above 60% to 65%, which is in equilibrium with seed moisture content of about 12.5%. The aeration system is turned off after the seed mass has cooled down and moisture content has stabilized. Thereafter, the system is activated periodically to prevent temperature stratification and moisture migration in the bin.

Drying—Soybean seed harvested above 14% moisture must be dried to 13% or less to maintain viability in bulk storage (7, 26). Natural air drying at flow rates of 2 to 3 cfm/bu are adequate for drying seed up to about 16% moisture. Supplemental heat is usually necessary for effectively drying seed with more than 16% moisture.

Very little information is available on heated air drying of soybean seed or grain. Soybean producers confronted with harvested beans containing up to 24% moisture in fall 1972 resorted to all sorts of drying systems; some were successful, others were not. The little available information on soybean seed drying indicates that air flow rates of 3 to 6 cfm/bu, drying bed depth less than 4 ft, and control of relative humidity of drying air so that it does not drop below 40%, are essential for effective, safe drying (7, 26, 56, 88). Since maintenance of the drying air relative humidity above 40% is critical, the permissible heat rise is determined by ambient relative humidity.

Processing

Soybean seed move from bulk storage bins through the cleaning plant and into the packaged seed storage warehouse as the processing season progresses (figure 3). Basic cleaning is accomplished with an air and screen machine (26, 87). The air and screen machine removes fragments of pods, stems and soybean seed, “splits,” weed seed, and other contaminants that are lighter, smaller, and larger than mature, intact soybean seed. Basic cleaning can increase germination percentage by a few points through removal of badly damaged, immature, and rotten (light weight) seed.

In many cases basic cleaning is all that is necessary to prepare the seed for packaging and marketing. An increasing number of seed producers, however, pass the seed over spiral separators after basic cleaning and before packaging. The spiral separator first came into use for soybean seed processing in the southern area in the late 1950’s to remove seed of moon flower (ipomoea turbinata) and soil peds in cyst nematode infested areas (figure 4). It was soon noticed that the spiral separator also separated out the remaining broken seed, splits, and misshapen seed (immature or severely weathered), thus, greatly improving appearance and increasing germination another few points. Because of its beneficial effects on appearance, spiral separators have been installed in many seed plants in the Midwest since the mid-1960’s.

Soybean seed are not difficult to clean. Most cleaning problems can be traced to attempts to “squeeze” too much capacity from the air and screen cleaner and spiral separators. It should also be pointed out that the cleaning machines, surge bins, and conveyors in the processing plant are potential sources of varietal contamination. Therefore, the entire processing plant should be thoroughly cleaned at the beginning of the processing season and between any change in soybean variety or seed kind during the processing season.

Treatment of soybean seed with a fungicide is beneficial, particularly when germination is less than 80% and the seed are infested with a disease such as pod and stem blight (8, 13). A relatively small proportion of soybean seed marketed, however, is treated because the risk of financial loss to the seedsman is too great. Once seed are treated with a fungicide they can only be used for
Planting. Thus, seed that are not marketed for any reason, e.g., drop in germination below market standard, slow market, etc., cannot be sold as grain; they must be dumped. At $8/bu, soybean seed make pretty expensive fertilizer. For this reason, when soybean seed are treated with a seed protectant, the chemical is most frequently applied in the planter box.

The final step in processing is packaging. Soybean seed are packaged in multiwall paper bags or less frequently, woven plastic bags.

Storage

The storage period for soybean seed begins at harvest (actually at time seed reach physiological maturity prior to harvest) and usually ends at planting time the following season. This period can be divided into two phases: the bulk seed storage phase and the packaged seed storage phase. The former was considered to some extent in connection with handling, aeration, and drying.

The longevity of seed in storage is influenced by four major factors: (a) inheritance or the species; (b) the quality of the seed at the time it enters storage; (c) temperature of the storage environment; and (d) the moisture content of the seed or ambient relative humidity (23, 24, 26, 32, 44, 53).

Species—Soybean seed are inherently short-lived as compared to other major crop species (32). Under climatic conditions in the southeastern U.S., germination percentage of the “average” soybean seed lot is maintained through May-June of the year following harvest after which it begins to decrease, sometimes rather abruptly. Thus, germinability of soybean seed in the Southeast is just barely maintained through the first planting season following harvest. Seed of corn, sorghum, cotton, and wheat, on the other hand, usually maintain germination through the second planting season following harvest, although seed vigor is often substantially reduced (table 3).

In subtropical and tropical areas, poor storability of soybean seed is a major constraint on production (32). Seed often drop in germination and are worthless for planting within 2 to 3 months after harvest.

Quality of seed entering storage—Storability of seed is greatly influenced by the degree to which they have deteriorated prior to storage. Soybean seed subjected to weathering before harvest, severely damaged during combining, and/or inadequately

Table 3. Comparison of germination percentages of different seed kinds during storage under ambient conditions at Mississippi State, Mississippi, in 1968-70 (28)

<table>
<thead>
<tr>
<th>Seed kind</th>
<th>0</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybeans “A”</td>
<td>90</td>
<td>91</td>
<td>86</td>
<td>84</td>
<td>71</td>
<td>33</td>
</tr>
<tr>
<td>“B”</td>
<td>82</td>
<td>62</td>
<td>23</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Corn</td>
<td>98</td>
<td>98</td>
<td>99</td>
<td>98</td>
<td>97</td>
<td>90</td>
</tr>
<tr>
<td>Wheat</td>
<td>94</td>
<td>95</td>
<td>92</td>
<td>94</td>
<td>90</td>
<td>82</td>
</tr>
<tr>
<td>Cotton</td>
<td>87</td>
<td>83</td>
<td>86</td>
<td>86</td>
<td>83</td>
<td>74</td>
</tr>
<tr>
<td>Sorghum</td>
<td>94</td>
<td>91</td>
<td>95</td>
<td>92</td>
<td>90</td>
<td>82</td>
</tr>
</tbody>
</table>

<sup>a</sup>Period of storage: 12/68 through 11/70.
<sup>b</sup>Each datum represents average germination percentage of four “commercial” seed lots of each kind.
Moisture content (\%): 4.3 6.5 7.4 9.3 13.1 18.8

Relative humidity (\%): 15

Relative humidity of the immediate environment of seed harvested at 16% moisture and loaded into a aerated. The relative humidity inside a mass of soybean seed is determined by the level for a considerable period regardless of relative humidity. The relative humidity within a mass of soybean seed is hygroscopic. They absorb moisture from the atmosphere or lose moisture to it until the vapor pressures of seed and atmosphere reach equilibrium. Since the vapor pressure of atmospheric moisture at a specific temperature and pressure is a direct function of the degree of saturation or relative humidity, the various kinds of seed attain characteristic moisture contents when exposed to different levels of relative humidity for sufficiently long periods of time. The seed moisture contents attained under these conditions are variously referred to as the equilibrium moisture content, or hygroscopic equilibrium. At 25°C, moisture contents of soybean seed in equilibrium with various levels of relative humidity are:

<table>
<thead>
<tr>
<th>Relative humidity (%)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>4.3</td>
<td>6.5</td>
<td>7.4</td>
<td>9.3</td>
<td>13.1</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Emphasis in seed storage studies or in practical storage operations is most often placed on the controlling influence of relative humidity on seed moisture content. This emphasis is proper during the packaged seed storage phase provided the packaging material is not moisture vapor-proof. The hygroscopic equilibrium between seed and ambient relative humidity, however, is a two-way street. During the critical days following harvest when seed are in bulk storage and during any phase of storage involving moisture vapor-proof packages, relative humidity of the immediate environment of the seed is paramount.

The relative humidity within a mass of soybean seed harvested at 16% moisture and loaded into a bulk storage bin is above 80%. It will remain at this level for a considerable period regardless of relative humidity outside the bin unless the seed are aerated. The relative humidity inside a 10-mil plastic bag of seed is similarly determined by the

It is important to consider both sides of the seed-moisture vapor equilibrium because relative humidity within the seed mass has effects other than on seed moisture content. The growth and reproduction of storage fungi, which contribute to quality losses in seed and grain, are very dependent on relative humidity within the seed mass. The important storage fungi cannot grow and reproduce in seed or grain in equilibrium with a relative humidity less than 65%-70% (12.5% moisture content in soybeans). Activity of storage insects also drops sharply at relative humidities below 50%.

The temperature of the storage environment and/or within the seed mass has a profound effect on maintenance of seed quality. In most instances temperature and seed moisture (or relative humidity) interact closely in their effects on longevity of seed. High moisture seed (e.g., 15%-18%) can be stored for a year or more at a temperature of 10°C or less, while low moisture seed (9% or less) can withstand temperatures in the range 30°-35°C for the same period without substantial loss of germination.

The classic study of Toole and Toole (85) illustrates very well the effect of temperature and seed moisture content on the longevity of soybean seed in storage (table 4). Germination of 9.4% moisture seed was maintained above 80% for more than 10 years at 10°C, 5 years at 20°C, and 1 year at 30°C. In contrast, germination of 13.9% moisture seed decreased below 80% within 5 years at 10°C, 2 years at 20°C, and 0.5 years at 30°C.

In a more recent study, Andrews (4) demonstrated the importance of seed moisture and temperature in “carry-over” storage of soybean seed (table 5). Seed packaged at 10.4% moisture or less in multiwall, 3-ply, paper bags with 2-mil polyethylene liners to retard moisture vapor transmission maintained germination above 75% through the second planting season after harvest.

<table>
<thead>
<tr>
<th>Moisture (%</th>
<th>Temperature (°C)</th>
<th>Years storage (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.4</td>
<td>10</td>
<td>93 95 98 93 99 92 94</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>97 99 96 94 89 90 0</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>96 87 0</td>
</tr>
<tr>
<td>13.9</td>
<td>10</td>
<td>95 98 96 92 88 49 0</td>
</tr>
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<td></td>
<td>20</td>
<td>98 93 0</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Effect of seed moisture content and temperature on germination percentage of soybean seed during storage (85)
under warehouse conditions in Mississippi. In a similar study conducted by Delouche and Baskin (28) in cooperation with a seed producer at Warehouse 5. Effect of initial seed moisture content, temperature and packaging material on germination of soybean seed during "carry-over" storage: June 1968-June 1969 (4)

<table>
<thead>
<tr>
<th>Package</th>
<th>Temperature</th>
<th>Initial moisture %</th>
<th>Months in storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Multiwall paper, 3-ply</td>
<td>6°C-50% RH</td>
<td>7.2</td>
<td>90</td>
</tr>
<tr>
<td>2-mil polyethylene</td>
<td></td>
<td>10.4</td>
<td>92</td>
</tr>
<tr>
<td>Warehouse (ambient)</td>
<td></td>
<td>12.8</td>
<td>90</td>
</tr>
<tr>
<td>Multiwall paper, 3-ply</td>
<td>6°C % RH</td>
<td>7.2</td>
<td>90</td>
</tr>
<tr>
<td>Warehouse (ambient)</td>
<td></td>
<td>10.4</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.8</td>
<td>90</td>
</tr>
<tr>
<td>2-mil polyethylene</td>
<td></td>
<td>9.0</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.4</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.8</td>
<td>92</td>
</tr>
<tr>
<td>Warehouse (ambient)</td>
<td></td>
<td>9.0</td>
<td>92</td>
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<tr>
<td></td>
<td></td>
<td>10.4</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.8</td>
<td>92</td>
</tr>
</tbody>
</table>

Windfall, Indiana, soybean seed packaged at 9.0% moisture in either multiwall paper or 7-mil polyethylene bags maintained germination through 40 months in a "cool" but unconditioned warehouse. Seed vigor, however, was substantially reduced after 24 months (figure 5).

For maintenance of both germination and vigor, soybean seed should be rapidly and properly conditioned to 10%-12% moisture after harvest and maintained at that level until planted the following spring. Successful carryover storage requires a seed moisture content of 10% or less and air conditioning to reduce temperature by 5°-10°C during the summer months.

Miscellaneous

**Varietal characteristics**—Inherited characteristics of soybean varieties can contribute to seed quality problems. In their study of the causes for sporadic emergence of some soybean varieties in Iowa, Grabe and Metzer (48) found that hypocotyl elongation of certain varieties was inhibited at 25°C, but "normal" at temperatures above and below 25°C, i.e., 10°, 20°, and 30°C. When seed of such varieties were planted at a depth of 4 inches and seedbed temperature was about 25°C, emergence was poor because of insufficient hypocotyl elongation. Subsequent studies (16, 38, 43, 48) of this phenomenon showed that temperature-induced hypocotyl inhibition is under genetic control, and that inhibition occurs at all temperatures between 21° and 28°C with maximum at 25°C. Procedures for evaluating temperature sensitivity of hypocotyl elongation of soybean varieties have been developed (16).

Keeling's (59) recent work on the nature of resistance to *Pythium* seed rot in soybeans provides an explanation for the notoriously poor emergence of the Hood variety. He found that seed of the Hood variety exuded about twice as much soluble carbohydrates during germination as seed of Semmes (a resistant variety), and that there was a direct relationship between the amount of soluble carbohydrates exuded during germination and *Pythium* seed rot.

The work of Walters and Caviness (89) and others (60, 51, 52) in developing soybean varieties with improved seed quality has already been mentioned.

**Seed moisture content at planting**—The recent work of Obendorf and Hobbs (70) suggests that soybean seed at 13% moisture and higher are less susceptible to injury from low seedbed temperature than seed at very low moisture contents (5%). These reactions in soybeans are very similar to those reported for cotton, corn, beans, and sorghum (22, 36, 71, 76).

Figure 5. Germination and cold test percentages of Clark soybean seed packaged in 3-ply multiwall paper bags during storage for 40 months in warehouse at Windfall, Indiana (28)
Seed-borne diseases—Detrimental effects of seed-borne diseases on quality of soybean seed have been reported by several workers (9, 10, 68, 69).

MAINTAINING VARIETAL PURITY
Varietal purity in soybeans is maintained through systematic seed multiplication and rigorous in-company quality control program, or participation in the multiplication and quality control systems of the various state seed certifying agencies.

Certification procedures designed to maintain varietal purity and other quality standards during multiplication/production and processing of soybean seed include (11a):

a. Limitation on generations—Multiplication of soybean varieties is limited to two generations beyond the foundation seed generation, namely, registered class seed, which are the progeny of foundation seed, and certified class seed, which are progeny of registered or foundation seed.

b. Control of seed source—The seed used to plant each seed crop for certification must be of the proper class, i.e., registered class seed must be produced from foundation seed; certified class seed must be produced from registered or foundation seed.

c. Land history—Soybean seed cannot be produced on land on which the previous crop was another variety of soybeans, or the same variety but not certified, unless the variety planted can be easily distinguished from the one grown the previous season. This is to prevent varietal contamination from volunteer plants.

d. Isolation—Soybeans are self-pollinated; nevertheless, fields of different varieties of soybeans must be adequately separated to prevent mechanical mixtures.

e. Field standards—Soybeans subject to certification are field inspected at least once—usually at maturity—to determine that the ratio of plants of other varieties to those of the variety certified does not exceed 1:1,000 for foundation seed, 1:500 for registered seed, and 1:200 for certified class seed.

f. Cleanliness of equipment and facilities—Harvesters, bulk storage units, conveyors, and cleaning machines must be thoroughly cleaned before use and between any change in variety. Selection of equipment for ease of cleaning is an important consideration in design of seed processing facilities.

g. Seed standards—After processing and packaging, certified class seed must not contain inert matter in excess of 2%, seed of other varieties in excess of 0.5%, and seed of objectionable weeds in excess of limits established by the different state seed certifying agencies and state seed laws. Minimum germination is 80%.

The foregoing are the minimum standards adopted by the Association of Official Seed Certifying Agencies. Individual state seed certification agencies may and do have more rigorous regulations and higher standards.

EVALUATION OF SEED QUALITY
The quality of soybean seed is routinely evaluated by standard test procedures (11). These procedures include a purity analysis, germination test, and usually a moisture test.

Purity analysis—In the purity analysis the percentage by weight of pure seed, other crop seed (including seed of other varieties as can be identified), weed seed and inert matter are determined. Modern soybean varieties can seldom be positively identified by seed characters alone. Very often, however, it is possible to determine that a particular seed is not of the variety specified. Although various seed and seedling characters are useful in determining trueness-to-variety in soybeans, field grow-out tests are generally necessary to accurately assess varietal purity.

Germination test—The percentage by number of seed capable of producing “normal” seedlings is determined. The germination test has serious limitations as a measure of the stand and crop producing potential of soybean seed as will be discussed below.

Moisture test—The moisture content of the seed, wet weight basis, is determined, usually with an electric moisture meter.

Germination, Deterioration, and Vigor
The stand and plant producing potential of soybean seed and other kinds of seed as well is most commonly evaluated by a germination test. Exacting procedures for determining germination percentage of seed lots have been developed and perfected over the past 100 years and are codified in the Rules for Testing Seed (11). In many ways, the standard germination test appears to admirably serve the needs and interests of seed analysts, seed control officials, and less professional seedsmen. It does not now, however, adequately serve the interests of farmers who need more assurance of the stand and crop producing potential of seed they purchase (or use) for planting, and those seedsmen who would like to provide such
assurance. Deficiencies of the germination test as a measure of performance potential of seed stem from three main sources: the overall philosophy of germination testing, the nature of seed deterioration, and germination labeling requirements.

Procedures for germination testing of seed have been established on the basis of the "optimization" principle, i.e., test conditions are optimized so that maximum germination percentages are obtained. Thus, germination tests are made largely on "artificial," standardized, essentially sterile media, in humidified, temperature controlled germinators for periods sufficiently long to permit even the weakest seed to make its debut as a normal seedling.

It has not been well established that the performance potential of a seed is progressively impaired through deteriorative processes which inevitably occur over time—a few minutes or many years. The identity and sequence of the deteriorative changes—or the manifestations of change—that occur in a seed as it dies are known only in a general way. Available evidence, however, suggests that during deterioration, essential systems and mechanisms are progressively impaired so that the consequences in terms of germination and subsequent growth and development become progressively more serious (1, 5, 23, 29, 46, 47, 55, 81).

Membrane degradation and loss of permeability control occur at an early stage during seed deterioration (2, 20, 29). Energy yielding and biosynthetic processes are impaired with resulting decrease in rates of respiration, transfer of dry matter from supporting tissues to embryonic axis, germination, and early seedling growth (29, 46, 55, 90, 91). At about this stage in the progress of deterioration, the seed appears to lose much of its natural resistance to environmental stresses and seed rotting micro-organisms.

Reduced rate of germination and early seedling growth are subsequently reflected in decreased rate of plant growth, delayed flowering and maturity and lowered yield. As deterioration progresses further, the seed fails to emerge from the seedbed even under rather favorable conditions. Finally, it loses its capacity to "germinate" even in the optimum environment of the germinator. Because seed within a lot are not uniform in physiological quality and they become progressively less uniform as deterioration advances, emergence, plant growth, development, and maturation become irregular and nonuniform as deterioration progresses toward the 0% germination stage.

The germination test is an insensitive and misleading measure of seed quality because it focuses primarily on the final, albeit most disastrous, consequence of deterioration, and does not adequately take into account the very substantial loss in performance potential that can and does occur before the germinative capacity is lost. Yet, the lesser consequences of seed deterioration—such as reduced resistance to environmental stresses, decreased seedling and plant growth rate, etc.—have become of greatest importance. Few seedsmen knowingly sell and few farmers knowingly plant dead or low germinating seed. Both seedsmen and farmers, however, are damaged all too frequently because seed of "good" germination fail to perform satisfactorily when planted in the field.

Labeling requirements and practices also contribute indirectly to deficiencies of germination percentage as an index of seed quality. The various seed laws in the U.S. all require that seed lots be labeled for germination percentage. This requirement, which in practice means that germination percentage must not be lower than stated within allowable tolerances coupled with present market standards has resulted in the widespread practice of "standard labeling." The majority of soybean seed lots marketed within an area are labeled with the same germination percentage, 80%, 85%, or 90% depending on area and season.

The dilemma created for the farmer by the practice of standard labeling and the inadequacy of germination % as an index of the stand and production potential of seed are evident in results from a study we did several years ago to compare laboratory germination and field emergence of soybean seed lots (82).

Samples from 100 commercial seed lots of soybean were taken more or less at random from a group of more than 1,000 official inspection samples. The only criterion used in selection was that the sample had to be from a seed lot labeled at least 80% germination. Fifty-three of the 100 seed lots were labeled 80% germination and 47 were labeled 85%. Six of the samples actually germinated less than 80% and were discarded. Of the 94 remaining samples, 29 actually germinated in range 90% to 94%, 47 in range 85% to 89%, and only 18 in range 80% to 84%. Four replications of 100 seed of each sample were planted in field tests in early May (1969). Field conditions were moderately unfavorable for germination and emergence. Emergence percentages are compared with laboratory germination percentages in terms of ranges of each in table 6.

There was a definite trend to high field emergence from lots of higher germination. While this trend might be of great significance to the researcher or specialist, it would have been no consolation to the farmers who purchased the three lots of 90%-94% germinating seed that emerged less than 60%, or the seven lots of
Table 6. Comparison of laboratory germination and field emergence percentages of samples from 94 soybean seed lots (82)

<table>
<thead>
<tr>
<th>Field emergence (%)</th>
<th>Laboratory germination (%)</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90-94</td>
<td>85-89</td>
</tr>
<tr>
<td>90+</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>80-89</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>70-79</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>60-69</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>50-59</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>40-49</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>40-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total No.</td>
<td>29</td>
<td>47</td>
</tr>
</tbody>
</table>

85%-89% germinating seed that emerged less than 50% (four lots less than 40%).

The most obvious conclusion from this study is that differences in degree of deterioration or level of vigor among the lots, hence their suitability for planting, were not reflected in either labeled or actual germination percentage.

Many attempts have been made to rigorously define the term vigor as applied to seed. The result is a Joseph's coat concept and numerous definitions—all of which have some degree of validity and applicability—that collectively cover the subject rather thoroughly (30, 55, 57, 58, 73, 75, 91). While space does not permit examination of the various definitions and concepts of seed vigor, it should be pointed out that vigor, as an attribute of quality, is meaningful only in reference to germinable seed. A nongerminable seed has zero performance potential, hence, no vigor. Vigor tests, therefore, supplement the standard germination test. The germination test establishes the percentage of germinable seed in a population or lot, while a vigor test evaluates the performance potential of the germinable seed. Vigor tests, of course, assay the extent of deterioration of seeds within a population which really determines their performance potential. Thus, vigor and degree of deterioration are essentially the positive and negative aspects, respectively, of performance potential.

A variety of vigor tests have been developed but only a few have been applied in a more-or-less routine manner in seed quality evaluation and control programs (30, 47, 55, 58, 75, 91). The more successful vigor tests evaluate response-reactions of individual seed which permit expression of test results as a percentage by number of seed tested much as in the germination test.

Byrd (19) and Byrd and Delouche (20) compared the efficiency of several of the more widely used vigor tests with the germination test for evaluating the progress of deterioration during storage and field emergence potential of soybean seed. They found that germination percentage was the least sensitive index of the progress of deterioration and reduction in emergence potential during storage (figure 6). Soybean seed stored in an environmentally controlled room at 30°C and 50% relative humidity did not significantly decrease in germination percentage until after 7 months. Accelerated aging and cold test responses significantly decreased after 1 to 4 months of storage, as did the field emergence percentage.

Preliminary results from studies being conducted by Andrews and Vaughan (6), with an objective to establish a vigor rating system for soybean seed lots, indicate that three vigor tests are promising—cold test, accelerated aging test, and tetrazolium test interpreted for vigor.

**Accelerated aging test**—The accelerated aging test was developed for evaluating the storability of seed lots (29). Everson (37) and associates at the Iowa State University Seed Testing Laboratory have effectively used the test to determine the

![Figure 6. Response-reactions of Lee 68 soybean seed during storage at 30°C to 50% r.h. relative to levels at beginning of storage (0 mos. = 100%). (AA—germination % following accelerated aging at 42°C to 100% r.h. for 48 hr; CT—soil cold test emergence (13°C for 5 days, followed by 4 days at 30°C); FE—14-day field emergence; SGR—seedling length after 4 days at 25°C; GE—germination %.)](image-url)
“carry-over” potential of soybean seed. For this purpose they use accelerated aging conditions of 40°C and 99% r.h. for 30 hours followed by a 7-day regular germination test.

The accelerated aging test has also proved useful as a vigor test for evaluating the stand producing potential of seed. Storability, after all, is influenced by vigor or degree of deterioration just as is rate and percentage of emergence. Accelerated aging of soybean seed under conditions of 40°C and 100% r.h. for 48 hours of 40°C and 100% r.h. for 72 hours followed by regular germination test produced results closely correlated with field emergence.

Cold test—The cold test used for evaluating vigor of soybean seed is a modification of the cold test routinely applied to corn seed (57). For the cold test, a 1:1 v/v mixture of builders sand and topsoil from a soybean field adjusted to a moisture content of 60% field capacity is the medium. After planting, the test trays are incubated at 13°C for 4 days, then transferred to a 25°C room (or room temperature) for about 4 days, after which emergence percentage is determined.

Tetrazolium test—The tetrazolium test is widely used to estimate the germination percentage of seed lots. Procedures for this use of the TZ test have been developed and published (33, 45). The TZ test is equally applicable for evaluating vigor of seed, long advocated by Moore (66, 67). When conducted by an experienced analyst, it is probably the most informative of all tests for evaluating the physiological quality of seed.

We use the classification system developed by Moore. Category 1 represents the most vigorous seed, category 2 the second more vigorous, etc., through category 5 which represents the least vigorous of the germinable seed. Categories 6, 7, and 8, which encompass nongerminable seed, are usually not used in establishing a vigor rating but do provide useful information regarding the progress of deterioration in the lot. The numbers of seed falling into categories 1 and 2, or 1, 2, and 3, are used to compute a germination or tetrazolium “energy” percentage, i.e., % vigorous seed.

In our view, quality control programs for soybean seed should utilize at least one vigor test in addition to the regular germination test to assess seed quality. These should be conducted at least twice with the last as close to the end of the storage period as possible.

QUALITY AND CROP PERFORMANCE

The decrease in performance potential of a seed or seed lot as deterioration progresses and vigor decreases has several consequences of signal importance to farmers and seedsmen.

Stand failures and inadequate stands—Stand failures or inadequate stands can result from any one or a combination of factors: poor seedbed preparation, low or excessively high seedbed temperatures, excessive or insufficient moisture, soil micro-organisms and other pests, chemical injury, and low quality seed. Although low quality seed are listed last, they are certainly not the least important. More often than not poor quality seed are a major factor in stand failures or near stand failures, because they are very susceptible to adverse conditions and stresses in the seedbed. Poor quality seed usually produce a good stand only under very favorable conditions. A stand failure is the most obvious consequence of seed deterioration and is very costly to the farmer. Cost of production is increased by expenses involved in replacement of seed, the replanting operation, and other operations that may be necessary. Less evident losses connected with a stand failure include upsets in scheduling subsequent operations, especially when two or more kinds of crops are included in the farming operation, and reduced yields in replanted crops.

Because of problems associated with replanting, farmers frequently retain inadequate “skippy” stands. While the soybean plant has a remarkable capacity to “compensate” for population deficiencies, inadequate stands often have greater weed problems, reduced yield per unit area, and greater losses during harvest.

Growth, development, and productivity—Until recently it was assumed that the influence of seed vigor on performance did not extend much beyond emergence. It is not clear whether seed vigor of seed influences the growth, development, and productivity of crops such as corn, sorghum, cotton, rice, some vegetables, and probably soybeans as well (5, 39, 47).

Edje and Burris (34) studied the relationships of seed quality to field performance using artificial aging treatments to establish a “vigor gradient” in initially high quality seed lots. They found that once a stand was established, there were no significant differences in yield between high, medium, and low vigor seed.

Similar studies by Byrd (19) produced similar results. Working with six seed vigor levels of Lee 68 produced by accelerated aging treatments, Byrd found that low vigor seed emerged more slowly and produced poorer stands as compared to seed of higher vigor. When stands among vigor levels were equalized at seven seedlings per linear foot of row by hand thinning, however, yield did not differ significantly among vigor levels. (It should be noted that, in this planting, overall yield was
exceptionally low because of stress from drought.)

In another planting with the same seed vigor classes but at a different time (month earlier) and location, Byrd planted 10 seed per foot of row and carried the resulting stands through yield—i.e., stands were not equalized among vigor levels. Average stand ranged from 9 plants per meter of row for the lowest vigor seed to 28 plants per meter for the highest vigor seed. Leaf area index (LAI) and plant dry weight per unit area (m²), and yield significantly decreased as seed vigor level decreased (table 7).

In more recent work, Popingis (78) studied the influence of seed vigor level on yield of Lee 68 soybeans at different population densities. Foundation seed hand harvested from the previous season’s production and stored in a cold room at 10°C and 50% r.h. until planted were used as the high vigor class; combine harvested foundation seed stored for 3 years in same cold room were used as low vigor class; and a 1:1 mixture of the high and low vigor seed were used on an intermediate or mixed vigor class.

The three vigor classes were planted in a split-plot design, thinned 16 and 28 days after planting to six population densities per vigor class ranging from 263,158 plants/ha (3.8 cm spacing in rows 1 m apart) to 16,666 plants/ha (60 cm apart). Yield significantly decreased as seed vigor level or population density decreased (table 8). There was no interaction between population density and vigor level.

Popingis (78) also found that within the mixed high-low vigor population, individual plants from high and low vigor seed produced relatively more

<table>
<thead>
<tr>
<th>Plants/ha (1,000)</th>
<th>High</th>
<th>Mixed</th>
<th>Low</th>
<th>Density means (C. V. = 13%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>263.2</td>
<td>3.721</td>
<td>3.285</td>
<td>3.335</td>
<td>3,447a</td>
</tr>
<tr>
<td>200.0</td>
<td>3.661</td>
<td>3.460</td>
<td>3.228</td>
<td>3,450a</td>
</tr>
<tr>
<td>100.0</td>
<td>3.612</td>
<td>3.260</td>
<td>2.910</td>
<td>3,261a</td>
</tr>
<tr>
<td>50.0</td>
<td>2.834</td>
<td>2.675</td>
<td>2.463</td>
<td>2,659b</td>
</tr>
<tr>
<td>33.3</td>
<td>2.490</td>
<td>2.220</td>
<td>2.140</td>
<td>2,283b</td>
</tr>
<tr>
<td>16.6</td>
<td>1,785</td>
<td>1,550</td>
<td>1,510</td>
<td>1,615c</td>
</tr>
</tbody>
</table>

Vigor means (C. V. = 10%) = 3,017a 2,742b 2,599b

Table 7. Effect of accelerated aging treatments (vigor level) on germination, emergence, growth and productivity of soybeans at population densities established by emergence % (rows 1 m apart)(19)

<table>
<thead>
<tr>
<th>Aging trt.</th>
<th>Emerg. (56 days) (%)</th>
<th>Stand (No. plts/m)</th>
<th>LAI (cm²/m)</th>
<th>Plt. D.W. (gms/m)</th>
<th>Yield (gms/plot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>88a</td>
<td>28</td>
<td>34,850a</td>
<td>321a</td>
<td>1,204a</td>
</tr>
<tr>
<td>5</td>
<td>85a</td>
<td>27</td>
<td>33,572ab</td>
<td>292a</td>
<td>1,114ab</td>
</tr>
<tr>
<td>10</td>
<td>76b</td>
<td>25</td>
<td>21,189bc</td>
<td>185b</td>
<td>1,099ab</td>
</tr>
<tr>
<td>15</td>
<td>46c</td>
<td>14</td>
<td>19,518c</td>
<td>143b</td>
<td>993b</td>
</tr>
<tr>
<td>20</td>
<td>36cd</td>
<td>11</td>
<td>14,742e</td>
<td>186b</td>
<td>843c</td>
</tr>
<tr>
<td>25</td>
<td>32d</td>
<td>9</td>
<td>13,271c</td>
<td>130b</td>
<td>820c</td>
</tr>
</tbody>
</table>

C. V. = 11.7 33.8% 23.1% 9.4%

Aging treatment: 12.3% moisture content seed “stored” in sealed glass jars at 38°C for indicated period.

Means in columns followed by same letter are not significantly different at 1% level.

and less beans, respectively, than they did in populations uniform for vigor. Assuncao (12) reported similar responses.

Seed size effects—In recent years it has been shown that the smaller seed within a soybean seed population are lower in quality and do not perform as well as the medium and larger seed (17, 18, 31, 40, 83). The qualification “within a population” is important because there is very little evidence that the variations in mean seed size “normally” encountered among populations of the same variety produced at different locations, or in different seasons, or among populations from different varieties (35), have an effect on performance potential of seed.

The reasons for low performance potential of soybean seed substantially smaller in size than the mean of the population are not known. In some respects, response-reactions of the small seed are similar to those of deteriorated (low vigor) seed, while in others they are similar to “immature” seed—e.g., metabolic activity per unit weight is higher in the small seed than in the larger seed.

| Vigor means (C. V. = 10%) | 3,017a 2,742b 2,599b |

Table 8. Yield (kg/ha) of Lee 68 soybeans produced from plantings of high, mixed, and low vigor seed at six population densities (78)

SUMMARY

A large-scale, widespread soybean seed industry has developed since the early 1950’s in response to rapidly increasing demand. Primary emphasis during this period of rapid growth has necessarily been given to expansion of capacity. Only slight improvements have been made in quality of soybean seed offered in the market.

Seed quality in soybeans is only moderately good, and periodically poor. Moderately good quality seed, however, are not now satisfying the expectations of farmers, who are becoming
increasingly aware of the importance of high quality seed for efficient, maximal production of soybeans. The most chronic seed quality problems in soybeans relate to germinability and vigor. Soybean seed are inherently short lived and structurally weak as compared to other kinds of seed. Substantial losses in germinability and vigor are caused by hot, dry weather during seed maturation, weathering from rainfall and warm temperatures during the harvest period, and mechanical abuse during harvesting and handling operations. Production of high quality soybean seed requires timely harvest followed by aeration and/or drying as necessary to reduce seed moisture content to 12% or less, and careful combining and handling to minimize mechanical damage.

Germination percentage is not a reliable index of the stand and crop producing potential of soybean seed. Seed lots of good germination but low in vigor can and do perform poorly in the field even under rather favorable conditions. Therefore, use of vigor tests to supplement information provided by the germination test is recommended.

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