Chapter 33

# TECHNIQUES TO EVALUATE PLANTING SEED QUALITY

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## INTRODUCTION

Maintaining the quality of cotton seed at the level that it is at harvest (or as nearly as possible) is a primary concern in producing high quality seed. The condition of seed cotton at the time of storage, the management in storage, as well as the condition and management of bulk seed in storage have a marked effect on seed quality.

The same factors are important regardless of the length of storage. Proper storage of seed cotton is often difficult because of varying field conditions. Adequate precautions are not always taken to protect seed cotton during storage.

As with any seed the primary factors affecting storability are moisture and temperature. Properly designed and constructed facilities, knowledge of conditions necessary for safe storage and how to achieve these conditions are necessary in order to maintain seed quality.

Measuring seed quality is important in the selection of lots for conditioning and in the quality control program of a seed company. Eliminating lots not suitable for planting from the market can be invaluable to a seed company as well as to a farmer.

# SEED STORAGE

## HYGROSCOPIC EQUILIBRIUM

The single most important factor affecting seed quality in storage of both seed cotton and bulk cotton seed is moisture. Other factors contribute to physiological quality and length of life in storage. Their effect, however, is superimposed on the effect of moisture. Thus, other factors modulate but never supersede the important effect of moisture (Altschul, 1948). Cotton seed will come into equilibrium with the moisture content of the surrounding air and/or other material. In this way relative humidity, green material, wet or damp lint, etc. exert a great influence on the storability of seed.

Equilibrium moisture content of cotton seed is reached in eight to ten days and will range from less than 5 percent at 10 percent relative humidity to about 18 percent at 90 percent relative humidity (Altschul, 1948; Robertson and Campbell, 1933; Simpson and Miller, 1944). Griffin and McCaskill (1964) concluded that the behavior of cottonseed in seed cotton form appeared to be identical to that reported for cottonseed in bulk storage. The moisture content and rate of germination decline in cottonseed stored in small quantities at seven locations in the southeastern United States for a period of seven years was related to atmospheric conditions at the storage site (Table 1).

Table 1. Fluctuation in moisture content and decline in germination of fuzzy cottonseed in ambient storage (from Simpson, 1946).

| Storage site | Variation in seed moisture (%) | Seed germination (%) | | |
|---|---|---|---|---|
| | | Initial | Later | Time interval |
| Jackson, TN | 8.3- 9.7 | 92 | 72 | 5 years |
| Knoxville, TN | 8.4- 9.8 | 90 | 76 | 5 years |
| Greenville, TX | 8.0-10.2 | 91 | 76 | 4 years |
| Clemson, SC | 9.2-10.6 | 92 | 69 | 3½ years |
| Florence, SC | 8.2-11.1 | 92 | 77 | 2 years |
| Mississippi State, MS | 9.1-11.1 | 91 | 76 | 2 years |
| Baton Rouge, LA | 10.1-11.2 | 92 | 68 | 1½ years |

Seed stored in the drier climate of Arizona germinated well after considerable longer periods of storage. Seed of 20 strains of Egyptian cotton averaged 85 percent germination after 7 to 14 years storage, while seed of upland cotton germinated up to 95 percent after 16 years storage in ambient conditions (Ishy, 1950). However, when cottonseed are stored in relatively large masses, the natural air movement through the mass is negligible. Thus, atmospheric conditions would be expected to have a minor effect on cottonseed in unaerated storage for normal 6 to 18 month storage periods.

## SEED QUALITY MOISTURE-TEMPERATURE RELATIONSHIP

Initial seed moisture is critical if viability and quality are to be maintained in storage. There is a definite relationship between seed moisture and storage temperature. Simpson (1942) found seed with initial germination of 90 percent, stored at ambient temperatures and 7-9 percent moisture, declined very little in germination in 36 months, while seed at 11 percent moisture germinated less than 40 percent in the same period. Seed at 13 and 14 percent moisture were dead in 24 and 12 months, respectively. When seed were stored at 32C and 7 percent moisture, germination dropped to 60 percent after 36 months, while seed at 9, 11, 13 and 14 percent moisture were dead after 28, 17, 12 and 4 months, respectively. Seed stored at 21C and 7 to 9 percent moisture germinated over 80 percent after 36 months; seed at 11 percent moisture germinated approximately 70 percent; while seed at 13 percent germinated near zero, and seed at 14 percent moisture were dead after 17 months storage. Seed stored at 0C maintained initial germination for all moisture contents for 36 months.

Pate and Duncan (1964) reported on a similar study but extended the time period up to 25 years. Cottonseed stored in sealed containers at 0C and 7, 9 and 11 percent moisture showed little or no decline in germination after 25 years. Seed at 13 and 14 percent moisture maintained 70 percent or higher germination for 15 and 3 years, respectively. Increasing temperature to 21C considerably reduced length of life in storage. Seed at 7, 9 and 11 percent moisture maintained germination above 80 percent for 13½, 5½ and 2 years, respectively, while seed at 13 and 14 moisture did not maintain 80 percent for one year. At 32C only the 7 percent moisture sample maintained 80 percent germination for one year or longer.

Higher temperatures for shorter periods of time, such as those resulting from drying seed cotton at gins, can also damage cottonseed. These may present more of a management problem than temperatures after cottonseed is in the warehouse because there is little, if anything, that can be done until seed can be aerated. Sorrenson and Wilkes (1959) studied effects of 26C, 38C and 60C temperatures on seed stored at 8 to 9 percent moisture. The 26C temperature caused no reduction in germination during the 21-day period, but 38C reduced germination, and 60C completely killed the seed during the 21-day time period.

Cherry (1976) reported that exposing cottonseed with 9 percent moisture to 60C for 72 hours reduced germination to zero. He also reported measuring seed temperatures of 49C-55C immediately after ginning. As a result, California planting cottonseed distributors have made it a policy to eliminate or seriously question the quality of any seed exposed to temperatures over 49C. Many seed conditioners accept cottonseed at 12 percent or less moisture instead of 10 percent and never measure temperature.

Ideally seed should be conveyed from the gin to the warehouse. However, in many, if not most instances, this is not possible. Seed must be trucked from gins to warehouse storage. The length of time they must remain on the truck will vary; all

day or over night is not uncommon. Temperature could be a very important factor in this length of time.

## VARIATION IN SEED MOISTURE CONTENT

There can be a considerable variation in seed moisture in seed cotton. The indeterminate fruiting habit of the cotton plant results in quite a variation in the length of time bolls are opened before they are picked. Sorenson (1973) studied seed moisture content in seed cotton at various times after boll opening. His findings are presented in Table 2. Considering percentage of bolls opened and

Table 2. Variation in moisture content of individual seeds, composite samples of seeds in individual locs and individual bolls at 0, 4, 12, 16 and 20 days after boll opening (From Sorenson, 1973).

| Component | Days after boll openings | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 4 | 8 | 12 | 16 | 20 |
| | Range in moisture (percent) | | | | | |
| Seeds | 10-22 | 11-21 | 10-16 | 10-13 | 8-13 | 8-12 |
| Locs | 10-21 | 12-20 | 10-12 | 10-17 | 8-11 | 7-11 |
| Bolls | 14-17 | 11-18 | 10-12 | 10-12 | 9-11 | 8-11 |

seed moisture contents, if cotton were picked at 20 days after the first bolls were open, only 67 percent of the seed would contain 12 percent moisture or less.

Sorenson (1973) also conducted studies of germination of seed from seed cotton stored at different moisture contents and different densities for various lengths of times. He concluded that, at densities of 7 to 12 pounds per cubic foot, storage times without loss of seed germination could be:

| Percent seed moisture | Days of storage |
|---|---|
| 8-10 | 30 |
| 10-12 | 20 |
| 12-14 | 10 |
| 14-15 | 3 |

Seed at 8-10 percent moisture could be stored at 20 pounds per cubic foot without reducing germination. Based on these figures, cotton would have to be ginned rather rapidly in order to prevent loss of seed quality.

## PRESENCE OF HIGH MOISTURE FOREIGN MATERIAL

This is much more of a problem in the southern area than in areas where plant growth and defoliation can be controlled and regrowth is not a problem. Harvesting in the Southeast, in particular, without getting some green material is almost

Table 3. Effect of storing seed cotton with different amounts of foreign material (stems, leaves, and other plant parts) on changes in moisture content of the seed cotton and seed (From Sorrenson and Wilkes, 1974).

| Moisture content of foreign material at start of shortage (percent[1]) | Foreign material in stored seed cotton (percent) | Moisture content of seedcotton and seed (percent) | | | | Moisture content of foreign material at end of storage (percent) |
|---|---|---|---|---|---|---|
| | | Seed cotton | | Cottonseed | | |
| | | Start of storage | End of storage | Start of storage | End of storage | |
| 80 | 5 | 8.0 | 11.5 | 9.1 | 12.7 | 19.5 |
| | 10 | 8.0 | 15.4 | 9.1 | 17.2 | 29.5 |
| | 15 | 8.0 | 18.5 | 9.1 | 21.2 | 34.5 |
| | 20 | 8.0 | 20.9 | 9.1 | 24.5 | 46.2 |
| | 25 | 8.0 | 24.6 | 9.1 | 28.0 | 49.4 |
| 65 | 5 | 6.9 | 9.1 | 7.8 | 10.2 | 14.0 |
| | 10 | 6.8 | 10.4 | 7.6 | 12.8 | 19.5 |
| | 15 | 7.0 | 14.4 | 7.8 | 15.7 | 25.6 |
| | 20 | 7.2 | 16.4 | 7.8 | 18.5 | 30.0 |
| | 25 | 7.0 | 18.2 | 7.7 | 20.6 | 31.1 |
| 46 | 5 | 6.9 | 8.6 | 7.8 | 9.7 | 13.8 |
| | 10 | 6.9 | 10.0 | 7.7 | 11.4 | 16.6 |
| | 15 | 7.0 | 11.2 | 7.8 | 12.7 | 18.8 |
| | 20 | 7.1 | 12.5 | 7.8 | 14.4 | 21.7 |
| | 25 | 6.8 | 12.8 | 7.7 | 14.6 | 22.7 |

[1]Seed cotton samples containing foreign material with an initial moisture content of 80 percent were stored for 42 days. Samples containing foreign material with initial moisture contents of 65 and 46 percent were stored for 28 days.

impossible due to uneven or incomplete defoliation and regrowth on occasions. Sorenson and Wilkes (1974) measured moisture transfer from foreign material at different moisture contents and in different quantities to seed cotton and cotton seed (Table 3). This study clearly demonstrates the moisture problems that can be created when seed cotton contains green material.

## STORAGE IN TRAILERS

Griffin and McCaskill (1964) studied the effects of storage of seed cotton in trailers on fiber quality. Heating was a problem. Temperatures up to 60C were observed when seed moisture content was 16.4 percent. They concluded that trailer storage was not safe unless cottonseed moisture was 10 percent or less. Cooling and drying trailer stored seed cotton by forced aeration was too slow and unpredictable to be a practical means of preventing storage damage. Seed cotton densities ranged from 6 to 8 pounds per cubic foot.

## STORAGE IN THE FIELD

Field storage in the dry, western cotton production area has been a practice for a number of years. Field storage has varied from uncovered piles in fields to ricks where cotton is stored on pallets. A study in 1965 (USDA Southern Cooperative Series, 1965) concluded seed cotton with low moisture content could be safely stored in the field on well drained sites without a cover in the High Plains, but in areas where even limited rainfall occurred, seed germination was drastically reduced in uncovered seed cotton.

Numerous studies of seed cotton stored in mechanically packed modules on pallets (Baskin, 1976a; Baskin, 1965b; Roberts *et al.*, 1974) have reached essentially the same conclusion as earlier trailer studies. Dry seed cotton with dry seed, 10 percent or less moisture, and little or no green foreign materials can be stored at densities of 12 to 14 pounds per cubic foot without any problems, provided adequate protection is provided from precipitation and the storage site is well drained.

## DRYING AND AERATION

Shaw and Franks (1962) concluded after some nine years of research that drying cottonseed at the cotton gin substantially benefited perserving seed germination, provided that the seed were adequately cooled shortly after drying. However, drying of seed is not practiced except maybe for small quantities for breeding purposes. Drying of cottonseed is not necessary every year, even in the high rainfall area of the southeastern United States. The general practice is to harvest cotton as dry as possible, measure moisture content after ginning and, if seed moisture content is not acceptable, send the seed to the oil mill. Seed moisture contents of 10 or 12 percent or less are generally acceptable. Whether 10 or 12 percent is the maximum acceptable level depends on the standards of the individual seed company and, to some extent, the capability of aeration in storage.

Cooling cottonseed as it comes from the gin and maintaining the stored mass under conditions that will prevent hot spots and moisture buildup are necessary to prevent loss of quality. The most economical means of maintaining cottonseed at safe storage temperatures is by aeration (Cherry, 1976).

Aeration systems used for planting seed should be designed for planting seed. Higher air flow rates are necessary. These may be as high as 20 ft.$^3$/min/ton but should not be less than 10 ft.$^3$/min/ton, compared to 2 to 5 ft.$^3$/min/ton for oil mill storage (Smith, 1975).

The general practice in cottonseed aeration is to draw air down through the seed because: (1) the natural tendency for air to move is upward from the warm seed to the cool upper surface is in part offset, (2) the warm moist exhaust air in early aeration is expelled in the lower part of the bin, and possible condensation at the cooler upper surface is prevented and (3) the operator can detect any offensive odors in the exhaust air (Cherry, 1976).

Smith (1975) suggested the manifold aeration system for planting seed. The advantages of this system are: (1) aeration can be started as soon as enough seed is placed in storage to cover one or two ducts to a sufficient depth, (2) as additional seed is stored and more ducts are covered, additional slide gates can be opened, (3) if an area is not cooling sufficiently or a hot spot develops, all gates can be closed except the one in the trouble spot, and all of the air can be directed through that area and (4) adjustments can be made for selective removal of cottonseed from the storage area.

Aeration to remove ginning heat is usually started as soon as the first lots are in storage. Although there are times when little cooling occurs, aeration is still beneficial to remove the heat and moisture of respiration. Temperatures of 30C or lower at a relative humidity of 80 percent or less are recommended for aeration after ginning heat has been removed. A final seed mass temperature of 10C-13C is desirable for storage of planting seed (Smith, 1975). Sorrenson and Wilkes (1959) found that quality could be maintained for seven months when seed mass temperatures were lowered to 13C.

Some drying may occur during aeration. Sorenson and Wilkes (1959) measured from zero to a 1.3 percent decrease in seed moisture content. However, the rate of moisture removal at these air flow rates is very slow and is not sufficient for drying high moisture cottonseed.

## EVALUATION OF SEED QUALITY

The concept and importance of seed quality and a review of the studies for evaluating seed quality are presented in Chapter 32. The need for evaluation other than the standard germination test is also discussed, as is the concept of vigor.

Our purpose here is to discuss some tests that are being employed in the cottonseed industry, in addition to standard germination, to evaluate cottonseed.

We will also discuss the relationship between density and seed quality and how this is being employed in the industry.

## TETRAZOLIUM EVALUATION

The tetrazolium test provides a rapid evaluation of seeds and can provide timely guidance concerning the extent and nature of seed quality problems during harvesting, conditioning and storage and distribution.

The test can be used to estimate both seed germination and vigor. For an estimation of germination, stained seed are placed in a germinable or non-germinable category based on the overall color, location and amount of dead tissue (Delouche *et al.*, 1962). For an estimation of vigor the germinable seed are classified into categories, or vigor levels, based on the intensity and/or depth of staining, lack of staining and location of weak or dead embryo parts.

The tetrazolium salt commonly used in seed testing is 2, 3, 5,-triphenyl tetrazolium chloride. Tetrazolium salt is an oxidation reduction indicator. The 2, 3, 5,-triphenyl tetrazolium chloride is reduced by accepting hydrogen from dehydrogenase enzymes. The reaction produces formazan, an insoluble red compound, and hydrochloric acid. Since dehydrogenase enzymes are involved in respiratory activity of biological systems, the reaction takes place within the cells. The insoluble formazan does not diffuse out the cell, therefore, there is a sharp delineation between the red, viable, respiring tissue and colorless, non-viable, non-respiring tissue.

Several dehydrogenase enzyme systems appear to be capable of catalyzing the reaction (Jensen *et al.*, 1951). Smith (1952) made a detailed study of the reduction of 2, 3, 5,-triphenyl tetrazolium chloride in corn embryos. He concluded that the reaction is catalyzed by diphosphopyridine nucleotide-linked dehydrogenase in malic and alcohol systems and is mediated by diaphorase.

The tetrazolium test is, then, a test for dehydrogenase enzyme activity. The loss of activity of these systems parallels the loss in seed viability and vigor.

**Evaluation**—The basis for viability and vigor evaluation involves the identification, location and appraisal of sound, weak and dead embryo tissue related to seedling development (presence and condition of essential structures), overall strength of the developing seedling and possible influence on length of life of the seed in storage. Differences in color, lack of color and tissue turgidity or flaccidness help distinguish sound, weak or dead tissue. Observation of the location and extent of the fractures, missing embryo parts and abnormalities provide additional information in evaluation of embryo soundness. The presence, amount, depth and location of embryo inperfections near or within essential embryo structures are also important to the evaluation.

There are basically two systems for grouping seeds into categories: classifying seeds as either strong or weak, and classifying seeds as high, medium or low vigor. Both systems, of course, would have a nongerminable category. Either system is

adequate, but the three-category system allows a more critical evaluation of the seed.

*High vigor* seed are completely stained or with only minor unstained areas on or near the chalazal end of the seed. Staining is uniform and bright, not deeply stained. Tissue is firm. Radicle tip is stained but is darker than the cotyledons.

*Medium vigor* seed may have minor unstained or darkly stained areas over various portions of the cotyledons. Embryo axis is uniformly stained but not dark except for the radicle tip. The extreme tip of the radicle may be unstained. Tissue is firm but may be slightly darker than high vigor seed.

*Low vigor* seed may have large areas of the cotyledon unstained but none in the area near the axis, which is considered essential. The tip of the radicle may be unstained into the extreme tip of the vascular tissue (stele). Cotyledons may be darkly stained or with a slight milky appearance in parts of the cotyledons. Tissues may be somewhat flaccid (Baskin, 1981).

*Nongerminable* seed include those with one-third or more of the radicle extremely dark (almost black) or unstained, one-third or more of the cotyledonary tissue unstained, entire seeds stained very dark, seeds stained grayish or cloudy (milky), seeds with one-third or more of the radicle missing and very flaccid embryos.

To classify seeds as strong or weak, simply combine the high and medium vigor categories.

## ELECTRICAL CONDUCTIVITY

As previously indicated, the measurement of the electrical conductivity of the seed soak water has been employed as a measure of seed vigor (biochemical test). According to the scheme of seed deterioration proposed by Delouche and Baskin (1973), electrical conductivity should be a sensitive vigor test, if it is an accurate measure of membrane degradation. They propose that membrane degradation is the first step in seed deterioration. Experimental evidence generally supports the test as a relatively good indicator of membrane integrity and, hence, vigor in many crops.

To better understand the concept of measuring seed vigor by the use of electrical conductivity, a general understanding of the structure and function of cellular and organelle membranes is necessary. The membranes, among other functions, provide for compartmentalization of cellular and organelle constituents, are semipermeable barriers for the movement of various substances and are sites for numerous enzymatic and growth regulator reactions. Compositionally, the two major components of membranes are lipids and proteins. Although the exact structure of membranes is not clearly understood, it is generally accepted that they consist of a bilayer of phospholipids oriented such that a nonpolar portion is positioned toward the center of the membrane while a polar portion is positioned outward on both sides. Protein is embedded in and associated with the phospholipid layers.

Cellular membranes are usually considered to reach their maximum level of structural organization during seed development. According to Abdul-Baki (1980), the greatest structural changes in membranes occur during the seed maturation phase (dehydration) and during the germination (imbibition/rehydration) phase. As the seeds mature and dehydrate, the membranes become disorganized and are rendered inefficient as barriers. Presumably this occurs when the seeds reach a moisture content of about 20-30 percent and is likely due to reorientation of the phospholipid bilayer. The membranes, and consequently the seed, remain in this disorganized state until imbibition (rehydration) occurs during the germination phase (assuming good storage conditions). Abdul-Baki (1980) concluded that reorganization of seed membranes during the rehydration process is critical in that the reorganization must occur before the cell is hydrated. Otherwise the mixing and/or loss of cellular constituents may occur, resulting in reduction or complete loss of seed vigor. This led him to propose that, on a biochemical level, three conditions had to be met to attain and maintain vigor: "First, a highly organized organelle/membrane system must exist in the seed during development; second, disorganization of the organelle/membrane system during seed maturation and dehydration must proceed in an orderly manner such that its reorganization upon hydration becomes possible in the shortest possible time; third, upon rehydration, all membranes must become fully organized before the cells become fully hydrated". Thus, the loss into the imbibing medium of cytoplasmic solutes with electrolytic properties provides the basis upon which the electrical conductivity test measures seed quality for planting purposes.

Presley (1958) was among the first to report a relationship between seed leachate electrical conductivity and seed viability. In studying cotton, he noted that the soak water of deteriorated seeds was more turbid than that of nondeteriorated seeds and, subsequently, measured the electrical conductivity. It was then that he observed and reported a positive relationship between conductivity and seed deterioration (as measured by a germination test). Later, Matthews and Bradnock (1968) and Matthews and Whitbread (1968) evaluated the relationship between seed exudation (electrical conductivity) and the field emergence of peas (wrinkle-seeded) and French beans. They observed a highly significant negative correlation and, thus, proposed the use of this test to detect seed of low planting value (vigor). Since these studies, numerous investigations as to the relationship between electrical conductivity and viability/vigor have been conducted with several different crop species.

In corn, several workers (Gill and Delouche, 1973; Joo *et al.*, 1980; Tao, 1980a,b) have evaluated the electrical conductivity test as a measure of seed vigor. All have reported that the conductivity test correlated well with vigor; however, Joo *et al.* (1980) and Tao (1980a,b) indicated that genotypic differences do exist. Therefore, care needs to be exercised in the interpretation of test results.

In the United States, more recent work has probably been done with soybeans than any other crop relative to the use of electrical conductivity as a measure of

seed quality. Abdul-Baki and Anderson (1973) and Yaklich and Abdul-Baki (1975) noted an increase in the leaching of labeled materials from the embryonic axes of soybean seeds of low vigor. McDonald and Wilson (1979) reported a relationship between electrical conductivity (measured using a commercial instrument—ASA-610) and the germination of soybean seedlots with values below 20 percent and above 80 percent. McDonald and Wilson (1980) also reported that the electrical conductivity (ASA-610) accurately evaluated the quality of soybean seeds that had been subjected to both mechanical damage and accelerated aging. Other workers (Miles and Copeland, 1980; Tao, 1980a.b) noted that the electrical conductivity test correlated well with soybean field emergence.

A limited amount of research has been conducted with other crop species. In general, the conductivity test has correlated well with seed quality in bush bean, peanut, cotton and navy bean (Levengood *et al.*, 1975); cowpea (Beighley and Hopper, 1981); navy bean (Suryatmana *et al.*, 1980); clover and ryegrass (Ching and Schoolcraft, 1968); barley (Abdul-Baki and Anderson, 1970); and rice (Agrawal, 1977).

Most of the work reported for cotton indicates that the electrical conductivity test is a good indicator of seed quality. As previously indicated, Presley (1958) was among the first to evaluate the test as it relates to cotton. He observed from his studies that seed of high viability soaked in water resulted in high resistance (low conductivity) readings and that the resistance readings decreased as the degree of seed deterioration increased. Later, Bird and Reyes (1967) reported just the opposite response in that increasingly deteriorated (by high relative humidity and temperature) cottonseed resulted in higher electrical resistance values. However, they only soaked the seeds in distilled water for two minutes and made no mention of the initial seed moisture content. Both of these could affect the results. Halloin (1975), in an attempt to resolve this discrepency, aged cottonseeds (high temperature and humidity) at low (7-8 percent) and high (20 percent) initial moisture levels prior to measuring the seed soak water electrical conductivity. He reported, as Presley (1958) had previously, an increase in the conductance and a subsequent reduction in the germination of those seeds deteriorated at low initial seed moisture levels. However, when he adjusted the seed moisture level to 20 percent prior to deterioration, the electrical conductivity, as affected by seed deterioration, was not consistent. It is likely that by adjusting the seed moisture content to 20 percent prior to deterioration the membranes had an opportunity to become reorganized before the seeds were soaked and, thus, would be expected to lose less electrolytes by leakage. Bishnoi and Delouche (1980) also reported a lower resistance (higher conductivity) in cottonseed that was artificially deteriorated.

In the mid-1970's, a company (Agro Sciences, Inc.) developed and began marketing an instrument (MSS-110) that would directly measure the conductivity across individual seeds after they had been soaked in water. Although the process of handling each seed individually was somewhat time-consuming, most

workers observed a good relationship between seed electrical conductivity and seed quality (Levengood *et al.*, 1975; Bondie *et al.*, 1978; Brashears *et al.*, 1979; Hopper, 1981). Hopper (1981) soaked seeds from several lots of Blightmaster A5 in deionized water (15 min.) and separated them into four conductivity categories. The seed in each category were then subdivided and germination and emergence (growth chamber and greenhouse) studies were performed on the seed (Table 4). Seed in the higher conductivity categories exhibited poorer levels of germination and emergence (both growth chamber and greenhouse). In the

Table 4. The relationship between seed electrical conductivity and the germination and emergence (growth chamber and greenhouse) of five seed lots of Blightmaster A5.

| Conductivity category | Germination (percent) | Emergence (percent) | |
|---|---|---|---|
| | | Growth chamber | Greenhouse |
| μAmps | | | |
| 0-14.9 | 73 | 70 | 77 |
| 15-29.9 | 57 | 54 | 73 |
| 30-44.9 | 41 | 40 | 51 |
| ≥45 | 22 | 20 | 19 |

Table 5. The relationship between seed electrical conductivity and seedling plant height of five seed lots of Blightmaster A5 grown in the growth chamber.

| Conductivity category | Days after planting | | | | Mean |
|---|---|---|---|---|---|
| | 8 | 10 | 12 | 14 | |
| μAmps | Height (cm) | | | | |
| 0-14.9 | 5.2 | 6.8 | 8.2 | 8.6 | 7.2 |
| 15-29.9 | 4.6 | 6.6 | 7.8 | 8.4 | 6.9 |
| 30-44.9 | 4.2 | 5.4 | 6.0 | 6.2 | 5.5 |
| ≥45 | 3.2 | 4.4 | 5.2 | 5.8 | 4.7 |

emergence study, seedling heights were also measured 8, 10, 12 and 14 days after planting in the growth chamber (Table 5) and 4, 6, 8 and 10 days after planting in the greenhouse. The growth chamber data (Table 5) indicated lower vigor levels from the seed in the higher conductivity categories, as evidenced by the reduced seedling heights. The same general trends were observed in the greenhouse emergence study. Other workers have generally reported a concomitant decrease in germination as electrical conductivity increased (Levengood *et al.*, 1975; Bondie *et al.*, 1978).

During the late 1970's Agro Sciences, Inc. developed and began marketing another instrument with a multi-electrode head (ASA-610) that would measure

the electrical conductivity of the seed soak water of 100 seeds—each soaked in an individual cell. As would be expected, this greatly speeded the testing procedure. The work reported thus far with cotton generally indicates a good relationship between this form of the electrical conductivity test and seed quality. Hopper and Hinton (1980) observed that the instrument provided a good estimate of the germination of seed lots with reasonably good viability (69-86 percent). The results, however, were much more variable when they used poor quality seed (0-65 percent germination). Hyer *et al.* (1980) and Glat *et al.* (1982) also reported that the instrument provided good estimates of germination when they measured the electrical conductivity of the seed exudates after soaking in distilled water.

Most of the work with cotton and other crops indicates that the use of electrical conductivity provides very useful information relative to seed quality. It should be noted that certain factors have been reported that may affect the reliability of test results. These include factors such as initial seed moisture, chemical seed treatments, temperature conditions and seed size (Andersen *et al.*, 1964; McDonald and Wilson, 1979); the type of filter paper (Tao, 1980c); mechanically injured seed (McDonald and Wilson, 1980); and possibly others. However, as previously indicated, under controlled conditions valuable information relative to seed quality may be obtained by use of the electrical conductivity test. A description of the test, in addition to numerous other vigor tests, may be found in the Seed Vigor Testing Handbook (Association of Official Seed Analysts, 1983).

## RELATION OF DENSITY AND WEIGHT TO SEED QUALITY

Tupper (1969) conducted research to relate a seed's physical characteristics (diameter, length, weight, volume and seed density) to its ability to germinate and grow. Ungraded 'Lankart 57' and 'Stoneville 213' seed were selected under a magnifying glass to remove all visibly damaged seed. The identity of each of the 800 seed randomly selected from each variety was maintained throughout the entire experiment.

The length and maximum diameter of each seed were measured with a micrometer. Seed were allowed to equilibrate for a minimim of 14 days at a constant temperature (10C) and relative humidity (50 percent) before being weighed in air and in distilled water. A single seed was submerged in water about 30 seconds. Turner (1929) found that the apparent specific gravity of cottonseed changed by only 8 percent when seed were submerged in water for 15 minutes. Thus, a cottonseed apparently absorbs water rather slowly when first submerged. The following equation was used to measure volume, V, of the seed.

$$Y = \frac{W_a - W_l}{D_l}$$

Where:

$W_a$ = Weight (g) of seed in air

$W_l$ = Weight (g) of seed submerged in liquid

$D_l$ = Density of liquid (g/cc) at the temperature of the liquid.

A standard laboratory day-night seed germinator was used by Tupper *et al.* (1970). In a standard germination test, the germinator was set to operate at 20C for 16 hours and 30C for 8 hours through the 7-day experiments. The germinator was set to maintain a constant 18½C for the cold test. From each variety, 400 seed were germinated in the standard and in the cold test.

The seed were put in visual germination cells which were placed in a vertical position in the germinator. These cells allowed the seedlings to grow in their normal position without physical disturbance when they were observed at 24 hours intervals.

**Germination Response**—After the seeds were germinated, the data for each lot of 400 seeds were ranked in order from the lowest to the highest numerical value of each physical characteristic, as reported by Tupper *et al.* (1971). The percentage of seed germinated was calculated for each day of the experiment.

Correlation coefficients were calculated for the relationship between each physical characteristic and the percentage germination on each day of the experiment. Each physical characteristic was treated as an independent variable.

Seed density was the physical characteristic which had the greatest influence on germination response. Seed volume and diameter were influential on the 3rd and 4th days but had little influence thereafter. A time period is needed for the center or a large diameter of high volume seed to reach a high enough moisture content to trigger the germination process. After sufficient time for moisture absorption, these two physical characteristics apparently have only a minor role in the germination response.

**Growth Response**—A multiple regression analysis was used to eliminate the least significant variable until all remaining variables were significant at the 5 percent level. In the standard germination test physical characteristics of seed were less important than when seed were stressed in the cold test. In cold tests with Stoneville 213 and Lankart 57, seed weight had the greatest influence on seedling growth. Though the results were not as evident for growth as they were for germination, seed weight provided the best relationship to growth of a seedling in the germinator. Cotyledons of the heavy seed may have provided more stored energy which was available for use in the growth process.

**Combination of Germination and Growth**—Each of the 400 seeds was analyzed for growth irrespective of the day the seed germinated. This procedure provided a more practical approach to seed selection because it considered a combination of germination and growth responses.

Seed density was the only physical characteristic which contributed significantly to the regression equations relating to root and hypocotyl growth of both varieties in the standard germination test and for Stoneville 213 in the cold test. After 10 days in the cold test with Lankart 57, only seed density was contributing

significantly to seedling growth. The influence of seed density on the earliness of germination apparently overshadowed the influence of seed weight on growth.

Based on these data, seed selection equipment should be designed to select the highest density cottonseed for planting purposes. Additional separation could be made on the basis of seed weight to remove light seed.

## SEPARATION OF SEED USING THE DENSITY FACTOR

The value of the density factor in separating cottonseed was recognized as early as 1907. Webber and Boykin (1907) separated cottonseed with a column of moving air. In subsequent field test, plants from heavy seed yielded approximately 10 percent more seedcotton than plants from light seed. Chester (1938, 1940) separated acid delinted cottonseed using water as a medium to produce a density gradient. He compared gin run, ungraded acid delinted seed, acid delinted floaters and acid delinted sinkers. Over a two year period the heavy (sinkers) acid delinted seed produced 32, 52, and 159 percent greater emergence than did ungraded acid delinted, gin run and light (floaters) acid delinted seed, respectively.

The practice of density separations using water never gained wide acceptance, however. Kunze *et al.* (1969) demonstrated differences in field emergence and growth response of cottonseed of different physical characteristics, density being a primary factor. A study of liquid separation was conducted by Kunze (1978). He developed a dynamic or continuous liquid separator. As with other liquid separations over the years commercial application has never been attained. Justice *et al.* (1965) separated cottonseed using a gravity table (separator). They concluded that the heavier fractions of acid delinted seed were superior to the lighter fraction in field tests. Heavier seed had a higher percentage emergence and more rapid early seedling growth than lighter fractions. They did not report weight per bushel or other parameters of the various density fractions.

Gregg (1969), using 19 lots composed of 10 cultivars planted in Mississippi, separated acid delinted seed into 10 different density fractions using an Oliver model 160 gravity separator. The physical parameters, standard bulk density (weight per bushel), screened bulk density, pack bulk density, compactibility, true volume, weight per 100 seed and specific gravity were measured on each of the 10 fractions. The biological parameters, germination percentage, soil cold test, germination after accelerated aging, seedling growth rate, free fat acidity and field emergence were measured.

Standard bulk density (weight per bushel) was a good indicator of seed quality. Ranges in standard bulk density of seed for respective positions (1-10, light to heavy) of the gravity separator are presented in Table 6. Among lots, coefficients of correlation between standard bulk density and standard germination of treated seed ranged from .802 to .959, and for field emergence the range was from .800 to .946. The general conclusion from Gregg's work (1969) was that if weight per

bushel is above 42 pounds, seed are suitable for planting, and that seed above 44 pounds per bushel might be considered as a premium quality product.

Johnson *et al.* (1973) found that as bulk density increased, germination, field emergence and three-week seedling survival increased. Lint yield of high density seed, however, was not significantly higher than that of ungraded seed (Table 7). It must be pointed out that there were some exceptions, and this cannot be accepted as an absolute measure of seed quality. Other tests need to be combined with standard bulk density to measure the planting value of cottonseed.

Table 6. Range in standard bulk density (wt/bu) of acid delinted cottonseed from different discharge positions of a gravity separator.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Low | 26.05 | 35.30 | 36.15 | 37.43 | 40.83 | 42.78 | 43.63 | 44.00 | 44.58 | 45.30 |
| High | 38.48 | 43.88 | 44.68 | 46.78 | 47.20 | 47.83 | 48.20 | 47.88 | 48.33 | 49.63 |

Table 7. Germination, bulk density, field emergence, seedling dry weight and lint yield of different seed density classes from two lots of acid delinted cottonseed.[1]

| Density class | Seed per class (%) | Germ. (%) | Density (lbs/bu) | Field emerg. (%) | 3-wk D.W. (gm/plt) | Lint yield (lbs/A) |
|---|---|---|---|---|---|---|
| | | | | Stoneville 7A | | |
| D-1 | 31 | 82 a[1] | 49.3 | 78 a | .80 a | 989 a |
| Upgraded | — | 81 a | 47.3 | 60 b | .65 b | 900 a |
| D-2 | 28 | 76 ab | 45.9 | 61 b | .74 ab | 820 b |
| D-3 | 25 | 68 b | 42.3 | 54 c | .68 b | 929 a |
| D-4 | 16 | 41 c | 36.8 | 32 d | .27 c | 774 c |
| | | | | Stoneville 213 | | |
| D-1 | 29 | 86 a | 50.0 | 85 a | .68 a | 1027 a |
| D-2 | 28 | 83 a | 48.3 | 74 b | .67 a | 969 a |
| Upgraded | — | 77 a | 46.0 | 70 b | .85 b | 944 a |
| D-3 | 23 | 79 a | 46.5 | 65 bc | .58 b | 851 b |
| D-4 | 19 | 59 b | 41.4 | 46 d | .52 b | 772 b |

[1]Means not followed by the same letter are significantly different at the 5 percent level.