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STUDIES ON THE RELATIONSHIP AMONG SEED QUALITY TESTS AND FIELD EMERGENCE OF SUGAR BEETS (*Beta vulgaris L.*) IN MICHIGAN

By

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ABSTRACT

STUDIES ON THE RELATIONSHIP AMONG SEED QUALITY TESTS AND FIELD EMERGENCE OF SUGAR BEETS (*Beta vulgaris L.*) IN MICHIGAN

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Two experiments to evaluate differences in sugar beet seed vigor and the influence of seed size on seed/seedling vigor and performance were carried out both in laboratory and field tests in 1998 and 1999. Experiment One utilized seed lots with a wide range of seed quality, representing different production years and lengths of storage. Seed lots for Exp. 2 were of high quality representing three varieties with three different seed sizes. Laboratory tests used to evaluate seed quality and vigor included standard pleated germination test, cold test, the high moisture cold test, standard accelerated aging test, accelerated aging test incubated over NaBr, sand test, and bulk conductivity test. Field emergence data were collected at Saginaw, Ingham and Huron counties in 1998 and in Saginaw and Ingham counties in 1999.

No single vigor test had the best correlation with field emergence over all planting environments. Combinations of tests in multiple regression equations, for each soil environment resulted in R^2 values between 0.486 and 0.980. The use of the pleated germination test plus the cold test gave the best indication of potential field emergence under most field conditions found in Michigan.

DEDICATION

To all those who believed in me…
Specially to Mr. Cal Bricker for all his support, inputs and commitment to this research, Cal with all my respect, admiration and appreciation this work is dedicated to you…

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INTRODUCTION

Sugar beets are an important agronomic crop in Michigan, accounting for 10.2% of the United States production in 1997. Over 71,000 hectares were planted in 1998, representing an eight percent increase from the previous year.

While the cost of sugar beet seed is only about eight percent of the total production costs per hectare, the results of planting poor quality seed are more costly. Replanting costs of $70-$75 ha, along with the increased labor, soil compaction, and possible decrease in yield due to delayed planting can drastically reduce the net income from a sugar beet crop.

Recommendations for early planting and increased acreage of sugar beets in Michigan is thought to have increased the possibility of poor field emergence resulting from the planting of low quality seed. The lack of emergence of sugar beet seedlings and of successful stand establishment are often major factors limiting sugar beet production.

Seedling emergence requires the utilization of stored seed reserves to produce elongation of both the hypocotyl and radicle. Energy supply and seedling development are a result of catabolism and metabolism that are influenced by the soil environment. The state of the soil environment determines the efficiency of energy conversion into the expansive growth of the plant axis. During the many years in which multigerm seed was planted, no particular germination problems were encountered, unless the seed was damaged by insects. However when monogerm seed was introduced in the early 1950's, both germination and field emergence were reduced due to the nature of the single

germ seed type. This has led many growers and agronomists in the sugar beet industry to question the fundamental quality of monogerm relative to multigerm seed.

Commercial sugar beet seed is now routinely processed and graded to give a standard germination exceeding 90.0%. Field emergence, however, is often much lower than that potential. Consequently, accurate ways are needed to predict the performance of individual sugar beet seed lots in the field. Because of similar concerns in a wide range of crops, vigor tests to supplement the standard germination test have been frequently suggested by seed companies and growers because of the tendency for the standard germination test to overestimate field performance under most planting conditions (Delouche and Baskin, 1973; Delouche and Coldwele, 1960; Woodstock 1973; Yacklich et. al, 1979; Kraak et. al, 1984; and Lovato and Cogalli, 1992).

The many different factors that affect vigor and the variable conditions under which vigor tests may be performed in different seed laboratories, as well as the infinite array of seedbed conditions into which sugar beet seed is planted, have confounded research efforts to determine which vigor tests best predict field emergence results. This study was initiated with three major objectives: First, to evaluate which of several established seed testing procedures best determines field emergence and stand establishment in seedbed conditions in Michigan. The second objective was to determine seed quality levels of seed lots from various years and varieties and evaluate their performance in field emergence

and stand establishment. The final objective was to evaluate the effect of seed size and chemical seed treatments on seed/seedling vigor and field performance.

LITERATURE REVIEW

Seed and Seedling Vigor

Seed scientists have for many years accepted the concept of seed/seedling vigor as a seed quality factor. Within the last three decades it has also become a vital part of the quality control and marketing programs of many commercial seed companies.

According to Perry (1972), one of the earliest recognitions of vigor differences in seed was by Nobbe in 1876, who used the term "energy of germination." However, most of the research on vigor and vigor testing has been done in the last 35 years. In 1950, Franck used the term "vigor" in describing his work with soil germination tests at a meeting of the International Seed Testing Association (ISTA) (Perry, 1972). Seven years later Isley (1958) talked to members of the Association of Official Seed Analysts (AOSA) about vigor and vigor testing. Since then a great many papers have been published on this subject.

The expression of vigor can be described from two different viewpoints. Some researchers speak of seed vigor *per se* as an intrinsic property of the seed (Woodstock, 1973). Perry (1972) referred to vigor along with viability, seed health, structural soundness and size as seed quality components. Heydecker (1972) concluded that a population of seeds cannot be classified as being only good or bad, but in having a level of vigor that provides a continuum from poor to good.

The vigor of harvested seeds in storage has been called storage vigor (Heydecker, 1969), the vigor of the storage life of the seed (Bradnock, 1975) and the non-active vigor state (Heydecker, 1972). Descriptions of the totality and speed of germination in the absence of environmental influences have included the terms germination vigor (Heydecker, 1969), germination energy (Moore, 1963), germination capacity (Schoorel, 1956) and the intensity factor (Woodstock, 1969). These terms imply the importance of seed viability in describing seed vigor. Delouche (1974) concluded that vigor only relates to viable seeds, because a seed that does not germinate has no vigor potential.

The results of the interaction between the seed/seedling and environmental influences such as temperature, moisture, soil crusting and pathogenic microorganisms is the second way vigor can be expressed. Vigorous seeds/seedlings have a greater capacity for germination and emergence when subjected to adverse environmental conditions. These seeds/seedlings are said to have a higher field survival rate (Heydecker, 1972), a larger environmental range factor (Woodstock, 1969) or a better stand establishment capacity (Delouche and Caldwell, 1960). Once the seedling stand is established, the seedling survival rate (Bradnock, 1975) and seedling growth can be measured. Thus, seedling vigor (Heydecker, 1969) on an individual plant basis can have a major effect on the competitive interactions between plants (Pollock and Roos, 1972) and ultimately on yield potential (Bradnock, 1975).

Although the concept of seed and seedling vigor has been widely accepted, there was not a general agreement on a precise definition of vigor for

many years. Investigators have defined vigor to coincide with their own understanding and experiences. Isely (1957) defined seed vigor as "the sum total of all seed attributes which favor stand establishment under favorable conditions." Building on this definition, Delouche and Caldwell (1960) stated that seed vigor is "the sum of all seed attributes which favor rapid and uniform stand establishment." Woodstock (1965) proposed that seed vigor was "that condition of good health and natural robustness in seed, which, upon planting, permits germination to proceed rapidly and to completion under a wide range of environmental conditions." Eight years later, Perry (1978) identified seed vigor as physiological property determined by the genotype and modified by the environment which governs the ability of a seed to produce a seedling rapidly in soil and the extent to which the seed tolerates a range of environmental factors." By this time a consensus was rapidly emerging on a definition of seed vigor. In 1977, ISTA defined vigor as "the sum total of those properties of the seed which determinates the potential level of activity and performance of the seed or seed lot during germination and seedling emergence (Perry, 1978)." In 1979, AOSA defined the term as "the sum total of all those properties in seeds which, upon planting, result in rapid and uniform production of healthy seedlings under a wide range of environment including both favorable and stress conditions (McDonald, 1980)." Each definition is unique, but all deal with field performance potential. Thus, this parameter is the ultimate result of vigor, regardless of whether the vigor expressed is an intrinsic seed property or a result of seed/seedling interaction with the environment.

The AOSA definition of vigor was adopted for the planning and evaluation of this study.

Seed Quality and Vigor Testing

The first uniform method for conducting sugar beet seed germination tests was proposed by Skuderna and Doxtator (1938). They suggested reporting results of tests at the end of 10 d and supplementing laboratory tests with field tests wherever possible so as to determine vigor of seedlings as well as plants. Also, the scientists suggested that the choice of germinating beet seeds at a continuous temperature of 20.0°C would better predict field emergence. However, field emergence of a seed lot is dependent both on seed quality (Heydecker, 1969) and upon the environmental factors encountered by the seed, including temperature (Bierhuizen and Wagevoort, 1974), availability of oxygen (Côme and Tissaou, 1973), moisture (Koller, 1972), disease pressure (Baker and Rush, 1988; Rush, 1987) and sowing depth. Although a major component of seed quality is the germination capacity, it is a matter of continuing debate whether germination percentage measured under optimal conditions provides the best assessment of the performance potential of the seed in the field. Failure of germination percentage to relate to field emergence led to the term vigor. Seed lots are said to posses low vigor when field emergence is poor in comparison to other seed lots with comparable test germination percentages ('seed lot' for these studies refers to a particular amount of seed from which subsamples are drawn and used in the various tests). Differences in seed vigor caused by environmental conditions during seed development, harvesting procedures and

storage conditions may exist among seed lots having similar warm (standard) germination results. Planting in a pathogen-infested seedbed under cold temperatures and/or moisture stress can magnify the expression of these vigor differences.

Studies in recent years have approached the "vigor question" by trying different kinds of tests or seed treatments, including excess water stress (Perry, 1978), cold tests (Akeson and Widner, 1980; Kraak et al.; 1984), accelerated aging and conductivity tests (Kraak et al., 1984; Durrant and Loads, 1990). The good relationship between percentages of normal seedlings at the first count, i.e. from fourth to tenth day of standard germination and field performance has been noted (Orioli et al., 1979; Herzog, 1980; Orioli and Rosso, 1982).

Since the development of the cold test in the 1940's, seed scientists have been searching for better ways to measure this complex quality factor called vigor. Many different types of vigor tests have been proposed. Those adopted by the seed industry have been promoted as aides to the farmer for selecting only the highest quality seed lots available and thus maximizing field stand establishment.

Seed vigor is a complex concept that cannot be measured as easily as a single property like germination. Most researchers believe that no single test can adequately measure seed vigor and field performance across a wide range of seed quality and field conditions. Thus, a combination of physiological and biochemical indices has been suggested for improving the accuracy of predicting

field performance of a given seed lot (Ching et al., 1977; Edje and Burris, 1971; and Egli and TeKrony; 1979).

Seed Size

The monogerm sugar beet "seed" is in reality an indehiscent fruit (utricle) containing a single seed with the perianth attached. A seed lot at harvest comprises a wide range of fruit size, maturity, and other characteristics because of the indeterminate growth habit of the sugar beet plant (Scott *et al.*, 1974). Fruit of commercial seed lots are polished, graded, sorted for shape and gravity separated. The Michigan Sugar Company grades seed into four sizes, 2 (0.26 - 0.30-cm), 3 (0.30 - 0.34-cm), 4 (0.34 - 0.38-cm), and 5 (0.38 - 0.42-cm). According to Longden (1986), the most important factors that significantly affect the quality of sugar beet seed are its size and emergence capacity. Seed size has been shown to influence germination and field emergence (Lexander, 1981, Akeson, 1981). Seed grown in northern Europe was found to be larger in size compared to that grown in southern Europe due to the greater amount of cortex and not because of differences in true seed weight (Longden, 1986). Savitsky (1954) showed that with monogerm varieties, the weight of the true seed increased proportionally with the weight of the entire unconditioned fruit. With most crops, early growth is related to seed size but final yield is seldom affected (Black, 1959, Bleasdale, 1966) because inter-plant competition develops earlier between the larger plants from large seed. Large seeds had better germination and emergence compared to small seeds (Snyder and Filban, 1970) but large size did not necessarily result in good emergence since seeds produced under

low temperatures were large because of thick fruit walls and did not germinate well (Lexander, 1981). TeKrony and Hardin (1968) claim that the major cause of variable and poor seedling emergence is the occurrence of seedless fruits (lacking ovules) and those containing underdeveloped seeds, which might be less frequent in larger seed grades if size is some index of extent of development. Scott *et al.* (1974) reported that seedling size and root/shoot ratio increased with increasing seed size. Furthermore, the largest seeds resulted in increased sugar yields compared to smaller ones. McLachlan (1972) also presented evidence that the size of monogerm seed had a strong positive effect on final root yield but no effect on sugar content. Although his results suggested strong maternal effects on sugar beet root yield, no conclusions were drawn on the genetic relationship between seed size and root yield.

Varieties

One of the largest causes of variation in emergence in sugar beets appears to be varieties, where ranges of 20.0 - 30.0% in emergence have been noted (Steen, 1987). Highly productive monogerm varieties are available, but improvements are still needed to give higher and better emergence under a wide range of growing conditions.

Soil

Stehlik and Neuwirth (1928) studied stand establishment as a comprehensive problem and treated the ecological soil conditions as the most important factor affecting emergence and seedling survival. The correlation between germination capacity and field emergence declines when soil conditions

become less favorable. Seed lots that systematically perform poorly relative to other lots of the same species when field conditions deteriorate are by definition of lower vigor (Perry, 1978). Yonts et al. (1983) reported that soil temperatures affect the rate of emergence, but not the final number of plants which emerge. This linear relationship developed from the laboratory emergence indicates that maintenance of soil moisture tensions of less than six atmospheres would ensure an emergence rate of 60.0% or more. Hunter and Dexter (1950) reported that air-dry segmented sugar beet seeds germinated only at between 12 and 20.0% soil moisture. They observed that an additional small amount of water in contact with the seed induced germination in soils drier than the critical soil moisture of 12.0%. Hunter and Erickson (1952) plotted the minimum soil moisture percentages required for germination of seeds of various species in several soils on a moisture tension curve for each soil and found the maximum moisture tension which produced satisfactory germination was constant at 3.5-atmospheres for sugar beets. They concluded that greater attention should be paid to the soil moisture conditions when sugar beets are planted since they require considerably more moisture for germination than other crops.

Another factor which may have an important influence on germination and emergence of sugar beet seedlings is soil compaction. The extent of compaction of the plow layer is mainly determined by the soil moisture content, the wheel track distribution, the number of passes by the wheels, the load on the wheels, the wheel arrangement and characteristics including the tire pressure (Ljungars, 1977). Because of its effect on aeration, compaction of the soils in the seedbed

undoubtedly has some effect on emergence, however, available references do not fully explain the effects of this factor. Emergence is also reduced by the presence of soil crusts that can form naturally under the effect of rain followed by drying by sun and/or wind. However, the impact of crusting can be reduced either by methods of preparing soils, removing the risk of subsequent formation of crusts, or by selecting varieties capable of exerting greater growth forces (Goyal, 1982).

Environmental Factors

Wind erosion is a major problem in the establishment of sugar beets in some areas. Sugar beet seedlings are more vulnerable during the establishment period when wind speed is the highest, i.e., May and June. Cultural methods that leave residues on the surface appear to have the greatest potential for combating the effects of erosion problems.

Snyder and Zielke (1973) showed that the rate of imbibition of sugar beet seed was related to their sensitivity to excess water. They suggested that to obtain reliable germination and emergence data, the quantity of water available to the seed must be rigidly controlled.

Wanjura and Buxton (1972) developed a systematic procedure for developing seedling emergence models. They developed a model to describe cotton seed water uptake during imbibition and hypocotyl elongation until emergence. Laboratory experiments were used to define the values of the environmentally-dependent coefficients of selected soil parameters in the model. In validation tests, the model predicted radicle emergence time within ± nine

percent. Hypocotyl elongation was not significantly different from observed values in nine of ten comparisons done by the authors.

Many studies suggest that the pre-emergence seedling growth stages are sensitive to very wet conditions. Thus, increased risk is associated with early sowings and many of the post-germination losses probably result from waterlogging. Possible approaches to minimize this problem include more tolerant varieties (Durrant, *et al.*, 1984), pre-treating the seeds (Heydecker and Coolbear, 1977; Akeson, *et al.*, 1981) and the avoidance of excessive soil compaction.

Planting Depth/Spacing

Yield of sugar beet is similar whether planted to stand or planted more thickly and hand thinned when grown in 55.0 to 76.0-cm rows at population density of 10,000 - 16,000 plants/ha (Fornstrom, 1980). Planting to stand (desired plant populations) has been successful in 76.0-cm rows as well as 56.0-cm rows if the plant populations are maintained (Cattanach and Schoeder, 1980; Fornstrom and Jackson, 1983; Winter and Wiese, 1977). Planting depths greater than 2.5 cm appear to reduce the emergence of sugar beet seeds (Cattanach et al., 1979; Fornstrom and Miller, 1987). Four to six percent higher emergence was obtained when using a 1.9-cm seeding depth compared to a 3.2-cm seeding depth, but the results were not always consistent (Fornstrom and Miller, 1989). Also, more sugar beet seedlings emerged and at a faster rate as the depth of seeding decreased from 4.5 to 1.6 cm. Herbicide injury to sugar beet seedlings

increased as depth of seeding increased to more than to 2.5 cm (Wilson et al., 1990).

Seedling Diseases

Stehlik and Neuwirth (1928) concluded that the most critical period during planting and stand establishment is usually from the time of seed swelling to the four-leaf stage, during which the young seedlings are very vulnerable to fungal attack. However, it is primarily the suitable ecological conditions that enable the seed to germinate and emerge. Sugar beet is susceptible to numerous seed/seedling diseases, expressed as seed decay, pre-emergence damping-off, post-emergence damping-off and infection of the radicle and hypocotyl of emerged plants. The severity of the diseases is influenced by the susceptibility of the host, the inoculum potential of the pathogen, environmental factors, (including temperature, moisture, and soil characteristics) and the effectiveness of control measures.

Seedling infection by *Phoma* is often called "black leg." Infection by *Aphanomyces* is often referred as "black root." Because of possible confusion of black leg and black root and the imprecise use of these terms, use of the generic name of the pathogen is preferable in identifying seedling diseases, e.g., *Pythium* damping-off, *Rhizoctonia* damping-off, *Aphanomyces* (or beet water mold) seedling disease, and *Phoma* seedling infection.

Pythium ultimum Trow is present to some extent in nearly all arable soils and attacks unprotected seedlings at all temperatures favorable for the germination of beet seed. The pathogen is favored by high moisture and attacks

seedlings of many other crops, causing pre-emergence damping-off. Post-emergence damping-off may follow under moist soil conditions.

Pythium aphanidermatum (Edson) Fitzp., a high-temperature fungus, attacks seedlings only in warm soils with abundant soil moisture.

Rhizoctonia solani Kühn causes some pre-emergence death of seedlings but inflicts most of its damage on emerged seedlings. Infection is initiated below the soil surface and extends up the hypocotyl, with a distinct margin between infected and healthy tissue. Lightly infected seedlings often survive and may produce nearly normal roots. The same fungus, however, may later in the season cause crown rot or dry rot canker on maturing roots.

Seedlings infected by *Aphanomyces cochlioides* Drechs. can usually be distinguished from those infected by *Phoma betae* or *Pythium spp.* because the entire hypocotyl becomes thin and black, with cotyledon necrosis at the base. Seedlings attacked but not killed by *P. betae* or *Pythium sp.* usually recover rapidly, but *Aphanomyces* persists and stunted plants still occur in July. The fungus can be found on the lateral roots of beet plants in infested fields throughout the season. This disease is favored by warm, moist soil and thus occurs most often in late-sown crops. In Europe, a survey conducted by Asher and Payne (1989) of randomly selected sugar beet fields confirmed the presence of *Aphanomyces cochlioides* Drechs and *Pythium sp.* on about one-third of the fields tested.

Phoma betae Frank is the only important seed-borne pathogen of sugar beet seedlings. It first appears to a limited extent in the fall as seedling or leaf

spot infections and persists through the winter as infections on leaf or crown tissue. With spring growth and bolting, leaf spots, crown infections and later, lesions on the seed stalks appear. During periods of rainfall or high humidity, pycnidia of the fungus exude spores in gelatinous masses. These spores are readily spread by splashing rain or overhead sprinklers or, when dry, may become air-borne and by these means, come into contact with developing floral parts and result in seed infection. However, the most important period of seed infection appears to occur during the harvest period. When the seed is ready to harvest, the seed stalks are cut, swathed and allowed to cure in the field for a period of 10 to 20 d before the actual threshing of the seed.

Seed Treatment

In Europe, an excellent survey by Dunning (1972) showed that plant pathologists in 13 countries believed that the most important seedling pathogen of sugar beets was *Phoma betae* and that effective seed treatments against this pathogen were indispensable. In the United States, however, the experience has been less consistent. Prior to the 1930's when most of the seed was imported from Europe, *Phoma* seedling disease was quite serious and mercury-based seed treatments such as diethyl mercuric phosphate (EMP) were commonly used as the only effective means of control. With the initiation of domestic seed production in the arid southwest, sugar beet seed was found to be essentially free from *Phoma* (Leach, 1940 and 1944), thus allowing attention to be focused on the soilborne seedling pathogens. After the use of mercury seed treatments was discontinued, newer often selective fungicidal seed treatments were

introduced. However, when domestic seed production was later shifted to Oregon for the production of non-bolting varieties, some seed lots were again found to carry considerable amounts of *Phoma*. Several factors prompted the reevaluation of the use of EMP. First, attitudes have hardened against the continued use of mercuric compounds. Secondly, a shorter treatment than 24 h may be adequate, since a survey of *Phoma betae* levels in sugar beet seed (Payne, 1986) suggests that severe infestations are rare. Thirdly, the need for improved stand establishment has been highlighted (Durrant, Jaggard and Scott, 1984), and studies (Durrant and Loads, 1984, 1987) have indicated that enhancing the seed by prolonged steeping should help to achieve more rapid establishment of an adequate number of plants. Therefore, an alternative treatment with comparable efficiency was needed. The candidate chemical, Thiram (tetra-methyl thiuram disulphide), gave maximum control of deep-seated infections in several species but only when the seed was steeped in a 0.2% suspension for 24-h at 30.0°C (Maude, 1966, 1986; Maude, Vizor and Shuring, 1969) and without being harmful to human health. In a series of experiments between 1977 and 1979 Byford (1985) confirmed that steeping in Thiram was as effective as EMP.

Knott (1925) described soaking seed of some vegetables in water to promote germination and utilization of food reserves, the use of oxygen and the release of carbon dioxide. Some of the factors which affect this beginning of growth are, the time (length) of soaking, the temperature of the water, the relative amount of water, the movement of the water, the amount of water surface

exposed to air, the size of the seed and the density of the seed mass. More injury due to the loss of soluble food reserves might be expected. However, this is not the case, probably because of the better supply of oxygen and the removal of carbon dioxide. Knott (1925) concluded that soaking seed of beets in shallow distilled water for 24 h shows no definite influence on later growth and yield. In 1944, Stout and Tolman concluded that synthetic growth-regulating substances did not give significant benefits to seedling emergence, vegetative growth, sucrose content, purity, or yield of roots per acre. Miyamoto and Dexter (1960) reported that monogerm seed need more moisture to germinate than multigerm seed. In another study (Dexter and Miyamoto 1959), they found moisture uptake and emergence to be accelerated if the sugar beet seed balls were coated with hydrophilic colloids.

In the late 1970's and early 1980's, the so-called "crop success" that 70.0% of the seeds sown must give harvestable roots was still not achieved. Durrant and Scott (1981) stressed the possibility of improving stand establishment by making the seed more tolerant to sub-optimal conditions in the seedbed environment by treating it under controlled conditions before sowing. Such treatments have utilized various combinations of water, different salts, sugars or polyethylene glycol solutions with steeping, wetting and drying cycles, vigorous bubbling, etc. The treatments were divided into two types - those which "advance" seed (Genkel, 1946; Austin, Longden, and Hutchinson, 1969; Longden, 1971) and those which "prime" seed (Heydecker, 1974). Both treatments increase the rate of germination, however, during "advancement" all

seeds are affected equally so there is little effect on the speed of germination, whereas with "priming," the target is to bring all seeds to a similar physiological stage resulting in highly synchronized germination. In general, treatments utilizing water or dilute solutions "advance" seeds, while treatments with sufficiently concentrated osmotica to restrict water enough to prevent germination "prime" seeds. Although in laboratory experiments certain pre-treatments substantially improved both the speed and percentage germination, there are inconsistent effects, particularly on seedling numbers in field experiments (Heydecker and Coolbear, 1977; Longden *et al.*, 1979), which make it difficult to evaluate the usefulness or potential of such treatments. In the late 1980's, a new method of priming was introduced termed solid matrix priming (SMP) (Taylor *et al.*, 1988). This method controls hydration through the matric potential in contrast to traditional priming methods that employ osmotic potential. Rush (1991) confirmed that SMP promoted early emergence, suppressed pre-emergence damping-off and produced a greater final stand than osmoprimed treatments on sugar beets. However, significant suppression of post-emergence damping-off, mainly caused by *P. ultimum and A. cochlioides*, was not achieved by using SMP (Rush, 1992).

Pelleting tends to improve flow through precision drills and also provides a convenient carrier for insecticides, fungicides and some nutrients (Dunning, *et al.*, 1986). Until now, the principal component of the coating is a clay called 'Filcoat' that in the dry state has a few small pores. However, there is evidence (Vanstallen, 1971; Thompson, and Woodwark, 1975; Verveka, 1983) that under

very wet conditions, such coatings decrease both the rate of germination and final germination percentage and that the less vigorous seeds are probably affected most. There have been many comparisons of unpelleted and pelleted seed in field experiments, although, the results have not been consistent. However, pelleting significantly increased establishment in about ten percent of the comparisons in England (Hibbert, *et al.*,1975).

Dunne *et* al. (1998), in order to satisfy both the public health and environmental concerns, presented an alternative means for disease suppression by using biological control. They found that the combined use of *Pseudomonas flourescens*, F113 and *Stenotrophomonas maltophilia* W81 protected sugar beet seedlings form *Pythium*-mediated damping-off as much as when chemical pesticides when added in the pelleting medium.

Economic Impact

In the past five years, Michigan has produced approximately 13,000,000 Mg of sugar beets, making the crop one of the most important in the state. Generally speaking, yield is the most important factor in determining net profit from sugar beet production. A profitable yield needs to be preceded by a satisfactory stand, however, it is estimated that 15.0 to 20.0% of fields need to be replanted annually due to inadequate stands (Dr. R. Zielke, Director Research, Michigan Sugar Company, Carrollton, Mich., personal communication). Poor seedling vigor and problems with seedling survival to the four-leaf stage appear to be major factors. It is estimated that loss of yield on replanted hectares is approximately 300,000 Mg of beets. Replanting costs are about $12/ha and the

loss in yield from replanting is estimated to be more than $36/Mg. Thus, the total cost of replanting is around $12 million annually to the Michigan sugar industry. Much of this loss could be prevented by greater success in sugar beet emergence, stand establishment and survival.

MATERIALS AND METHODS

Three experiments were conducted in 1998 and 1999. In the first, results of seven different laboratory tests were compared with the field emergence of 20 seed lots. In the second, nine seed lots consisting of three different varieties and three seed sizes were further compared in laboratory and field tests in both 1998 and 1999. Finally, the effects of five different coating treatments on laboratory and field performance were evaluated on one seed lot.

Plant Material:

The seed lots used in the field and laboratory experiments were obtained from Michigan Sugar Co. (Caro, MI) and Monitor Sugar Co. (Bay City, MI). However, the companies that produced the seed were American Crystal Sugar Co., Betaseed (Shakoppee, MN) and Holly Hybrids (Sheridan, WY). All of the seed was conditioned to remove a fraction of the outer portion (corky layer) of the pericarp. The seed was then graded through sieve plates from sizes 2 (0.26 - 0.30-cm) through 5 (0.38 - 0.42-cm) in 0.04-cm increments. Since most of the seed lots were commercially available, they were obtained pre-treated with a commercial application of either Thiram or Apron® at the rate of 1.5 and 8 oz per 454-kg of seeds, respectively. Seed Systems Inc. (Gilroy, CA) applied all the treatments in the seed enhancement experiment.

The seed lots were monogerm, a mendelian genetic trait, which produces a single seed per fruit. The seed lots were of various ages depending on the

year of production. A smaller number of older seed lots with poor germination (≤ 80%) were also selected.

Description of Laboratory Tests:

Laboratory tests for the three experiments in both years were performed in a randomized complete block design. The procedures for each test were identical for all the experiments, unless otherwise specified. Standard methods for analysis of variance were used to analyze the laboratory data. All data were analyzed using the SAS 7.0 Statistical Software package (SAS Institute Inc. 1998). The MIXED model procedure was used, allowing the handling of both fixed and random effects in a linear model, giving a continuous response.

1. Pleated Germination Test (PT)

Seeds were soaked in deionized water overnight (16 h) in 400-ml beakers. Cheesecloth was attached to the top of each beaker with a rubber band. Immediately after the soaking period the water was decanted and the container refilled and emptied five times for complete rinsing. The seed was then placed on paper towels to dry for an hour.

Pleated germination paper (Anchor Paper Co., St. Paul, MN) was placed into 12.7x17.8x12.7-cm plastic boxes containing 30 ml of deionized water. Seeds were placed between the flutes at the rate of four seeds per flute, 100 seeds per lot, two lots per box. A paper clip was placed on the paper separating the two seed lots within each box. Approximately 5 ml of additional water was added by using a misting bottle to achieve uniform wetness of the paper. The

boxes were sealed when the seeds were in place. Four randomized replications of each seed lot were 31

31germinated concurrently in boxes maintained at 23.0°C in a constant temperature room under continuous fluorescent light. Germination counts were made at 5 (PT-5) and 10 d (PT-10) after planting.

Ungerminated seeds were opened with needle-nose pliers and judged to either be live or dead, based on the embryo appearance. Abnormal seedlings were not counted as germinated.

2.Cold Germination Test (CT)

Seeds were soaked overnight (16 h) in 400-ml beakers and rinsed as described in the pleated paper germination test procedure, then planted in soil from the Saginaw Valley Bean and Beet Farm near Saginaw, Michigan (Misteguay soil complex having a silty clay texture) that had been passed through a 0.64-cm sieve. One kg of soil was placed into plastic boxes measuring 18x33x9 cm, then leveled to a depth of approximately 1.9 cm. Then 50 seeds were placed onto the soil using a counting board to assure equal spacing, and another 1.0 kg of dry soil was placed over the seeds. Water was added from a plastic bottle with a cap with small holes to allow even application without disturbing the soil surface. Sufficient water was added to bring the soil to 20% moisture (2/3 of moisture at field capacity).

Seed containers were randomized within germination chambers, with each plastic box serving as one 50-seed replication. Two movable germination chambers were utilized to represent two replications of each seed lot. The

chambers were placed in a constant temperature room maintained at approximately 10.0°C for 4 d, then moved to a constant temperature room maintained at 23.0°C for the duration of the test. Finally, three open plastic containers were used to add deionized water to the top, middle and bottom part of the chambers to assure high relative humidity.

Germination counts were made at 5 (CT-5) and 10 d (CT-10) of incubation at 23.0°C. Seedlings were removed from each box after counting. Upon completion of the final count, the soil was air dried for a short time by passing it again through a 0.64-cm sieve and allowing it to dry. After mixing, the soil was again weighed into the boxes and the test repeated.

3. High Moisture Cold Test (CTHM)

This test was similar to the CT, except that soil at 35% moisture was used and germination counts were made at 3 and 6 d instead of 5 and 10 d.

4. Accelerated Aging Test (AA)

The initial seed moisture content was determined by weighing 5.0 g of each seed lot (fresh weight) and drying in an oven at 105.0°C for 2.5 h; then the seeds were reweighed (dry weight). If the seed moisture content was greater than 14.0%, the seeds were dried to 10-14% moisture before the aging test (AOSA).

The plastic accelerated aging boxes (11.0x11.0x3.5-cm) and the wire-mesh trays (10.0x10.0x3.0 cm) were washed in a 15.0% sodium hypochlorite solution (Clorox) and then dried. Forty ml of water were added to each. Then a

dry wire-mesh tray with approximately 17.0 g of sugar beet seeds in a uniform layer was placed in each plastic box which was then sealed by placing a Vaseline layer over the lid corners. The accelerated aging oven chamber was set at 41.0°C for 12 h before the test. Then plastic boxes were placed on a shelf spaced approximately 2.5 cm apart and held at 41.0°C for 72 h with the door continuously closed to prevent temperature fluctuations. After the aging period, the plastic boxes were removed and cooled to room temperature for an hour before planting the seeds in pleated germination tests. Germination was evaluated at 2 (AA-2) and 4 d (AA-4) after planting.

5. Saturated Accelerated Aging Test (AANaBr-2 and AANaBr-4)

This test was similar to the AA test, except that 60 ml of NaBr saturated solution was added to each plastic box (11.0x11.0x3.5 cm) to maintain the relative humidity at about 54.0%. All solutions were saturated at 41.0°C (Jianhua, and McDonald, 1996).

6. Conductivity Test (COND)

Prior to initial use, the conductivity meter was calibrated using a potassium chloride solution. To calibrate the dip cell of the conductivity meter, 0.745 g of pure analytical grade potassium chloride (dried at 150.0°C for 1 h and cooled in a desiccator before weighing) was dissolved in 1 L of deionized water to make a 0.01M KCl solution, giving a 1 - 5 $\mu S\ cm^{-1}$ which was slightly higher than the $1.27 \mu Scm^{-1}$ (at 23.0°C) expected because of the low conductivity of the

deionized water. If the reading was incorrect, the calibration test was repeated and the meter adjusted.

The initial seed moisture content was determined by weighing 5.0 g of each seed lot (fresh weight) and drying in an oven at 105°C for 2.5 h; then the seeds were reweighed (dry weight). All seed lots had a seed moisture content of 11 - 14%.

Fifty ml of deionized water was placed in 50-ml flasks which were covered with aluminum foil to prevent dust contamination and equilibrated at 23.0°C for approximately 24 h prior to placing the seeds in the water. A control flask containing only deionized water was included to monitor water quality.

Four subsamples of 75 treated seeds each were weighed and placed in the 50-ml flasks containing the deionized water (75 seeds per flask). Each flask was gently swirled for ten seconds to ensure that all seeds were completely immersed. Flasks containing water and seeds were recovered with aluminum foil prior to being placed at 23.0°C for 24 h.

Immediately following the end of the 24-h soaking period, the conductivity of the water in the flasks was measured at 23.0°C. The flasks (with seeds) were swirled for 10 s, the foil removed and the conductivity ($\mu S\ cm^{-1}$) determined by immersing a pipette-type cell into the solution without filtration. Direct contact of the cell with the seeds was avoided and the dip cell was rinsed twice with deionized water between samples. All hard seed (floating) observed during the test were removed, surface dried, weighed, and the weight subtracted form the

initial weight of the 75-seed subsample. All the conductivity evaluations were made inside the 23.0°C chamber to avoid temperature fluctuations.

7. Sand Test (ST)

Seeds were soaked overnight (16 h) in 400-ml beakers and rinsed as described in the pleated paper germination test procedure, then planted in blast silica sand (Magnum Blast co.). First, 1.0 kg of sand was weighed in a plastic bag and 40 ml of deionized water added to give four percent moisture. The sand and water contained in the plastic bag were mixed for approximately one minute to ensure even moisture distribution in the sand. The sand (1.0 kg) was placed in18.0x33.0x9.0-cm plastic boxes and leveled to a depth of approximately 1.3 cm; then 50 seeds were placed on top of the sand using a counting board to assure equal spacing. Another 1.0 kg of moist sand (4% moisture) was then placed over the seeds and leveled. Finally, plastic wrap was placed onto the boxes to prevent loss of moisture.

Seed lot containers were randomized within the germination chambers. Each plastic box served as one 50-seed replication. Two movable germination chambers were utilized to provide two replications of each seed lot and placed in a constant temperature room maintained at 23.0°C for 10 d. Finally, 3 plastic containers with deionized water were added to the top, middle and bottom part of the chambers to assure maintenance of high relative humidity.

Germination counts were made at 5 (ST-5) and 10 d (ST-10) of incubation at 23.0°C. Emerged seedlings were removed from each box after the first count. Upon completion of the final count, the sand was discarded.

Experiment 1 (Seed Quality)

A. Seed Lots:

Twenty seed lots representing 12 varieties and seven different years of production were used in 1998 (Table 1). Another 20 seed lots different from those used in 1998 were tested in 1999. These consisted of eight varieties representing six different production years (Table 2).

B. Laboratory Tests:

Six laboratory tests (PT, CT, AA, AANaBr, ST, COND) were conducted on the 20 seed lots in 1998 as previously described. All tests except AA, AANaBr, and ST were repeated in 1999. However, CTHM was conducted only in 1999.

Table 1. Seed lots tested in Exp. 1 (Seed Quality) in 1998.

Entry	Variety	Source	Lot No.	Year	Size
1	ACH-197	Michigan	6055324	93	3
2†	ACH-308	Monitor	470348	93	3
3	ACH-319	Michigan	6102320	95	3
4	Beta 5931	Michigan	6105325	96	3
5	HM E 4	Michigan	635312	92	3
6	HM E 10	Michigan	6060321	93	3
9†	USH-20	Michigan	uncertain	93	3
10	ACH-185	Monitor	219598	91	5
11	ACH-185	Monitor	328404	92	4
14	ACH-197	Monitor	320207	92	2
15	Beta 5931	Monitor	214208	92	2
16	HM E 4	Monitor	336420	92	4
17	HM E 4	Monitor	324211	92	2
18†	USH-20	Monitor	82032	78	4
20	USH-23	Monitor	279307	86	3
21	ACH-185	Michigan	608310	96	3
52	HM E4	Michigan	931138	93	4
54	HM E4	Michigan	93514	93	3
56	ACH-319	Michigan	950427	95	2
57	ACH-319	Monitor	950427	95	3

† Untreated Seed.

Table 2. Seed lots tested in Exp. 1 (Seed Quality) in 1999.

Entry	Variety	Source	Lot No.	Year	Size
77	HM E10	Michigan	941025	94	4
78	ACH-319	Michigan	950514	95	2
79	ACH-319	Michigan	960027	96	3
80	HM E17	Michigan	960017	96	2
81	HM E17	Michigan	97005	97	3
82	HM E17	Michigan	960021	96	3
83	HM E17	Michigan	960019	96	3
84	ACH-555	Monitor	980444	98	4
85	ACH-648	Monitor	980285	98	3
86	ACH-555	Monitor	980444	98	2
87	HM E17	Monitor	970097	97	3
88	ACH-648	Monitor	980285	98	4
89	ACH-555	Monitor	980444	98	3
90	ACH-1353	Mi/Mo	980443	98	3
91	ACH-1353	Mi/Mo	980443	98	2
92	ACH-1353	Mi/Mo	980443	98	4
93	HM E17	Monitor	970095	97	4
94	HM E17	Michigan	960019	96	3
95	HM E17	Michigan	960015	96	2
96	HM E4	Michigan	931138	93	2

C. Field Study:

1998: Twenty seed lots were planted in three different locations. An eight-row vacuum planter was used in location one and three with a space of 76 cm between rows. A four-row Almaco belt cone planter was used for location two, with a space of 71 cm between rows. Planting depths were 1.3, 4.2 and 1.3 cm, respectively. Planting dates, locations and soil type are given in Table 3. The seed spacing was 6.4 cm at all locations. Plot length was 6.1 m for all locations. Single row plots were arranged in a randomized complete block design with eight replications. Three field emergence counts were made at each location. The number of days after planting to final emergence for each count and respective dates are shown in Table 4.

Single linear correlation coefficients (r) were calculated to show the association among all laboratory tests and between single laboratory tests and field emergence. The linear regression model for r was $y = a + bx + \epsilon$. However, simple coefficients of determination (r^2) were used to illustrate the differences. Multiple regression equations (R) were used to further explain the variability of field emergence using various laboratory tests in the same equation, rather than single linear correlation coefficients. Although the values were calculated as multiple regression equations (R), multiple coefficients of determination were used (R^2) to explain the differences in results. The equation used for the multiple regression analysis was $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \epsilon...$ where Y was field emergence, X_1 was the germination percentage in the pleated germination test and X_2 was the percent germination in the different vigor tests and ϵ was the error term that measured the deviation of a random variable from its mean.

Table 3. Farm, soil series and planting dates for field studies of sugar beet seed lots in 1998.

Location	County	Farm or Farmer	Soil Series	Planting Date
1	Saginaw	MSU B&B	Misteguay silty clay	4/20
2	Ingham	MSU Campus	Metea sandy loam	4/24
3	Huron	Maust	Kilmanagh loam	4/22

Table 4. Soil series, counting dates and days after planting for field studies of sugar beet seed lots in 1998.

Location	Soil Series	Date 1st Count	2nd Count	3rd Count
1	Misteguay	5/7	5/13	5/20
(Dap)†		17	23	30
2	Metea	5/6	5/12	5/19
(Dap)		13	19	26
3	Kilmanagh	5/4	5/14	5/21
(Dap)		12	22	29

† Dap= Days after planting.

1999: The twenty seed lots were planted in three different locations using a four-row Almaco belt cone planter unit with 71-cm spacing between rows. Planting depths were 3.2, 1.9 and 1.9 cm respectively. Planting dates, locations and soil types are given in Table 5. The seed spacing was 6.4 cm and plot length was 6.1 m for all locations. Single row plots were arranged in a randomized complete block design with eight replications.

Table 5. Farm, soil series and planting dates for field studies of sugar beet seed lots in 1999.

Location	County	Farm or Farmer	Soil Series	Planting Date
1	Saginaw	MSU B&B	Misteguay silty clay	4/28
2	Ingham	MSU Campus Botany	Capac loam	4/14, 5/3†
3	Ingham	MSU Campus Crop & Soil	Metea sandy loam	5/4

† Late sowing for Experiment Two.

Experiment 2 (Seed Sizes)

A. Seed lots:

Nine different seed lots were tested in both 1998 and 1999, consisting of three varieties (ACH648, ACH503, ACH555) and three seed sizes (2, 3, 4), all of which were produced in 1997. Entry number, variety, source, lot number, year of production and size are given in Table 6.

Table 6. Description of nine seed lots in Exp. 2 (Seed Size) in 1998.

Entry	Variety	Source	Lot No.	Year	Size
58	ACH-648	Michigan	970253	97	2
59	ACH-648	Michigan	970253	97	3
60	ACH-648	Michigan	970253	97	4
68	ACH-503	Monitor	970247	97	2
69	ACH-503	Monitor	970247	97	3
70	ACH-503	Monitor	970247	97	4
71	ACH-555	Monitor	970250	97	2
72	ACH-555	Monitor	970250	97	3
73	ACH-555	Monitor	970250	97	4

B. Laboratory Tests:

Seven laboratory tests (PT, CT, CTHM, ST, AA, AANaBr, COND,) were conducted throughout both 1998 and 1999 on the nine seed lots as previously described.

C. Field Study:

1998: The nine different seed lots were sown in three different locations. An eight-row vacuum planter was used in locations one and three with 76 cm between rows. A four-row Almaco cone planter unit was used at location

two, with 71 cm between rows. Planting depths were 1.3, 4.2 and 2.5 cm respectively. Planting dates, locations and soil type are given in Table 3. Plot length was 6.1 m and seed spacing was 11.4 cm for all locations. Single row plots were arranged in a randomized complete block design. A block consisted of the nine experimental units (seed lots) and each block was replicated eight times. Three field emergence counts were made at each location. The dates and number of days after planting for each count are shown in Table 4.

Simple coefficients of determination (r^2) were calculated for association between laboratory and field emergence results. Multiple coefficient of determination (R^2) equations were used to establish the relationship between laboratory test results and field emergence for each planting date.

1999: The nine different seed lots were planted in two different locations. However, in location two an early (4/14) vs. late (5/3) planting was used to compare the differences due to date of planting. A four-row Almaco belt cone planter unit was used for all locations, with 71 cm between rows. Planting depths were 3.2, 1.9 and 1.9 cm, respectively. Planting dates, locations and soil type are given in Table 5. A seed spacing of 10.2 cm and plot length of 6.1 m was used. Single-row plots were arranged in a randomized complete block design, with each block consisting of the nine experimental units (seed lots) and each block replicated eight times within each location.

Experiment 3 (Seed Enhancement)

A. Seed Lots:

1998: One seed lot of variety HM E-17 produced in 1995 was selected for this study. Five seed treatments were compared with the current treatment, Celpril, as treatment number one. This gives a film-coated treatment of the fungicide Tetramethylthiuram disulfide, often known as Thiram®, along with a dye to color the seed. The second treatment was a pelleted treatment containing the fungicide, but no additional treatment (Plain Pellet). The third was a pelleted seed that had been conditioned by a process referred to as priming advanced treatment (PAT), a patented priming process to enhance speed of emergence. During conditioning, PAT seed undergoes removal of germination inhibitors as well as sophisticated control of moisture and temperature to promote the very early stages of embryonic development. The fourth treatment consisted of pelletized seed with the fungicide Tachigaren® added (TACH) to control the seedling diseases caused by the soilborne *Aphanomyces* fungi. The fifth treatment utilized a pelleted seed combining the PAT process plus Tachigaren® (PAT + TACH).

A second seed lot of HM E-17 produced in 1996 (as opposed to 1995) was selected in 1999; otherwise, all the seed coating techniques used were the same.

B. Laboratory Tests:

Two laboratory tests (PT, CT) were conducted on the five seed lots in 1998 and 1999 as previously described.

C. Field Study:

1998: Field plots were planted at the Saginaw Valley Bean and Beet Farm near Saginaw, Michigan on a Misteguay silty clay soil. All plots were planted with a John Deere-71 plate planter unit mounted on a tool bar adapted for the three-point hitch attachment to a tractor. Single row plots 12.2 m long were arranged in a randomized complete block design with six replications but were planted at 71 cm between rows. Seed was spaced at a distance of 10.2 cm and a depth of 1.9 cm. An early (4/15) vs. late (5/15) planting was conducted to compare the differences due to planting date. Emergence was measured seven times for each planting date. A simple two-way analysis of variance (ANOVA) was used to determine differences among treatments. However, correlation or multiple regression analysis was not performed due to the lack of data points.

1999: Field plots were again planted at the Saginaw Valley Bean and Beet Farm. However, three sites with different disease pressure were chosen within the farm. The area with low disease pressure had not had sugar beets grown in the field for more than 25 years. The medium field location had a rotation in which sugar beets were grown every three years. The high disease pressure field had a history of diseases and was one in which sugar beets had been grown in both 1997 and 1998. Soil samples from the three sites were sent to the Plant Disease Clinic at the University of Minnesota and assayed for the presence of *Aphanomyces sp.* and other root rot pathogens. The disease index for the three sites is provided in Table 7. A late planting date (5/11) was chosen

to provide optimum conditions for disease development. Type of planter, plot length, row space and seed spacing were the same as that used in 1998.

Table 7. Organism index values for the three sites for Exp. 3 (Seed Enhancement) in 1999.

Site	Organism Index†	Classification
1	3	Low
2	28	Medium
3	94	High

† Values fall between 0 and 100. A value of 0 means that no disease was detected. A value of 100 means that roots of all plants were severely rotted or that all seedlings died in the greenhouse bioassay.

Planting depth was increased to 2.5 cm to attain a more uniform plant stand because of more optimum moisture for germination. A single block consisted of the five treatments repeated four times. Emergence was measured four times at 9, 14, 17 and 21 d after planting for all sites. A simple two-way analysis of variance was used to determine the differences between treatments.

RESULTS AND DISCUSSION

I. Laboratory Tests

A. Means and Coefficients of Variance

The highest mean emergence of 92.5% occurred for the 10-d pleated germination test for the Exp. 1 (Seed Quality) in 1998 (Table 8). On the other hand, the lowest mean germination (13.7%) occurred at the 2-d accelerated aging test for the same experiment. The difference between the 10-d pleated germination (PT-10) and the 10-d cold test (CT-10) results was 13.1% for Exp. 1 in 1998. A difference of 13.0% germination occurred between means of the 10-d sand test (ST-10) and PT-10. A similar difference of 15.4% occurred between results of the 4-d accelerated aging test and the sodium bromide (AANaBr-4) test, however, a larger germination difference of 56.0% occurred between the 2-d standard accelerated aging (AA-2) and PT-10 tests. In Exp. 1 in 1999 the PT-10 again produced the highest mean emergence at 94.0% (Table 9). However, the lowest mean emergence of 58.3% occurred for the 3-d cold high moisture test (CHM-3). For the same experiment, a mean difference of only 2.0% occurred between germination results for the PT-10 and CT-10. However, there was a 14.1% germination difference between the PT-10 and 6-d high moisture cold germination test (CTHM-6). Similar differences occurred in Exp. 2 (Seed Size), however, the largest difference of 78.6% occurred between PT-10 and AA-2 (Table 10). The highest mean emergence of 94.0% also occurred at the PT-10 and the lowest mean emergence occurred at the 2-d count of the accelerated aging test. In Exp. 3 (Seed Enhancement) in 1998 the highest mean of 98.6%

for PT-10 was shared between the advanced primed seed (PAT) and the plain pelleted seed (Plain), however, Tachigaren-treated (TACH) seed germinated only 67.0% (Table 11). All 10-d cold germination test means in Exp. 3 were above 90.0%, including Celpril treated seed at 99.0%, but were only 92.0% for PAT. However, the highest PT-10 mean germination in 1999 was from plain pelleted seed at 96.3%, and the lowest for PAT+TACH at 80.5%. In the CT-10 the Plain treatment produced the highest mean at 97.5% and the lowest was PAT + TACH at 79.5%.

Table 8. Mean, coefficient of variance and range of laboratory test results averaged over all seed lots tested, Exp. 1 (Seed Quality), 1998.

Lab Tests	Mean (% germinated)	CV	Range†
PT-5	87.9	18.8	17 - 100
PT-10	92.5	9.73	59 - 100
CT-5	76.7	28.4	0 - 100
CT-10	79.4	25.5	10 - 100
ST-5	66.7	34.3	0 - 100
ST-10	79.5	22.7	10 - 100
AA-2	13.7	128.0	0 - 73
AA-4	36.5	54.8	1 - 75
AANaBr-2	28.6	75.2	0 - 80
AANaBr-4	77.1	26.2	13 - 100
COND‡	480.1	16.9	299.9 - 620.5

† The range of values is for all the replications.
‡ Values for the tests are expressed as % of seed germinated, except COND that is in $\mu S\ cm^{-1} g^{-1}$.

Table 9. **Mean, coefficient of variance and range of laboratory test results averaged over all seed lots tested, Exp. 1 (Seed Quality), 1999.**

Lab Tests	Mean (% germinated)	CV	Range†
PT-5	93.2	4.6	80 - 100
PT-10	94.0	4.8	80 - 100
CT-5	90.9	7.6	62 - 100
CT-10	92.0	7.3	64 - 100
CTHM-3	58.3	41.1	0 - 92
CTHM-6	79.9	17.9	38 - 98
COND‡	531.7	19.0	391.5 - 840.0

† The range of values is from four replications.

‡ Values for the tests are expressed as % of seed germinated, except COND that is in $\mu S\ cm^{-1} g^{-1}$.

Table 10. Mean, coefficient of variance and range of laboratory test results averaged over all seed lots tested, Exp. 2 (Seed Size).

Lab Tests	Size	Mean (% germinated)	CV	Range†
PT-5	--	93.2	4.8	80 - 100
PT-10	--	94.0	4.6	80 - 100
CT-5	--	89.9	5.1	82 - 98
CT-10	--	91.5	4.7	84 - 100
CTHM-3	--	49.1	74.8	10 - 74
CTHM-6	--	78.9	23.2	66 - 98
ST-5§	2	55.8	21.8	30 - 70
	3	70.7	14.2	56 - 86
	4	71.0	46.7	52 - 82
ST-10§	2	78.8	12.1	66 - 98
	3	86.7	6.0	76 - 96
	4	85.7	7.4	72 - 98
AA-2	--	0.81	138.6	0 - 5
AA-4	--	15.4	37.4	3 - 29
AANaBr-2	--	7.2	70.5	1 - 22
AANaBr-4	--	77.8	13.0	38 - 92
COND‡,§	2	579.4	16.7	424.5 - 713.0
	3	488.2	13.7	361.2 - 570.6
	4	455.2	10.9	379.3 - 529.2

† The range of values is for all the replications.

‡ Values for the tests are expressed as % of seed germinated, except COND that is in $\mu S\ cm^{-1} g^{-1}$.

§ Only tests where the variable size was significant $P \leq 0.05$ in the ANOVA.

Table 11. Mean, coefficient of variance and range of seed treatment test results, Exp. 3 (Seed Enhancement).

	1998			1999		
Lab Tests	Mean	CV	Range†	Mean	CV	Range
	% germination of seed tested					
PT-5						
Celpril	86.0	6.2	88.0 - 94.0	87.8	4.4	84.0 - 3.0
PAT	98.6	3.8	98.0 -100.0	84.0	7.5	76.0 - 89.0
TACH	61.0	13.6	56.0 - 66.0	79.3	4.2	75.0 - 83.0
PAT+TACH	83.6	21.6	76.0 - 96.0	77.5	3.9	73.0 - 79.0
Plain	98.0	4.8	96.0 - 100.0	95.5	1.8	94.0 - 98.0
PT-10						
Celpril	97.6	5.2	94.0 - 100.0	91.2	3.1	88.0 - 95.0
PAT	98.6	3.8	96.0 - 100.0	86.3	6.0	79.0 - 90.0
TACH	67.0	12.4	62.0 - 72.0	83.5	4.4	80.0 - 88.0
PAT+TACH	89.6	22.4	76.0 - 98.0	80.5	4.6	76.0 - 84.0
Plain	98.6	3.8	96.0 - 100.0	96.3	1.3	95.0 - 98.0
CT-5						
Celpril	97.0	3.9	92.0 - 100.0	95.0	3.6	92.0 - 100.0
PAT	91.0	5.2	84.0 - 94.0	88.0	9.3	78.0 - 98.0
TACH	93.0	1.2	92.0 - 94.0	93.5	4.7	90.0 - 100.0
PAT+TACH	97.0	1.2	96.0 - 98.0	78.0	7.5	72.0 - 84.0
Plain	95.0	2.7	92.0 - 98.0	97.0	3.6	92.0 - 100.0
CT-10						
Celpril	99.0	2.0	96.0 - 100.0	95.0	3.6	92.0 - 100.0
PAT	92.0	5.9	84.0 - 96.0	88.5	9.3	78.0 - 98.0
TACH	94.0	1.7	92.0 - 96.0	95.0	4.0	92.0 - 100.0
PAT+TACH	97.5	1.0	96.0 - 98.0	79.5	6.6	74.0 - 84.0
Plain	95.5	2.0	94.0 - 98.0	97.5	3.9	92.0 - 100.0

† The range of values is for all the replications.

The wide range between the pleated and cold test germination in Exp. 1 in 1998 showed the variation of seed quality. This is largely due to the impact of seed lots 18 and 10, which represented the lowest quality (Table 12). Although this may have been expected due to the age of these particular entries, the variation in seed quality for Exp. 1 in 1998 was also reflected by the larger coefficient of variation when compared with the other experiments (Table 8 - 11). Although viability tests usually do not detect vigor differences, they can be useful in determining some differences when such large variation in seed quality exists.

Most seed lots in Exp. 1 in 1999 and the other two experiments were of acceptable market quality, defined by the sugar beet industry as 92.0% or higher in the pleated germination test. Most lots in these studies would have been acceptable except seed lots 85, 91 and 96, which did not meet the criteria in our pleated germination test (Table 13).

Application of external stress to the seed holds promise as an additional means of measuring seed quality. In these experiments, three such tests were evaluated. Generally, there was a lower germination for the vigor tests than for the pleated test. Ten-day pleated germination averaged 92.5% across 20 entries in Exp. 1 in 1998, but none of the vigor tests averaged above 80.0% (Table 12). The sand emergence, accelerated aging over sodium bromide and cold test all had similar averages (77.1 - 79.6%). Accelerated aging over water had much lower values, with an average of 36.5%. This test was not particularly

Table 12. Laboratory test results for the 20 seed lots in Exp. 1 (Seed Quality), 1998.

Entry Number	Pleated Test		Cold Test		Sand Test		Accelerated Aging				Conductivity
							Water		NaBr		
	5 day	10 day	5 day	10 day	5 day	10 day	2 day	4 day	2 day	4 day	
	% germination of seed tested										$\mu S\ cm^{-1}g^{-1}$
1	93.8	95.8	71.0	76.0	60.5	74.0	2.50	25.5	23.5	71.5	574.5
2	97.0	97.8	74.0	76.0	85.5	90.5	68.5	73.0	34.5	95.0	435.4
3	91.8	93.3	79.5	80.0	75.5	82.0	6.00	41.0	38.0	89.5	534.5
4	93.8	94.5	85.0	85.0	76.0	84.0	14.0	56.0	53.0	87.5	394.5
5	93.0	96.3	96.5	98.5	79.5	95.5	1.50	31.0	69.0	86.5	525.9
6	91.3	95.0	87.0	89.0	75.3	67.5	7.00	42.5	35.0	83.0	466.2
9	98.3	98.5	90.5	91.0	98.0	99.5	46.0	74.0	62.0	98.5	358.9
10	65.0	69.3	38.5	42.0	49.0	58.0	11.0	22.0	2.50	53.0	423.9
11	91.8	92.0	70.5	71.0	83.5	91.0	21.5	50.5	34.5	84.0	476.6
14	89.3	92.0	79.0	81.5	76.5	86.5	23.0	56.0	28.5	54.0	565.0
15	93.3	96.3	73.0	76.0	66.5	83.5	7.50	40.5	26.0	83.0	575.9
16	94.8	96.8	83.0	84.5	84.5	89.0	31.0	56.5	34.0	89.0	472.5
17	94.8	95.5	84.5	84.5	72.0	83.5	12.0	39.5	44.5	87.0	590.4
18	24.0	64.8	4.00	14.0	3.00	35.0	0.00	1.50	0.00	14.0	310.7
20	85.0	92.0	65.0	71.5	74.0	68.0	5.00	18.5	1.00	71.0	514.1
21	94.8	97.8	82.5	84.0	59.5	76.5	12.0	33.0	36.5	96.0	528.6
52	88.5	93.8	86.5	94.0	58.5	77.5	0.50	21.0	8.00	68.0	374.9
54	91.8	96.5	96.0	100.0	50.5	74.0	3.50	18.0	16.5	74.0	440.8
56	90.3	94.8	94.5	95.0	70.5	87.0	0.00	15.5	15.0	76.5	542.3
57	95.3	96.8	93.5	94.5	72.0	89.5	1.00	15.0	10.0	81.5	497.4
Average	**87.9**	**92.5**	**76.7**	**79.5**	**68.5**	**79.6**	**13.7**	**36.5**	**28.6**	**77.1**	**480.1**

Table 13. Laboratory test results for the 20 seed lots in Exp. 1 (Seed Quality), 1999.

Entry Number	Pleated Test		Cold Test		Cold High Moisture Test		Conductivity
	5 day	10 day	5 day	10 day	3 day	6 day	
	% germination of seed tested						$\mu S\ cm^{-1}g^{-1}$
77	94.5	95.5	89.0	93.0	30.0	53.0	817.2
78	97.5	97.8	94.0	95.5	24.0	56.0	520.5
79	95.5	96.0	94.5	95.0	47.0	80.0	406.2
80	97.3	97.8	94.5	94.5	67.0	85.0	505.7
81	94.3	94.3	91.5	92.5	75.0	91.0	555.7
82	96.8	97.3	97.0	97.0	82.0	97.0	459.6
83	96.0	96.3	91.5	91.5	61.0	84.0	508.2
84	94.8	95.3	94.5	96.5	71.0	87.0	674.1
85	87.5	89.3	84.0	85.0	48.0	66.0	444.4
86	95.0	95.0	92.0	93.0	67.0	86.0	655.3
87	95.0	95.3	92.0	92.5	30.0	81.0	437.9
88	84.3	85.0	74.0	74.5	36.0	64.0	458.8
89	92.5	94.0	97.0	98.0	71.0	89.0	671.1
90	92.5	95.0	88.0	91.0	72.0	88.0	492.4
91	87.0	88.0	90.0	90.0	55.0	73.0	551.1
92	93.5	93.8	89.0	91.0	71.0	84.0	509.9
93	94.5	95.5	95.5	96.0	81.0	89.0	487.7
94	96.0	96.5	95.0	96.0	81.0	91.0	499.3
95	95.0	95.8	93.5	95.0	53.0	93.0	471.7
96	84.8	85.8	81.0	83.0	43.0	60.0	508.1
Average	93.2	94.0	90.9	92.0	58.3	79.9	531.7

Table 14. Laboratory test results for the nine seed lots in Exp. 2 (Seed Size).

Entry	Size	Pleated Test 5 day	Pleated Test 10 day	Cold Test 5 day	Cold Test 10 day	Cold High Moisture Test 3 day	Cold High Moisture Test 6 day	Sand Test 5 day	Sand Test 10 day	Accelerated Aging Water 2 day	Accelerated Aging Water 4 day	Accelerated Aging NaBr 2 day	Accelerated Aging NaBr 4 day	Conductivity
		% germination of seed tested												$\mu S\ cm^{-1}g^{-1}$
58	2	87.0	92.3	88.0	89.0	60.0	83.0	62.5	76.0	1.50	18.3	7.00	74.5	621.8
59	3	93.0	96.5	85.5	89.5	67.0	84.0	77.0	86.0	0.25	15.8	13.0	83.3	525.2
60	4	90.5	93.3	86.5	89.5	53.0	74.0	77.5	87.0	2.75	19.5	7.50	82.3	459.7
68	2	94.3	98.3	90.5	91.0	42.0	82.0	63.0	87.0	0.25	23.3	9.75	85.3	653.7
69	3	92.0	97.3	91.0	91.5	39.0	69.0	76.5	88.0	0.25	16.3	10.0	84.0	535.5
70	4	95.0	98.5	88.5	90.0	42.0	68.0	72.0	86.0	0.75	17.0	6.25	82.5	507.1
71	2	89.8	93.0	91.0	92.0	64.0	83.0	42.0	73.5	0.50	9.5	1.25	59.8	462.8
72	3	88.8	92.0	94.0	94.5	42.0	78.0	58.5	86.0	0.50	10.8	5.50	74.8	403.8
73	4	90.3	92.3	95.0	96.5	33.0	89.0	63.5	84.0	0.50	8.3	4.75	73.0	398.9
Average		**91.2**	**94.9**	**90.0**	**91.5**	**49.1**	**78.9**	**65.8**	**83.7**	**0.81**	**15.4**	**7.22**	**77.8**	**507.6**

Table 15. Laboratory test results for the five seed treatments in the Exp. 3 (Seed Enhancement), 1998 and 1999.

Seed Treatment	1998 Pleated Test 5 day	1998 Pleated Test 10 day	1998 Cold Test 5 day	1998 Cold Test 10 day	1999 Pleated Test 5 day	1999 Pleated Test 10 day	1999 Cold Test 5 day	1999 Cold Test 10day
	% germination of seed tested				% germination of seed tested			
Celpril	92.0	97.5	97.0	99.0	87.8	91.8	95.0	95.0
PAT	98.5	98.5	91.0	92.0	84.0	86.3	88.0	88.5
TACH	61.0	67.0	93.0	94.0	79.3	83.5	93.5	95.0
PAT+TACH	83.5	89.5	97.0	97.5	77.5	80.5	78.0	79.5
Plain Pellet	98.0	98.5	95.0	95.5	95.5	96.3	97.0	97.5

useful because of excessive mold development on some entries during incubation at 41.0°C. Similar results were found in the rest of the experiments. However, cold test results across seed lots in Exp. 1 (1999), 2 and 3 (1998 - 1999) were more than 10.0% higher than that of Exp. 1 in 1998 (Table 12 - 15). These higher results may have been due to temperature fluctuations (lower than 9.0°C) in the cold room and lack of proper maintenance of the soil moisture. Both factors have a direct effect on soilborne plant pathogens, which is thought to be the primary factor influencing the cold test germination (Woltz, *et. al.* 1998). This observation is also supported by the lower mean germination in the high moisture cold test for the same experiment (Table 13 and 14).

The conductivity test produced the lowest average conductance values in Exp. 1 in 1998 (480.1 $\mu S\ cm^{-1}\ g^{-1}$, Table 12). This was unexpected because Exp. 1 had the two lowest quality seed lots (entries 10 and 18). Low vigor seeds generally possess poor membrane structure and leaky cells, resulting in greater loss of electrolytes such as amino acids, inorganic ions and organic acids from seeds. These electrolytes increase conductivity in the soak water; therefore, a low vigor seed lot should posses the highest conductivity. However, this high conductance typically produced by low vigor seed lots was not observed (Table 12). Although the conductivity test on sugar beets has not been a good indicator of seed quality in previous investigations (Longden and Johnson, 1974 and Kraak *et al.*, 1984), a possible explanation for poor quality seed lots

producing a low conductance might have been due to a masking effect of seed size on conductance. In conductivity measurements of the soak water in which a bulk sample (75 seeds) had been steeped, seed size had a direct influence on the conductance. To illustrate the point, the size of this entry (# 18) was four (Table 1), the second largest of the four sugar beet sizes. Large seeds have a smaller surface area per unit weight, resulting in a lower diffusion rate than from small seed (Tao, 1978 and Bekendam, et al 1987). This observation was also confirmed in Exp. 2, in which smaller seed within the same variety had the highest conductivity of the three varieties tested (Figure 1). Otherwise there is large inconsistency in both conductivity and germination test results. However, another possibility for these results was the potential influence of seed treatment in the conductance of the water. Following the rationale explained above, seed from smaller size posses the largest amount of seed treatment per unit weight, thus perhaps influencing conductance. This emphasizes the need for standardization of vigor test procedures.

B. Simple Coefficients of Determination

Simple coefficients of determination were used to establish the relationship between field emergence and laboratory test results. Significant coefficients of determination of r^2 in excess of 0.500 occurred among results in Exp.1 and 2 (Tables 16, 17 and 18). A relationship of $r^2 = 0.787$ occurred between the 5- and 10-d germination periods for the sand emergence, and the

2- and 4-d counts of the accelerating aging test over water and NaBr in Exp. 1 in 1998 (Table 16). However, there was a better relationship within the 5- and 10-d counts for the pleated test (r^2 = 0.890) and a larger coefficient of determination between 5- and 10-d counts of the cold test (r^2 = 0.990). Similar results were found in 1999, where relationships between the pleated germination and cold test were r^2 = 0.980 and 0.966, respectively (Table 17). However, the high moisture old test had a 3- and 6-d coefficient of determination of just r^2 = 0.691. In Exp. 2 the relationships between pleated germination and cold test results were also high (r^2 = 0.853 and r^2 = 0.875). Smaller coefficients (r^2 < 0.780) occurred

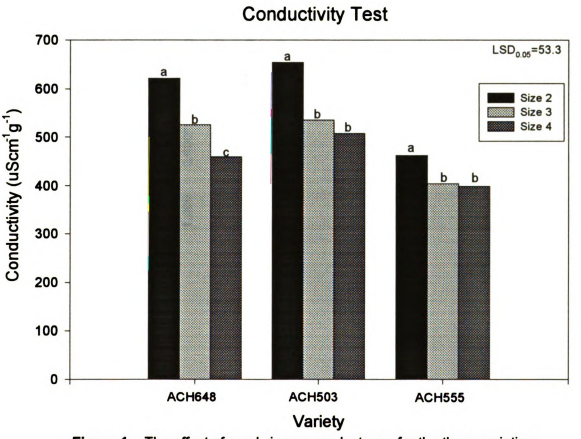

Figure 1. The effect of seed size on conductance for the three varieties tested on Exp. 2.

Table 16. Simple coefficients of determination r^2 among laboratory test results for Exp.1 (Seed Quality), 1998.

Lab Tests	PT-5	PT-10	CT-5	CT-10	ST-5	ST-10	AA-2	AA-4	AANaBr-2	AANaBr-4	COND
PT-5	1.000	0.890*	0.822*	0.786*	0.734*	0.737*	0.080	0.285*	0.282*	0.804*	0.254*
PT-10		1.000	0.825*	0.820*	0.581*	0.661*	0.057	0.216*	0.283*	0.726*	0.208*
CT-5			1.000	0.990*	0.530*	0.658*	0.005	0.111	0.265*	0.620*	0.153
CT-10				1.000	0.472*	0.602*	0.001	0.079	0.220*	0.560*	0.139
ST-5					1.000	0.787*	0.270*	0.556*	0.397*	0.690*	0.107
ST-10						1.000	0.185*	0.401*	0.435*	0.647*	0.126
AA-2							1.000	0.705*	0.147	0.647	0.047
AA-4								1.000	0.482*	0.361	0.000
AANaBr-2									1.000	0.442*	0.019
AANaBr-4										1.000	0.110
COND											1.000

* Significant at the $p \leq 0.05$.

Table 17. Simple coefficients of determination r^2 among laboratory test results for Exp. 1 (Seed Quality) 1999.

Lab Tests	PT-5	PT-10	CT-5	CT-10	CTHM-3	CTHM-6	COND
PT-5	1.000	0.980*	0.703*	0.718*	0.078	0.227*	0.011
PT-10		1.000	0.718*	0.750*	0.095	0.240*	0.013
CT-5			1.000	0.966*	0.210*	0.362*	0.020
CT-10				1.000	0.183	0.297*	0.062
CTHM-3					1.000	0.691*	0.000
CTHM-6						1.000	0.039
COND							1.000

* Significant at the $p \leq 0.05$.

Table 18. Simple coefficients of determination r^2 among laboratory test results for Exp. 2 (Seed Size).

Lab Tests	PT-5	PT-10	CT-5	CT-10	CTHM3	CTHM6	ST-5	ST-10	AA-2	AA-4	AANaBr-2	AANaBr-4	COND
PT-5	1.000	0.853*	0.062	0.049	0.059	0.148	0.187	0.355	0.126	0.138	0.208	0.366	0.066
PT-10		1.000	0.133	0.201	0.022	0.243	0.218	0.245	0.139	0.379	0.348	0.455*	0.324
CT-5			1.000	0.875*	0.465*	0.060	0.257	0.001	0.201	0.157	0.280	0.170	0.212
CT-10				1.000	0.376	0.138	0.152	0.003	0.163	0.268	0.214	0.156	0.434
CTHM-3					1.000	0.064	0.028	0.314	0.048	0.009	0.006	0.088	0.048
CTHM-6						1.000	0.220	0.199	0.037	0.009	0.023	0.216	0.002
ST-5							1.000	0.576*	0.067	0.248	0.611*	0.780*	0.023
ST-10								1.000	0.004	0.092	0.397	0.720*	0.003
AA-2									1.000	0.000	0.013	0.006	0.005
AA-4										1.000	0.487*	0.502*	0.779
AANaBr-2											1.000	0.717*	0.258
AANaBr-4												1.000	0.170
COND													1.000

* Significant at the $p \leq 0.05$.

among the other test results (Table 18), however, coefficients for the high moisture cold test and accelerated aging test over water were not significant. These data suggest that a 5-d count may be sufficient for the pleated germination and cold tests, but the longer period is needed for the other tests.

There was not a close coefficient of determination among results of the various tests for the two experiments ($r^2 < 0.830$, Table 16 - 19). However, the highest coefficient was between the pleated germination and cold test ($r^2 = 0.825$) in Exp. 1 in 1998. A similar coefficient ($r^2 = 0.804$) occurred between results of the pleated germination and accelerated aging over NaBr for the same experiment. Also, a relationship of $r^2 \leq 0.737$ occurred between results of the sand test and the pleated test. In Exp. 1 in 1999 the coefficient of determination between the pleated germination and cold test results was lower than expected ($r^2 = 0.750$), but was the highest among tests for that year (Table 17). Coefficients between the pleated germination and cold test results in Exp. 2 were not significantly different. The coefficient of determination between sand test and accelerated aging results over sodium bromide was of 0.780 for the same experiment. Results of Exp. 1 in both years support the use of the cold test as an indicator of viability, confirming observations of Akeson and Widner (1980) and Lovato and Cagalli (1992).

Conductivity test results were poorly correlated with other test results in all experiments ($r^2 \leq 0.254$). Sugar beet seeds consist of thick outer pericarp layers that disable the easy flow of the leakage of organic substances from the endosperm to the epidermis. The lack of significant coefficients of determination

between the conductivity test and other test results confirmed the research of Kraak, *et al.* (1984) and Bekendam, *et al* (1987).

II. Relationship Between Laboratory Test and Field Emergence

A. Simple Coefficients of Determination

Simple linear coefficients of determination were computed among all laboratory results and field emergence for Exp. 1 and 2, but not for Exp. 3 because of inadequate data points collected. Many significant coefficients of determination greater than 0.500 occurred in Exp. 1 in 1998 (Table 19), but only a few for the same experiment in 1999 and Exp. 2 (Table 20, 21 and 22). This is consistent with observations from studies by Burris (1976) and Durrant *et al.* (1984). They found when seed lots with poor viability were included, coefficients of determination between field emergence and laboratory results were higher than when only seed of acceptable market quality was used.

The 5-d cold test had the highest coefficient of determination ($r^2 = 0.917$) for the final count at the Metea location in Exp. 1, 1998 (Table 19). In all three locations the cold test and pleated germination test had the higher coefficients. In contrast, the conductivity test and the accelerated aging test over water had lower coefficients ($r^2 \leq 0.467$). The highest significant coefficient with field emergence of $r^2 = 0.588$ occurred for the 10-d pleated test in the same experiment in 1999 (Table 20). Although lower than $r^2 = 0.500$, the cold

Table 19. Simple coefficients of determination r^2 between laboratory test results and % field emergence as influenced by location for Exp. 1 (Seed Quality), 1998.

Location	Dap†	Laboratory Tests										
		PT-5	PT10	CT-5	CT-10	ST-5	ST-10	AA-2	AA-4	AANaBr-2	AANaBr-4	COND
Misteguay												
First Count	17	0.579*	0.517*	0.569*	0.509*	0.615*	0.594*	0.195	0.420*	0.371*	0.498*	0.038
Final Count	30	0.673*	0.664*	0.689*	0.649*	0.629*	0.570*	0.120	0.368*	0.393*	0.598*	0.087
Average‡	--	0.662*	0.629*	0.674*	0.616*	0.640*	0.605*	0.146	0.393*	0.385*	0.569*	0.077
Metea												
First Count	13	0.577*	0.542*	0.667*	0.601*	0.367*	0.566*	0.015	0.197*	0.467*	0.543*	0.148
Final Count	26	0.780*	0.767*	0.917*	0.886*	0.472*	0.598*	0.000	0.104	0.265*	0.600*	0.210*
Average	--	0.733*	0.707*	0.853*	0.865*	0.607*	0.752*	0.045	0.150	0.365*	0.614*	0.212*
Kilmanagh												
First Count	12	0.715*	0.742*	0.743*	0.704*	0.408*	0.595*	0.037	0.142	0.276*	0.630*	0.265*
Final Count	29	0.605*	0.681*	0.572*	0.586*	0.402*	0.544*	0.042	0.100	0.121	0.457*	0.053
Average	--	0.832*	0.879*	0.802*	0.790*	0.550*	0.712*	0.053	0.165	0.236*	0.687*	0.162

* Significant at the $p \leq 0.05$.
† Days after planting.
‡ Average of all stand counts within location.

Table 20. Simple coefficients of determination r^2 between laboratory test results and % field emergence as influenced by location for Exp. 1 (Seed Quality), 1999.

Location	Dap†	Laboratory Tests						
		PT-5	PT10	CT-5	CT-10	CHM-3	CHM-6	COND
Misteguay								
First Count	12	0.345*	0.335*	0.207*	0.149	0.163	0.295*	0.026
Final Count	34	0.577*	0.588*	0.392*	0.361*	0.198*	0.429*	0.014
Average‡	--	0.501	0.498	0.325	0.273	0.191	0.396	0.014
Metea								
First Count	14	0.099	0.094	0.241*	0.210*	0.307*	0.256*	0.119
Final Count	39	0.403*	0.383*	0.485*	0.474*	0.362*	0.436*	0.117
Average	--	0.294*	0.277*	0.414*	0.387*	0.359*	0.394*	0.116
Capac								
First Count	10	0.047	0.056	0.047	0.067	0.024	0.000	0.006
Final Count	28	0.041	0.036	0.003	0.001	0.049	0.033	0.019
Average	--	0.056	0.057	0.005	0.013	0.057	0.020	0.002

* Significant at the $p \leq 0.05$.
† Days after planting.
‡ Average of all stand counts within location.

Table 21. Simple coefficients of determination r^2 between laboratory test results and % field emergence as influenced by location for Exp. 2 (Seed Size), 1998.

		Laboratory Tests												
Location	Dap†	PT-5	PT-10	CT-5	CT-10	CTHM3	CTHM6	ST-5	ST-10	AA-2	AA-4	NaBr-2	NaBr-4	COND
Misteguay														
First Count	17	0.212	0.287	0.306	0.325	0.002	0.257	0.340	0.029	0.118	0.227	0.059	0.217	0.110
Final Count	30	0.061	0.067	0.151	0.109	0.027	0.106	0.381	0.071	0.124	0.123	0.056	0.228	0.009
Average‡	--	0.128	0.155	0.235	0.206	0.014	0.209	0.410	0.054	0.145	0.153	0.054	0.230	0.030
Metea														
First Count	19	0.000	0.028	0.400	0.480	0.428	0.000	0.010	0.229	0.022	0.044	0.001	0.007	0.215
Final Count	26	0.003	0.014	0.439	0.442	0.400	0.032	0.001	0.158	0.083	0.000	0.007	0.011	0.037
Average	--	0.007	0.036	0.433	0.486	0.390	0.025	0.003	0.163	0.000	0.006	0.001	0.005	0.102
Kilmanagh														
First Count	12	0.041	0.161	0.001	0.061	0.001	0.004	0.109	0.007	0.069	0.232	0.005	0.013	0.509
Final Count	29	0.184	0.056	0.091	0.116	0.413	0.290	0.059	0.167	0.006	0.081	0.062	0.020	0.262
Average	--	0.124	0.029	0.135	0.160	0.336	0.372	0.029	0.201	0.030	0.216	0.054	0.007	0.393

* Significant at the $p \leq 0.05$.
† Days after planting.
‡ Average of all stand counts within location.

Table 22. Simple coefficients of determination r^2 between laboratory test results and % field emergence as influenced by the time of planting for Exp. 2 (Seed Size), 1999.

Location	Dap†	Laboratory Tests												
		PT-5	PT-10	CT-5	CT-10	CTHM3	CTHM6	ST-5	ST-10	AA-2	AA-4	NaBr-2	NaBr-4	COND
Metea														
Early Planting														
First Count	17	0.389	0.226	0.225	0.368	0.255	0.001	0.004	0.204	0.072	0.185	0.040	0.002	0.465*
Final Count	37	0.027	0.239	0.656*	0.857*	0.275	0.077	0.140	0.012	0.045	0.475*	0.297	0.158	0.668*
Average‡	--	0.026	0.222	0.687*	0.873*	0.307	0.070	0.130	0.019	0.271	0.439	0.264	0.134	0.635*
Metea														
Late Planting														
First Count	8	0.100	0.183	0.162	0.166	0.000	0.013	0.311	0.253	0.022	0.458*	0.562*	0.469*	0.297
Final Count	37	0.004	0.035	0.634*	0.654*	0.193	0.160	0.150	0.003	0.357	0.074	0.040	0.094	0.100
Average	--	0.013	0.000	0.215	0.277	0.175	0.106	0.004	0.193	0.148	0.014	0.087	0.038	0.004
Misteguay														
Late Planting														
First Count	12	0.082	0.000	0.022	0.035	0.008	0.003	0.128	0.000	0.020	0.113	0.192	0.052	0.068
Final Count	34	0.004	0.060	0.241	0.286	0.020	0.056	0.424	0.070	0.019	0.417	0.542*	0.374	0.275
Average	--	0.007	0.052	0.169	0.211	0.016	0.032	0.340	0.050	0.001	0.374	0.497*	0.305	0.253

* Significant at the $p \leq 0.05$.
† Days after planting.
‡ Average of all stand counts within location.

test produced the second best coefficient for this experiment. The high moisture cold test performed no better than the standard cold test, for which the highest coefficient (r^2 = 0.394) occurred at the Metea location. The conductivity test did not produce significant coefficients with field emergence at any of the three locations and no significant coefficients for any test at the Capac location.

Coefficients of determination at all three locations for Exp. 2 in 1998 were low and not significant (Table 21), perhaps due to the small sample size (n=9), smaller vigor differences and generally higher quality seed than that used in Exp. 1 in 1998. Although not significant, the cold test results had the highest coefficients with field emergence at all locations for Exp. 2 in 1998. Few significant coefficients occurred for Exp. 2 in 1999 (Table 22). However, there was a better coefficient between the 10-d cold test and field emergence at the early sowing compared to the late sowing (r^2 = 0.857 vs. r^2 = 0.654) for the same number of days after planting. Surprisingly, the conductivity test had slightly lower significant coefficients of determination with field emergence than the cold test for the early planting, however, at the late planting, none of the conductivity coefficients were significant. These results could be due to the favorable soil conditions for the early planting.

Comparisons from all experiments showed that the cold test had the highest or second highest coefficient of determination with field emergence. Since the cold test measures emergence under artificially induced cold soil conditions it would be expected to correlate well with performance under field stress conditions, especially at the early planting of Exp. 2 in 1999 (Akeson and

Widner, 1980; Kraak *et al.*, 1984). The better soil environment simulates the conditions used to demonstrate the vigor response in the laboratory, resulting in better coefficients between cold test vigor and field emergence.

While coefficients of determination between pleated germination test results and field performance were highly significant in Exp. 1 in 1998, they were usually lower than those for all the experiments. These results agree with those of several other authors who have concluded that the standard germination test is reliable for predicting plant establishment of sugar beets in the field (Kraak *et al.*, 1984; Durrant, Brown and Bould, 1985).

The coefficients of determination between field emergence and sand test results were the third highest for Exp.1 in 1998 (Table 19), however, such coefficients were not achieved in any subsequent year or experiment. This is contrary to results obtained by Akeson and Widner (1980) in which sand test results for sugar beets were highly correlated with field emergence (r^2 = 0.792 - r^2 = 0.960).

Aging, which is considered to be a major cause of reduced vigor in seeds (Perry, 1972), also failed to result in high correlation between laboratory tests and field emergence (Durrant *et al.* 1984; Kraak, and Vos, 1987). However, the physiological changes during the accelerated aging test may be different from those produced by normal aging processes. The low correlation with field emergence is in striking contrast with results cited earlier for large-seeded crops such as corn and soybean in which the accelerated aging test over water is an important seed vigor test. However, its value for small-seeded crops has been

limited because moisture uptake is too rapid, resulting in rapid seed deterioration for some species. Therefore, the accelerated aging over NaBr which only provided a relative humidity of 55.0% vs. ~ 100.0% over water showed significant coefficients of determination only in Exp. 1 in 1999.

Measurement of the exudation of inorganic and organic electrolytes into water provides a rapid method for testing viability (Takayanagi and Murakami, 1968), however, for small-seed crops this measurement may not be useful (Longden, and Johnson, 1974; Kraak, and Vos, 1987). With the exception of the early planting in Exp. 2 in 1999, the conductivity test was poorly correlated with field emergence. Although this test is very convenient and can be completed in one day, its use in predicting field establishment does not merit further attention.

No single laboratory test consistently had the highest simple linear coefficient of determination with field emergence for all stand counts over all locations. This is consistent with the opinion of many scientists that a single laboratory test simply cannot correlate well with field emergence over the entire range of possible planting conditions. Although these data confirm this hypothesis, they also show correlations between field emergence and different laboratory test results.

B. Stepwise Multiple Regression Analysis

Laboratory and field emergence results were analyzed using a multiple stepwise regression technique. Results in Exp. 1 in 1998 (Table 23) show very good multiple coefficients of determination (R^2) between 0.814 and 0.879.

Table 23. Independent variables significantly contributing (p≤0.05) to a stepwise multiple regression equation of laboratory tests and the dependent variable % field emergence (mean of all sowing occasions) and the multiple coefficients of determination for these equations, as influenced by location for 1998, Exp. 1 (Seed Quality).

Location	Independent Variables[†]	R^2
Misteguay	CT5 + AA4	0.814
Metea	CT5[‡]	0.853
Kilmanagh	PT10[‡]	0.879

[†]CT5= Cold Test 5-d count.
AA4= Standard Accelerated Aging Test 4-d count.
PT10= Pleated Test.
[‡]Simple coefficients of determination (r^2) generated by the equation.

Table 24. Independent variables significantly contributing (p≤0.05) to a stepwise multiple regression equation of laboratory tests and the dependent variable % field emergence (mean of all sowing occasions) and the multiple coefficients of determination for these equations, as influenced by location for 1999, Exp. 1 (Seed Quality).

Location	Independent Variables[†]	R^2
Misteguay	PT5 + CHM6	0.611
Capac	CT5 + CHM3	0.531
Metea	PT5 + CT5 + CHM3	0.211^{ns}

ns= not significant at the 5.0% level.
[†]CHM3= High Moisture Cold Test 3-day count, CHM6= High Moisture Cold Test 6-day count.

Table 25. Independent variables significantly contributing (p≤0.05) to a stepwise multiple regression equation of laboratory tests and the dependent variable % field emergence (mean of all sowing occasions) and the multiple coefficients of determination for these equations, as influenced by location for 1998, Exp. 2 (Seed Size).

Location	Independent Variables[†]	R^2
Misteguay	ST5 + AANaBr2 + COND	0.800
Metea	CT10[‡]	0.486
Kilmanagh	PT10 + CT5 + CHM6 + COND	0.980

[†]ST5= Sand Test 5-d count.
AANaBr2= Accelerated Aging Over NaBr 2-d count.
COND= Conductivity Test.
CHM6= High Moisture Cold Test 6-d count.
[‡] Simple coefficient of determination (r^2) generated by the equation.

Table 26. Independent variables significantly contributing (p≤0.05) to a stepwise multiple regression equation of laboratory tests and the dependent variable % field emergence (mean of all sowing occasions) and the multiple coefficients of determination for these equations, as influenced by location for 1999, Exp. 2 (Seed Size).

Location	Independent Variables	R^2
Misteguay	AANaBr2	0.497
Capac		
Early Planting	CT10[‡]	0.873
Late Planting	CT10 + AANaBr2	0.645

[‡] Simple coefficient of determination (r^2) generated by the equation.

Table 27. Multiple coefficients of determination (R^2) for regression equations having Pleated Test 10-d count and Cold Test 10-d count as the independent variables predicting % field emergence for Exp. 1 (Seed Quality).

1998		1999	
Location	R^2	Location	R^2
Misteguay	0.654^{ns}	Misteguay	0.530^{ns}
Metea	0.806^{ns}	Metea	0.090^{ns}
Kilmanagh	0.888^{ns}	Capac	0.388^{ns}

ns= not significant at the 5.0% level.

Table 28. Multiple coefficients of determination (R^2) for regression equations having Pleated Test 10-d count and Cold Test 10-d count as the independent variables predicting % field emergence for Exp. 2 (Seed Size).

1998		1999	
Location	R^2	Location	R^2
Misteguay	0.251^{ns}	Misteguay	0.212^{ns}
Metea	0.504^{ns}	Capac	
		Early Planting	0.876^{ns}
		Late Planting	0.359^{ns}
Kilmanagh	0.313^{ns}	Metea	0.119^{ns}

ns= not significant at the 5.0% level.

The 5-d cold test was the significant variable in two of the three locations in Exp. 1. However, the 10-d pleated test alone accounted for 87.9% of the total variability for the Kilmanagh location.

The high moisture cold test appeared in three regression equations for Exp. 1 in 1999 (Table 24), with R^2 values ranging from 0.211 (not significant at $P \leq 0.05$) for the Capac location to 0.611 (significant at $P \leq 0.05$) for Misteguay. Although the high moisture cold test did not by itself have a high simple linear coefficient of determination with field emergence, along with the 5-d pleated germination or 5-d cold test, it made a significant contribution to the multiple coefficients of determination equations, explaining about 11.0% of the variation for this experiment.

The highest and the lowest R^2 values of 0.980 and 0.486 occurred for the Kilmanagh and Metea locations, respectively, for Exp. 2 in 1998 (Table 25). Again, the cold test appeared in the multiple coefficient of determination equation for two of the three locations, and the conductivity test made a significant contribution in two of the three equations. However, the conductivity test was not by itself significantly correlated with field emergence at any location.

The coefficient of multiple determination for Exp. 2 in 1999 (Table 26) was lower than that of the same location for 1998 (Misteguay). However, the 2-d accelerated aging over sodium bromide test accounted for more than twice the variability in 1999 than in 1998 for the same experiment. Furthermore, the 10-d cold test appeared as an independent variable for two of the three locations. Early planting had a higher coefficient of determination than late planting at 0.873

and 0.645, respectively, for the Capac location in the same experiment. Cooler soil and better soil conditions were factors that contributed to a higher R^2 value, confirming observations by Kraak, et al. (1984) and Payne and Williams (1990). High soil temperature and moisture during seedling development favor growth of *Aphanomyces cochlioides* and thus the incidence of infection. This is specially true for late plantings with warmer temperatures at which may lead to partial or complete stand establishment failure in some years. Damping-off caused by *Pythium spp.* is less frequent in the field, but may be under-reported because infected seedlings die before or soon after emergence.

Since the cold and pleated germination tests appeared in most of the stepwise multiple coefficients of determination, equations with these two variables were computed for all locations for both experiments in both years. However, Table 27 and 28 show that the R^2 values were not significant, and no better than those for the stepwise multiple regression equations when all other tests were included.

The use of a combination of tests to predict field emergence of sugar beet has been suggested by other investigators (Longden, and Johnson 1974; Kraak, *et al.* 1984; Yaklich and Kulik 1979; Durrant, *et al.* 1984; Lovato and Cagalli 1992). Likewise, in soybeans, Yaklich (1979) used the best R^2 values from all possible multiple regression equations to evaluate the usefulness of similar vigor tests. By using a number of laboratory tests to measure several different aspects of vigor, test combinations having high R^2 values have been found that will predict field emergence results under similar seedbed conditions. However,

vigor test results reflect the conditions of the individual test and may not explain all the processes and reactions occurring at the field level.

III. Influence of seed size on germination and field emergence (Exp. 2)

A. Laboratory Tests:

In most comparisons, seed size was not significantly associated with pleated seed germination (Table 29). The cold test did not produce significant differences among seed sizes. Three-day high moisture cold test results on seed size two was significantly different than on those of size four for the variety ACH55. Two of the three varieties showed a significant difference in the sand test performance between seed sizes two and four. Few differences also occurred among seed sizes in the accelerated aging test, however, little consistency occurred among results of accelerated aging tests over water vs. sodium bromide. Significant differences in conductivity test results between the smallest and largest seed sizes (two and four) occurred for the three varieties tested. Surprisingly, the smallest seed size produced the highest conductance and vice versa, however, an explanation for the masking effect of seed size on the conductance of water was previously explained in section IA.

B. Field Emergence:

Contrary to findings by Lexander (1981) and Akeson (1981), seed size did not have a significant overall influence on field emergence in 1998 (Table 30). The 12-d Kilmanagh and Misteguay 23-d counts for the ACH503 variety were the

only comparisons that produced significant emergence differences between size two and four for the same year. In 1999 the early planting produced no significant differences in emergence due to seed size, which is consistent with 1998 findings (Table 31). However, in the late planting most of the comparisons produced significant differences in emergence due to seed size. Although no relative ranking was made, significant differences between seed size two and four occurred in almost all of the comparisons.

Many growers believe that larger seeds have better emergence potential than smaller ones, however, my research did not support this belief. Although larger seeds had significantly higher emergence at the late planting in 1999, this "grower belief" can not be consistently confirmed because such late planting dates are not feasible. Akeson (1981) also reported no differences in field performance for seed size of 3.6 - 4.0-mm vs. 3.2 - 3.6-mm. Lodgen (1986) indicated that large seeds did not necessarily germinate better than small ones since large seeds could be a result of increased pericarp volume alone.

IV. Influence of Seed Treatment on Field Emergence (Exp. 3)

All seed treatments produced higher emergence than the standard Celpril treatment (film coating with Thiram) for all counts at the early planting (4/15) in 1998. However, the priming advanced treatment (PAT) resulted in earlier emergence than any other treatment. At the 11-d count, PAT-treated seed emerged 97.7%, more than the standard treatment with Celpril (Figure 2). Celpril treated seed always had the lowest emergence for this planting date. Although

Table 29. Seedling germination as influenced by seed size and variety in laboratory tests.

Variety	Size	Pleated Test		Cold Test		Cold High Moisture Test		Sand Test		Accelerated Aging: Water		Accelerated Aging: NaBr		Conductivity
		5 day	10 day	5 day	10 day	3 day	6 day	5 day	10 day	2 day	4 day	2 day	4 day	
		% germination of seed tested												$\mu Scm^{-1}g^{-1}$
ACH648	2†	87.0b‡	92.3a	88.0a	89.0a	60.0a	83.0a	62.5b	76.0b	1.5a	18.3ab	7.0 a	74.5b	621.8a
	3	93.0a	96.5a	85.5a	89.5a	67.0a	84.0a	77.0a	86.0a	0.3a	15.8b	13.0 a	83.3a	525.2b
	4	90.5ab	93.3a	86.5a	89.5a	53.0a	74.0a	77.5a	87.0a	2.8a	19.5a	7.5 a	82.3ab	459.7c
ACH503	2	94.3a	98.3a	90.5a	91.0a	42.0a	82.0a	63.0b	87.0a	0.3a	23.3a	9.8 a	85.3a	653.7a
	3	92.0a	97.3a	91.0a	91.5a	39.0a	69.0a	76.5a	88.0a	0.3a	16.3b	10.0 a	84.0a	535.5b
	4	95.0a	98.5a	88.5a	90.0a	42.0a	68.0a	72.0ab	86.0a	0.8a	17.0b	6.3 a	82.5a	507.1b
ACH555	2	89.8a	93.0a	91.0a	92.0a	64.0a	83.0a	42.0b	73.5b	0.5a	9.5a	1.3 a	59.8b	462.8a
	3	88.8a	92.0a	94.0a	94.5a	42.0ab	78.0a	58.5a	86.0a	0.5a	10.8a	5.5 a	74.8a	403.8b
	4	90.3a	92.3a	95.0a	96.5a	33.0b	89.0a	63.5a	84.0a	0.5a	8.3a	4.8 a	73.0a	398.9b

† 2 = smallest, 4 = largest seed size as defined in materials and methods.

‡ Values within the same variety with different letters are significantly different at the 5.0% level.

Table 30. Seedling emergence as influenced by seed size, variety, location and days after planting in 1998.

Variety	Size	Misteguay			Metea			Kilmanagh		
		17†	23	30	13	19	26	12	22	29
		% of seed planted								
ACH648	2	28.9 a‡	44.0 a	40.5 a	54.6 a	56.5 a	61.1 a	49.1 a	38.1 a	37.1 a
	3	31.5 a	46.3 a	43.3 a	57.4 a	56.9 a	62.0 a	39.2 a	39.7 a	39.2 a
	4	27.8 a	42.6 a	42.1 a	61.7 a	57.6 a	63.8 a	38.6 a	43.3 a	42.4 a
ACH503	2	32.4 a	51.2 a	47.5 a	60.6 a	58.6 a	66.5 a	61.9 a	40.5 a	39.2 a
	3	28.9 a	45.4 ab	45.8 a	63.9 a	60.4 a	65.9 a	44.4 b	47.9 a	44.0 a
	4	22.2 a	36.6 b	35.4 a	55.8 a	53.5 a	59.3 a	45.7 b	51.7 a	49.4 a
ACH555	2	35.0 a	52.5 a	51.9 a	58.6 a	56.7 a	62.5 a	46.8 a	42.7 a	40.7 a
	3	40.5 a	53.2 a	47.7 a	62.0 a	58.5 a	65.5 a	47.0 a	45.9 a	42.5 a
	4	31.9 a	45.1 a	42.4 a	64.7 a	61.7 a	68.1 a	37.6 a	50.4 a	49.8 a

† Days after planting.

‡ Values within the same variety with different letters are significantly different at the 5.0% level.

Table 31. Seedling emergence as influenced by seed size, variety and time of planting in 1999.

Variety	Size	Early Planting (4/14)†					Late Planting (5/3) †				
		17§	23	30	37	42	8	14	21	31	37
		% of seed planted									
ACH648	2	9.8 a‡	15.4 a	17.7 a	16.7 a	17.1 a	36.4 b	67.5 a	69.0 a	61.3 b	50.6 a
	3	10.8 a	18.1 a	19.0 a	19.6 a	20.6 a	44.0 ab	73.8 a	77.9 a	72.5 a	55.8 a
	4	15.4 a	19.6 a	21.0 a	22.1 a	21.5 a	47.1 a	73.5 a	75.8 a	65.6 ab	52.1 a
ACH503	2	12.1 a	18.3 a	21.3 a	21.3 a	21.7 a	51.7 a	82.1 a	81.7 a	75.0 a	62.3 a
	3	11.2 a	17.7 a	20.4 a	20.2 a	20.8 a	47.7 a	77.7 a	78.5 ab	76.5 a	63.8 a
	4	11.3 a	18.1 a	20.8 a	21.9 a	22.9 a	28.5 b	62.9 b	69.4 b	60.4 b	49.4 b
ACH555	2	10.6 a	19.4 a	22.3 a	24.4 a	24.2 a	29.4 a	71.5 a	74.2 b	69.0 b	62.7 a
	3	16.5 a	24.0 a	30.0 a	29.4 a	28.5 a	30.4 a	77.5 a	80.6 ab	75.4 ab	61.9 a
	4	15.0 a	24.0 a	29.2 a	30.6 a	29.6 a	32.5 a	79.2 a	85.8 a	82.9 a	67.7 a

† Both planting date were planted in the Misteguay soil series.
‡ Values within the same variety with different letters are significantly different at the 5.0% level.
§ Days After Planting.

the relative ranking among the other treatments was not consistent, all the seed treatments induced similar emergence to that of PAT treated seed at the later counts. At the last count (44-d) the PAT and Plain Pelleted seed emerged 60.0%, which was approximately 10.0% higher than Celpril treated seed. However, none of the seed treatments were able to meet the goal of the so-called "crop success" of 70.0%.

In the late planting (5/15) in 1998, overall trends in stand establishment were similar to those in the early planting, however, the stands for all seed treatments were significantly lower. Again, PAT treated seed emerged earlier than that of other treatments. Nineteen days after planting, 10.8% of seedlings from PAT treated seed had emerged, compared with only 2.6% of those from the Celpril treatment (Figure 2). However, the other three seed treatments induced similar emergence to that of PAT treated seed at later counts. Furthermore, the difference among treatments was not significant at the 38-d, 42-d and 45-d counts.

Priming has been shown to increase the earliness and uniformity of sugar beet seedling emergence (Durrant *et al.* 1983, Longden *et al.* 1979, Osburn, and Schroth, 1988), resulting in a lower incidence of seedling loss due to damping-off pathogens such as *Pythium ultimum* Trow (Harman and Taylor, 1988; Osburn, and Schroth, 1988 and 1989; and Rush 1991 and 1992). *Pythium spp.* is a soilborne pathogen that can infect the seed very quickly after planting, inhibiting germination and resulting in poor stands from both pre-emergence and post-emergence damping-off. However, the pre-emergence phase is more common.

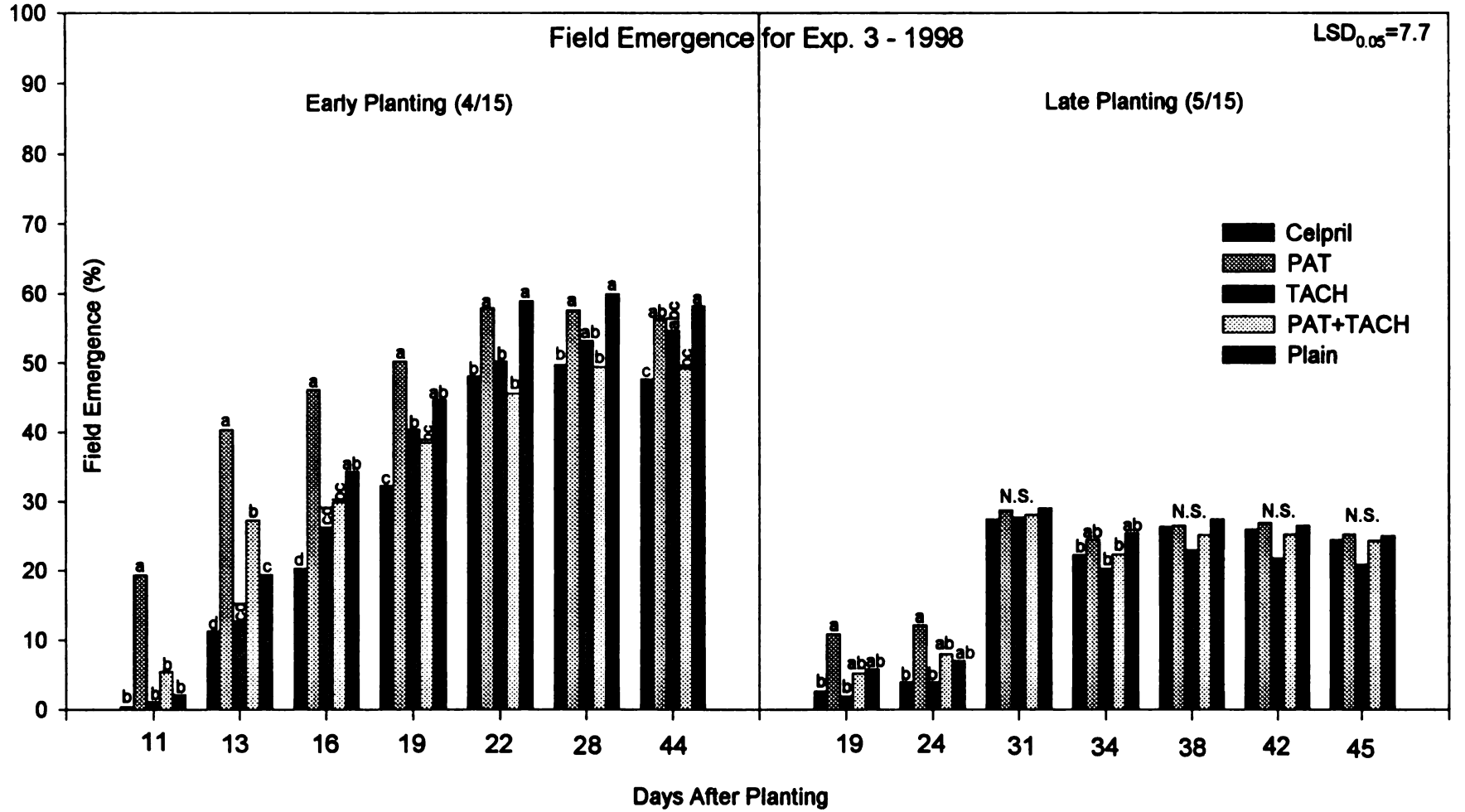

Figure 2. Influence of seed treatments and time of planting on field emergence for Exp. 3 in 1998

Protection against *Pythium ultimum* has been attributed to escape, reduction in seed exudates and a decrease in indigenous bacteria on primed seed (Leach, 1947; Leach and Smith, 1945; Osburn and Schroth, 1989). Although seed priming can reduce loss to seedling infection by *Pythium ultimum*, seedling disease caused by *Aphanomyces cochlioides* is not affected (Rush, 1992). *A. cochlioides* is a warm-temperature pathogen which typically infects the hypocotyls of sugar beet seedlings after emergence and is dependent on almost saturated soil for zoospore movement and infection (Buchholtz, 1944a and 1944b, McKeen, 1949; Papavizas and Ayers, 1974). However, in these studies, Celpril coated seed was not as effective as PAT against soilborne pathogens, especially in the late planting. Thiram is thought to be more effective against seedborne pathogens (like *Phoma betae*) rather than soilborne pathogens (Durrant, *et al.*, 1988, Payne, and Williams, 1990). However, there is a possibility that steeping seed in Thiram could exert some control on soilborne pathogens from either a fungicidal effect (Maude, 1983) or as a result of increased seedling vigor, reducing the period during which seedlings are susceptible to infection (Durrant, *et al.*, 1988). However, earlier studies showed that when Thiram and hymexazol are present in a seed pellet, protection against *Phoma betae*, *Phoma spp.* and *A. cochlioides* might be achieved, depending on the relative amount of soilborne pathogens present (Payne, and Williams, 1990).

Although similar stand establishment levels occurred at both planting dates, the overall mean emergence was much lower at the late planting. For example, plain pelleted seed had the highest emergence at 28.8% for the late

planting (31-d count) compared to 59.9% (28-d count) for the early planting. Colder temperatures during the first planting and warmer temperatures at the late planting, along with 36 mm of rain in the week before late planting and poorly drained soil conditions all contributed significantly to the lower stand counts for all seed treatments at the late sowing. *A. cochlioides* and *Pythium spp.* alone or in combination are frequently cited as significant causes of seedling loss in different countries (Dunning and Heijbroek, 1981, Papavizas and Ayres, 1974; Yanaguchi, 1977). However, *Pythium spp.* which attacks younger seedlings appears only briefly and do not cause major crop losses (Payne, and Williams, 1990). In contrast, the warm-temperature pathogen *A. cochlioides*, can cause detrimental effects by infecting the tap root and fibrous root system of the developing crop under high temperature and wet soil conditions (Papavizas and Ayres, 1974).

In a survey of fungi causing seedling diseases conducted in Europe in the early 1980's, *A. cochlioides* and *Pythium spp.* were found to occur in 39.0% and 31.0%, respectively, of 341 sugar beet fields surveyed (Payne, *et al.*, 1994). However, the frequency of *A. cochlioides*-infested soils varied widely in the different sugar beet growing areas. To mimic this variation in 1999 our research consisted of three sites with different indices of *Aphanomyces spp.*. A soil bioassay showed the index of 3, 28, and 94.0% for Sites 1, 2, and 3, respectively (Table 7).

In Site 1 where the organism index was low, no significant differences were found between seed treatments for the first three emergence counts (Figure 3). However, at the last count (21-d), significant differences in

emergence occurred between Plain pelleted seed and the combination of primed advance treatment with the fungicide Tachigaren (PAT+TACH). The highest (78.8%) and the lowest (64.5%) emergence occurred for Plain pellet and PAT+TACH treated seed respectively, throughout the four counts. The overall emergence for all seed treatments on Site 1 was high. This is not surprising since no beets had been grown in this field during the past 25 years, resulting in minimal disease inoculum potential. However, in Site 2, sugar beets had been grown in a three-year rotation with other crops, therefore the organism index was medium and clear emergence differences and lower mean emergence occurred. At the 21-d count the highest field emergence levels of 63.5 and 62.5% occurred for the standard film coating treatment Celpril and the Plain pelleted, respectively (Figure 3). Contrary to the findings in Sites 1 and 3, the highest emergence was with PAT+TACH treated seed (38.5%). There is a possibility that coating with Thiram (the fungicide in the Celpril treated seed) could exert control on soilborne pathogens, either from a fungicidal effect or as a result of enhancing seed germination and reducing the period during which seedlings are susceptible to attack. However, when Celpril was compared in a high organism index environment like that of Site 3, the incidence of seedling mortality from infection by *Aphanomyces spp.* was as low as that for Plain pellet treated seed (Figure 3). At the 21-d count 14.8% emergence occurred for both treatments, indicating that Thiram alone does not perform well under severe disease conditions. However, when combined with a treatment that will enhance germination with a fungicide (Tachigaren), like PAT+TACH treatment, a sugar beet stand can be tripled under

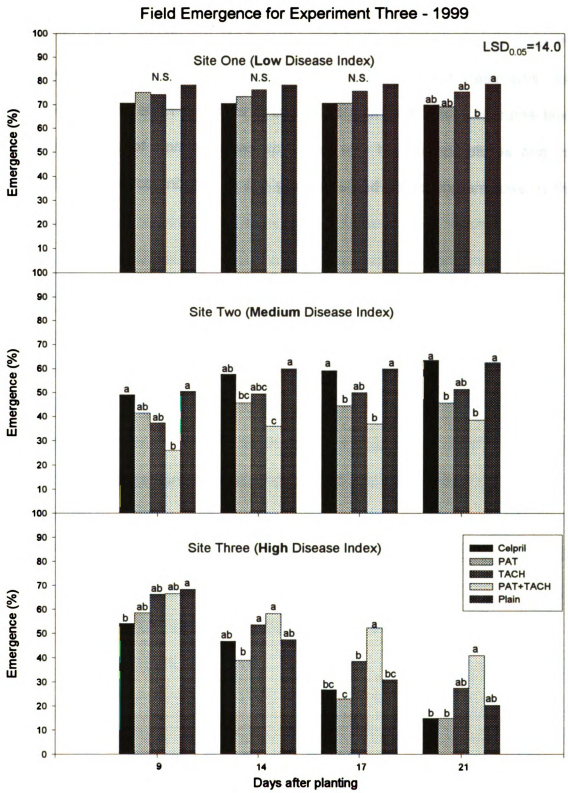

Figure 3. Effect of seed treatments on seedling emergence from soils infested with different level of *Aphanomyces spp.*

conditions with severe pathogen levels (41.0%). Thus, at the 9-d count all the treatments had a significantly higher emergence than those at Site 2 for the same count. However, the mean emergence of all seed treatments was significantly lower at 21-d in Site 3 compared with Site 2 for the same time. Higher incidence of *Aphanomyces spp.*, wet soil, high temperatures and cut worm damage all contributed to the gradual stand establishment loss in the Site 3.

SUMMARY

Comparisons of seed quality/vigor test and field emergence results were made in 1998 and 1999 in three different experiments. Experiment One utilized seed lots representing a wide range of seed quality, from different production years and lengths of storage. Seed lots used in Exp. 2 were of high quality and represented three varieties with three different seed sizes. Experiment Three consisted of a commercially grown seed lot enhanced with the following five seed treatments: Celpril (film coat of the fungicide Thiram); PAT (primed advance treatment); TACH (pelletized seed with the fungicide Tachigaren added); PAT+TACH (combines the primed advance treatment and Tachigaren) and Plain Pellet (Celpril treated seed covered in a pellet without further treatment).

Laboratory tests used to evaluate seed quality and vigor included the standard pleated germination test counted at 5 and 10 d, the 5- and 10-d cold test, the 3- and 6-d high moisture cold test, the 2- and 4-d standard accelerated aging test, the 2-and 4-d accelerated aging test incubated over NaBr, the 5- and 10-d sand test and the bulk conductivity test. Field emergence data were collected at Saginaw, Ingham and Huron counties in 1998 and in Saginaw and Ingham counties in 1999.

I. Laboratory Tests

Significant correlations between the pleated germination and cold test results occurred in Exp. 1 during both years. This confirmed the potential of

these tests to differentiate within a wide range of seed quality as that used in Exp. 1. Furthermore, the high correlations between the 5-d and 10-d counts for the pleated germination and cold tests suggest that the 5-d germination count may be sufficient. Although significant correlation also occurred between results of the sand and accelerating aging tests over sodium bromide for Exp.1 in 1998 and Exp. 2, the correlations were not as high as those found between the cold and pleated germination test. Poor correlations were also found for the high moisture cold test, the standard accelerated aging test and the conductivity test for both experiments.

II. Relationship Between Laboratory Test and Field Emergence

Results of pleated germination and cold tests were significantly correlated with field emergence for all three experiments when using the simple coefficients of determination. Cold test results were better correlated with field emergence under lower soil temperature conditions like those at the early planting in Exp. 2 in 1999. However, the cold test also performed well as soil temperatures increased. On the other hand, the high moisture cold test performed no better than the standard cold test. Correlations between the sand test results and field emergence were the third highest for Exp.1 in 1998. However, such correlations were not achieved during any subsequent year or experiment. Results of accelerated aging tests over water and sodium bromide were not significantly correlated with field emergence. With the exception of the early planting for Exp.

2 in 1999, conductivity test results were also poorly correlated with field emergence.

Multiple stepwise coefficients of determination were calculated for each location in Exp.1 and 2, with each equation consisting of a different set of independent variables (laboratory tests). For most equations, the coefficients of the variables on field emergence accounted for over 49.0% of the variability. The cold and pleated germination tests appeared in most of these equations. However, when these two variables were regressed on field emergence for all locations on both experiments, the resulting R^2 values were usually lower and did not significantly contribute to the equations.

III. Influence of Seed Size on Germination and Field Emergence

In the majority of the comparisons, seed size was not significantly associated with the laboratory test results. However, a masking effect of seed size was observed in the conductivity test. Overall, seed size in 1998 and early planting in 1999 did not significantly influence field emergence. However, at the late planting in 1999, most of the comparisons produced significant differences in percent stand establishment between seed size two and four. Although, these differences were significant, no relative ranking among seed sizes was made because of inconsistencies in performance of different seed sizes among varieties.

IV. Influence of Seed Treatments on Field Emergence

Two planting dates were selected in 1998 (4/15 and 5/15) to evaluate the influence of planting date on the emergence of the treated seed. In the early planting, all seed treatments produced higher emergence than the standard Celpril treatment. However, the priming advanced treatment (PAT) induced more rapid emergence than any of the other treatments. Celpril treated seed always produced the lowest emergence throughout all the counts. Again, in the late planting, seedlings from PAT treated seed emerged earlier than those from other treatments. However, the other three seed treatments (Celpril, TACH, PAT + TACH, Plain) induced similar emergence to that of PAT treated seed at later counts. On the other hand, Celpril coated seed was not as effective as PAT in controlling soilborne pathogens, especially at the late planting. Although a similar stand establishment trend occurred at both planting dates, the overall mean emergence was significantly much lower at the late planting date.

In 1999 all treatments were planted at the same time, however, three sites with varying *Aphanomyces spp.* indices were chosen (low, medium, high). In Site 1 the seedling emergence was not significantly different among the seed treatments for the first three counts. At the last count, significant differences occurred between Plain pelleted seed and the PAT + TACH. The overall emergence for all seed treatments on Site 1 was high. At Site 2, where the organism index was medium, the overall emergence was lower than that at Site 1 for all five seed treatments. Contrary to the findings in Site 1, the lowest emergence occurred for the PAT + TACH treated seed. At the last count, the

highest field emergences occurred for both Celpril and the Plain pelleted seed. However, when Celpril was compared in a high organism pressure environment like that on Site 3, the incidence of seedling survival was as low as that of the Plain pelleted seed, indicating that Thiram alone (fungicide contained in Celpril) does not perform well under severe disease conditions. However, when combined with a treatment that will speed up the germination with a fungicide like PAT + TACH, the resulting stand can be significantly improved under such severe disease conditions. This confirms the effect of TACH (Tachigaren) in controlling *Aphanomyces spp.*

CONCLUSIONS

The following conclusions can be drawn from these studies:

1. No single laboratory test can predict field emergence under all environments, because of the wide range of favorable and unfavorable soil and temperature conditions.

2. Variation in emergence under different planting conditions is likely due to varying environmental conditions, including biotic factors, rather than to intrinsic differences in seed quality/vigor. Even aging treatments, which are intended to test physiological vigor, failed to result in higher coefficients of determination between laboratory test results and field emergence.

3. The use of the pleated germination test plus the cold germination test should give the best indication of potential field emergence under most field conditions found in Michigan.

4. A 5-d germination count may be sufficient for the pleated germination and cold test.

5. No consistent association was found between seed size, germination and field emergence.

6. Celpril treated seed performed as well as other seed treatments/enhancements under low and medium disease environments at the late planting date.

7. PAT (Priming Advance Treatment) resulted in a lower incidence of soilborne diseases by reducing the period during which seedlings are susceptible to the pathogens.

8. PAT + TACH could be used to provide control over soilborne pathogens when field infestation is high.

Overall, these studies showed conclusively that there are no intrinsic problems with seed quality/vigor in the sugar beet industry in Michigan. The study also showed that emergence problems in sugar beet seed are unlikely to be avoided by the application of vigor tests. Therefore, more attention should be given to studying soil and environmental factors which limit germination and stand establishment. Rather than seed quality, the problem appears to be abiotic and biotic factors in the soil that affect germination and stand establishment, even with the use of high quality seed. Agronomic practices such as crop rotation should be continued to help minimize seedling loss from pathogens. Finally, seed treatment strategies should be continued to help avoid seedling loss during and immediately following germination. This, along with appropriate agronomic practices and the continued use of high quality seed should help keep the need for replanting to a minimum.

APPENDIX

Table A1. Analysis of variance for the pleated germination, cold and sand test results for Exp. 1 (Seed Quality), 1998 as influenced by variety, time of count and replication.

		Pleated Test		Cold Test		Sand Test	
Source	df	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F
Variety	19	76.08	<.0001*	1013.40	<.0001*	169.41	<.0001*
Time	1	305.93	<.0001*	56.85	<.0048*	1846.27	<.0001*
Rep	3	0.36	0.7791	6.38	0.0811	31.64	0.0090*
Var*Time	19	54.76	<.0001*	4.19	<.0001*	7.53	<.0001*

* Significant at the 0.05 probability level

Table A2. Analysis of variance for the accelerated aging test results for Exp. 1 (Seed Quality), 1998 as influenced by variety, time of count and replication.

		Accelerated Aging			
		Water		NaBr	
Source	df	F-value	Pr>F	F-value	Pr>F
Variety	19	86.22	<.0001*	9.94	<.0001*
Time	1	13053.1	0.0056*	22292.8	0.0043*
Rep	3	10.56	0.1900	51.18	0.0884
Var*Time	19	7.90	<.0001*	2.00	0.0699

* Significant at the 0.05 probability level

Table A3. **Slicing procedure for the interaction effect between variety and time of count for the pleated germination test in Exp. 1 (Seed Quality), 1998.**

Sliced by Time			
Time	df	F-Value	Pr>F
10 days	19	33.09	<.0001*
5 days	19	112.96	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
1	1	2.89	0.0942
2	1	0.41	0.5261
3	1	1.63	0.2071
4	1	0.41	0.5261
5	1	7.64	0.0076*
6	1	10.17	0.0023*
9	1	0.05	0.8324
10	1	13.06	0.0006*
11	1	0.05	0.8324
14	1	5.47	0.0227*
15	1	6.51	0.0133*
16	1	2.89	0.0942
17	1	0.41	0.5261
18	1	1200.41	<.0001*
20	1	35.42	<.0001*
21	1	6.51	0.0133*
52	1	19.92	<.0001*
54	1	16.31	0.0002*
56	1	14.64	0.0003*
57	1	1.63	0.2071

* Significant at the 0.05 probability level

Table A4. **Slicing procedure for the interaction effect between variety and time of count for the cold test in Exp. 1 (Seed Quality), 1998.**

Sliced by Time			
Time	df	F-Value	Pr>F
10 days	19	469.41	<.0001*
5 days	19	548.19	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
1	1	14.18	0.0004*
2	1	2.27	0.1375
3	1	0.14	0.7079
4	1	0.00	1.0000
5	1	2.27	0.1375
6	1	2.27	0.1375
9	1	0.14	0.7079
10	1	6.95	0.0108*
11	1	0.14	0.7079
14	1	3.55	0.0648
15	1	5.11	0.0277*
16	1	1.28	0.2633
17	1	0.57	0.4544
18	1	56.74	<.0001*
20	1	23.97	<.0001*
21	1	0.57	0.4544
52	1	31.91	<.0001*
54	1	9.08	0.0039*
56	1	0.14	0.7079
57	1	0.57	0.4544

* Significant at the 0.05 probability level

Table A5. **Slicing procedure for the interaction effect between variety and time of count for the accelerated aging test in Exp. 1 (Seed Quality), 1998.**

Sliced by Time			
Time	df	F-Value	Pr>F
2 days	19	40.84	<.0001*
4 days	19	53.28	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
1	1	37.06	<.0001*
2	1	1.42	0.2483
3	1	85.81	<.0001*
4	1	123.57	<.0001*
5	1	60.96	<.0001*
6	1	88.28	<.0001*
9	1	54.92	<.0001*
10	1	8.48	0.0090*
11	1	58.91	<.0001*
14	1	76.29	<.0001*
15	1	76.29	<.0001*
16	1	45.55	<.0001*
17	1	52.98	<.0001*
18	1	0.16	0.6958
20	1	12.77	0.0020*
21	1	30.89	<.0001*
52	1	29.44	<.0001*
54	1	14.73	0.0011*
56	1	16.83	0.0006*
57	1	13.73	0.0015*

* Significant at the 0.05 probability level

Table A6. **Slicing procedure for the interaction effect between variety and time of count for the sand test in Exp. 1 (Seed Quality), 1998.**

Sliced by Time			
Time	df	F-Value	Pr>F
10 days	19	62.38	<.0001*
5 days	19	114.56	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
1	1	27.65	<.0001*
2	1	3.79	0.0564
3	1	6.41	0.0141*
4	1	9.71	0.0029*
5	1	38.84	<.0001*
6	1	18.36	<.0001*
9	1	0.34	0.5614
10	1	12.29	0.0009*
11	1	8.53	0.0050*
14	1	15.17	0.0003*
15	1	43.84	<.0001*
16	1	3.07	0.0850
17	1	20.06	<.0001*
18	1	155.35	<.0001*
20	1	23.70	<.0001*
21	1	43.84	<.0001*
52	1	54.77	<.0001*
54	1	83.78	<.0001*
56	1	41.30	<.0001*
57	1	46.46	<.0001*

* Significant at the 0.05 probability level

Table A7. Analysis of variance for the pleated germination, cold, high moisture cold and conductivity test results for Exp. 1 (Seed Quality), 1999 as influenced by variety, time of count and replication.

		Pleated Test		Cold Test		Cold High Moisture Test		Conductivity Test	
Source	df	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F
Variety	19	11.31	<.0001*	5.65	0.000*	2.64	<0.202*	42.02	<.0001*
Time	1	42.34	<.0001*	5.26	0.0818	59.99	<.0001*	N/A	N/A
Rep	3	2.16	0.1032	0.93	0.9840	2.90	0.1047	0.23	0.8718
Var*Time	19	1.31	0.2168	0.29	0.1990	0.56	0.7692	N/A	N/A

* Significant at the 0.05 probability level
N/A = Effect Non-applicable for the test

Table A8. Analysis of variance for the pleated germination, cold, high moisture cold and sand test results for Exp. 2 (Seed Size) as influenced by variety, seed size, time of count and replication.

		Pleated Test		Cold Test		Cold High Moisture Test		Sand Test	
Source	df	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F
Variety	2	6.48	0.0317*	4.97	0.0534	0.97	0.5080	12.27	0.0076*
Size	2	0.50	0.6077	0.30	0.7459	1.50	0.2543	22.78	<.0001*
Time	1	25.98	<.0001*	3.17	0.0818	46.41	<.0001*	131.47	<.0001*
Rep	3	0.78	0.5468	0.05	0.9840	0.51	0.5488	0.17	0.9099
Var*Size	4	2.94	0.0307*	1.57	0.1990	0.56	0.6937	1.80	0.1446
Var*Time	2	0.36	0.6978	0.42	0.6619	1.28	0.3077	8.78	0.0006*

* Significant at the 0.05 probability level

Table A9. Analysis of variance for the pleated germination, cold and sand test results for Exp. 2 (Seed Size) as influenced by variety, seed size, time of count and replication.

		Accelerated Aging					
		Water		NaBr		Conductivity Test	
Source	df	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F
Variety	2	23.05	<.0001*	18.83	<.0001*	53.51	<.0001*
Size	2	2.01	0.1451	5.22	0.0089*	38.55	<.0001*
Time	1	452.59	0.0002*	24573.8	<.0001*	N/A	N/A
Rep	3	2.41	0.2449	13.91	0.0289*	0.87	0.4744
Var*Size	4	2.39	0.0642	2.40	0.0628	2.39	0.0892
Var*Time	2	19.59	<.0001*	4.23	0.0203*	N/A	N/A

* Significant at the 0.05 probability level
N/A = Effect Non-applicable for the test

Table A10. Slicing procedure for the interaction effect between variety and seed size for the pleated germination test in Exp. 2 (Seed Size).

Sliced by Size			
Size	df	F-Value	Pr>F
2	2	6.21	0.0041*
3	2	3.47	0.0397*
4	2	5.07	0.0103*
Sliced by Variety			
Variety	df	F-Value	Pr>F
ACH503	2	1.04	0.3604
ACH555	2	0.25	0.7790
ACH648	2	5.08	0.0103*

* Significant at the 0.05 probability level

Table A11. Slicing procedure for the interaction effect between variety and germination time for the sand test in Exp. 2 (Seed Size).

Sliced by Time			
Time	df	F-Value	Pr>F
10 days	2	1.88	0.1641
5 days	2	19.96	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
ACH503	1	37.28	<.0001*
ACH555	1	96.17	<.0001*
ACH648	1	15.58	0.0003*

* Significant at the 0.05 probability level

Table A12. Slicing procedure of the interaction effect between variety and aging time for the accelerated aging test in Exp. 2 (Seed Size).

Sliced by Time			
Time	df	F-Value	Pr>F
2 days	2	0.58	0.5626
4 days	2	42.06	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
ACH503	1	260.45	<.0001*
ACH555	1	62.60	<.0001*
ACH648	1	204.85	<.0001*

* Significant at the 0.05 probability level

Table A13. Slicing procedure of the interaction effect between variety and time of aging for the accelerated aging test over NaBr in Exp. 2 (Seed Size).

Sliced by Time			
Time	df	F-Value	Pr>F
2 days	2	2.97	0.0610
4 days	2	20.09	<.0001*
Sliced by Variety			
Variety	df	F-Value	Pr>F
ACH503	1	1380.32	<.0001*
ACH555	1	1040.48	<.0001*
ACH648	1	1228.80	<.0001*

* Significant at the 0.05 probability level

Table A14. Analysis of variance for pleated germination and cold test results for Exp. 3 (Seed Enhancement), 1998 as influenced by treatment, time of count and replication.

			Pleated Test		Cold Test
Source	df	F-value	Pr>F	F-value	Pr>F
Treatment	4	42.26	<.0001*	3.79	0.0204*
Time	1	12.96	0.0026*	9.22	0.0083*
Rep	3	0.99	0.4223	1.24	0.3306
Treat*Time	4	1.55	0.2341	0.45	0.8087

* Significant at the 0.05 probability level

Table A15. Analysis of variance for pleated germination and cold test results for Exp. 3 (Seed Enhancement), 1999 as influenced by treatment, time of count, and replication.

			Pleated Test		Cold Test
Source	df	F-value	Pr>F	F-value	Pr>F
Treatment	4	12.49	0.0002*	7.40	0.0030*
Time	1	47.66	<.0001*	9.14	0.0106*
Rep	3	1.31	0.3155	0.60	0.6297
Treat*Time	4	2.37	0.1110	1.29	0.3294

* Significant at the 0.05 probability level

Table A16. Multiple comparison and mean separation for the conductivity test in Exp. 2 (Seed Size).

Variety	Size	LSMEAN	SE	DF	t	Pr>|t|	LetGrp
ACH648	2	621.78	17.94	18	64.65	0.0001	A
ACH648	3	525.23	17.94	18	29.27	0.0001	B
ACH648	4	459.72	17.94	18	25.62	0.0001	C
ACH503	2	653.69	17.94	18	36.43	0.0001	A
ACH503	3	535.47	17.94	18	29.84	0.0001	B
ACH503	4	507.13	17.94	18	28.26	0.0001	B
ACH555	2	462.75	17.94	18	25.79	0.0001	A
ACH555	3	403.81	17.94	18	22.50	0.0001	B
ACH555	4	398.85	17.94	18	22.23	0.0001	B

Table A17. Multiple comparison and mean separation for the different planting dates and stand counts conducted in Exp. 3 (Seed Enhancement), 1998.

PLANTING	TMT	DAP	LSMEAN	SE	DF	t	Pr>|t|	LetGrp
Early	Celpril	11	0.45	2.69	390	0.17	0.8686	B
Early	PAT	11	19.33	2.69	390	7.19	0.0001	A
Early	PATACH	11	5.44	2.69	390	2.03	0.0435	B
Early	Plain	11	2.11	2.69	390	0.79	0.4325	B
Early	TACH	11	1.11	2.69	390	0.41	0.6794	B
Early	Celpril	13	11.34	2.69	390	4.22	0.0001	D
Early	PAT	13	40.33	2.69	390	15.01	0.0001	A
Early	PATACH	13	27.22	2.69	390	10.13	0.0001	B
Early	Plain	13	19.44	2.69	390	7.23	0.0001	C
Early	TACH	13	12.67	2.69	390	4.71	0.0001	CD
Early	Celpril	16	20.33	2.69	390	7.57	0.0001	D
Early	PAT	16	46.11	2.69	390	17.16	0.0001	A
Early	PATACH	16	29.78	2.69	390	11.08	0.0001	BC
Early	Plain	16	34.33	2.69	390	12.77	0.0001	B
Early	TACH	16	26.22	2.69	390	9.76	0.0001	CD
Early	Celpril	19	32.22	2.69	390	11.99	0.0001	C
Early	PAT	19	50.22	2.69	390	18.69	0.0001	A
Early	PATACH	19	38.45	2.69	390	14.30	0.0001	BC
Early	Plain	19	44.56	2.69	390	16.58	0.0001	AB
Early	TACH	19	40.33	2.69	390	15.01	0.0001	B
Early	Celpril	22	48.11	2.69	390	17.90	0.0001	B
Early	PAT	22	57.89	2.69	390	21.54	0.0001	A
Early	PATACH	22	45.55	2.69	390	16.95	0.0001	B
Early	Plain	22	58.89	2.69	390	21.91	0.0001	A
Early	TACH	22	50.22	2.69	390	18.69	0.0001	B

Table A 17. Cont.

PLANTING	TMT	DAP	LSMEAN	SE	DF	t	Pr>|t|	LetGrp
Early	Celpril	28	49.67	2.69	390	18.48	0.0001	B
Early	PAT	28	57.56	2.69	390	21.41	0.0001	A
Early	PATACH	28	49.45	2.69	390	18.40	0.0001	B
Early	Plain	28	59.89	2.69	390	22.28	0.0001	A
Early	TACH	28	53.22	2.69	390	19.80	0.0001	AB
Early	Celpril	44	47.67	2.69	390	17.74	0.0001	C
Early	PAT	44	56.33	2.69	390	20.96	0.0001	AB
Early	PATACH	44	49.22	2.69	390	18.31	0.0001	BC
Early	Plain	44	58.22	2.69	390	21.66	0.0001	A
Early	TACH	44	54.67	2.69	390	20.34	0.0001	ABC
Early	Celpril	49	45.89	2.69	390	17.07	0.0001	C
Early	PAT	49	54.44	2.69	390	20.26	0.0001	AB
Early	PATACH	49	48.89	2.69	390	18.19	0.0001	BC
Early	Plain	49	54.11	2.69	390	20.13	0.0001	AB
Early	TACH	49	53.78	2.69	390	20.01	0.0001	AB
Late	Celpril	19	2.56	2.69	390	0.95	0.3427	B
Late	PAT	19	10.78	2.69	390	4.01	0.0001	A
Late	PATACH	19	5.22	2.69	390	1.94	0.0528	AB
Late	Plain	19	5.78	2.69	390	2.15	0.0322	AB
Late	TACH	19	1.89	2.69	390	0.70	0.4827	B
Late	Celpril	24	3.89	2.69	390	1.45	0.1488	B
Late	PAT	24	12.11	2.69	390	4.51	0.0001	A
Late	PATACH	24	7.89	2.69	390	2.94	0.0035	AB
Late	Plain	24	7.00	2.69	390	2.60	0.0096	AB
Late	TACH	24	3.89	2.69	390	1.45	0.1488	B

Table A 17. Cont.

PLANTING	TMT	DAP	LSMEAN	SE	DF	t	Pr>|t|	LetGrp
Late	Celpril	31	27.45	2.69	390	10.21	0.0001	A
Late	PAT	31	28.56	2.69	390	1062	0.0001	A
Late	PATACH	31	28.00	2.69	390	10.42	0.0001	A
Late	Plain	31	28.89	2.69	390	10.75	0.0001	A
Late	Proprim	31	34.78	2.69	390	12.94	0.0001	A
Late	TACH	31	27.56	2.69	390	10.25	0.0001	A
Late	Celpril	34	22.22	2.69	390	8.27	0.0001	B
Late	PAT	34	24.45	2.69	390	9.09	0.0001	AB
Late	PATACH	34	22.33	2.69	390	8.31	0.0001	B
Late	Plain	34	25.33	2.69	390	9.43	0.0001	AB
Late	Proprim	34	30.45	2.69	390	11.83	0.0001	A
Late	TACH	34	20.22	2.69	390	7.52	0.0001	B
Late	Celpril	38	26.34	2.69	390	9.80	0.0001	A
Late	PAT	38	26.45	2.69	390	9.84	0.0001	A
Late	PATACH	38	25.11	2.69	390	9.34	0.0001	A
Late	Plain	38	27.45	2.69	390	10.21	0.0001	A
Late	Proprim	38	29.56	2.69	390	11.00	0.0001	A
Late	TACH	38	22.89	2.69	390	8.52	0.0001	A

Table A18. Multiple comparison and mean separation for the different sites and stand counts conducted in Exp. 3 (Seed Enhancement), 1999.

SITE	TMT	DAP	LSMEAN	SE	DF	t	Pr>|t|	LetGrp
Low	Celpril	9	70.75	4.91	195	14.41	0.0001	A
Low	PAT	9	75.25	4.91	195	15.32	0.0001	A
Low	PATACH	9	68.00	4.91	195	13.85	0.0001	A
Low	Plain	9	78.25	4.91	195	15.94	0.0001	A
Low	TACH	9	74.25	4.91	195	15.12	0.0001	A
Low	Celpril	14	70.50	4.91	195	14.36	0.0001	A
Low	PAT	14	73.50	4.91	195	14.97	0.0001	A
Low	PATACH	14	66.00	4.91	195	13.44	0.0001	A
Low	Plain	14	78.25	4.91	195	15.94	0.0001	A
Low	TACH	14	76.25	4.91	195	15.53	0.0001	A
Low	Celpril	17	70.75	4.91	195	14.41	0.0001	A
Low	PAT	17	70.75	4.91	195	14.41	0.0001	A
Low	PATACH	17	65.75	4.91	195	13.39	0.0001	A
Low	Plain	17	78.75	4.91	195	16.04	0.0001	A
Low	TACH	17	75.75	4.91	195	15.43	0.0001	A
Low	Celpril	21	70.00	4.91	195	14.26	0.0001	AB
Low	PAT	21	69.25	4.91	195	14.10	0.0001	AB
Low	PATACH	21	64.50	4.91	195	13.14	0.0001	B
Low	Plain	21	78.75	4.91	195	16.04	0.0001	A
Low	TACH	21	75.50	4.91	195	15.38	0.0001	AB
Medium	Celpril	9	49.00	4.91	195	9.98	0.0001	A
Medium	PAT	9	41.50	4.91	195	8.45	0.0001	A
Medium	PATACH	9	25.25	4.91	195	5.14	0.0001	B
Medium	Plain	9	50.50	4.91	195	10.28	0.0001	A
Medium	TACH	9	37.25	4.91	195	7.59	0.0001	AB
Medium	Celpril	14	57.75	4.91	195	11.76	0.0001	AB
Medium	PAT	14	45.75	4.91	195	9.32	0.0001	BC
Medium	PATACH	14	32.25	4.91	195	6.57	0.0001	C
Medium	Plain	14	60.00	4.91	195	12.22	0.0001	A
Medium	TACH	14	49.50	4.91	195	10.08	0.0001	AB

Table A18. Cont.

SITE	TMT	DAP	LSMEAN	SE	DF	t	Pr>|t|	LetGrp
Medium	Celpril	17	59.25	4.91	195	12.07	0.0001	A
Medium	PAT	17	44.50	4.91	195	9.06	0.0001	BC
Medium	PATACH	17	32.25	4.91	195	6.57	0.0001	C
Medium	Plain	17	60.00	4.91	195	12.22	0.0001	A
Medium	TACH	17	50.00	4.91	195	10.18	0.0001	AB
Medium	Celpril	21	63.50	4.91	195	12.93	0.0001	A
Medium	PAT	21	45.75	4.91	195	9.32	0.0001	BC
Medium	PATACH	21	33.50	4.91	195	6.82	0.0001	C
Medium	Plain	21	62.50	4.91	195	12.73	0.0001	A
Medium	TACH	21	51.50	4.91	195	10.49	0.0001	AB
High	Celpril	9	54.00	4.91	195	11.00	0.0001	B
High	PAT	9	58.50	4.91	195	11.91	0.0001	AB
High	PATACH	9	66.50	4.91	195	13.54	0.0001	AB
High	Plain	9	68.25	4.91	195	13.90	0.0001	A
High	TACH	9	66.25	4.91	195	13.49	0.0001	AB
High	Celpril	14	46.75	4.91	195	9.52	0.0001	AB
High	PAT	14	39.00	4.91	195	7.94	0.0001	B
High	PATACH	14	58.25	4.91	195	11.86	0.0001	A
High	Plain	14	47.50	4.91	195	9.67	0.0001	AB
High	TACH	14	53.50	4.91	195	10.90	0.0001	A
High	Celpril	17	26.75	4.91	195	5.45	0.0001	BC
High	PAT	17	23.00	4.91	195	4.68	0.0001	C
High	PATACH	17	52.25	4.91	195	10.64	0.0001	A
High	Plain	17	31.00	4.91	195	6.31	0.0001	BC
High	TACH	17	38.50	4.91	195	7.84	0.0001	B
High	Celpril	21	14.75	4.91	195	3.00	0.0001	B
High	PAT	21	14.75	4.91	195	3.00	0.0001	B
High	PATACH	21	41.00	4.91	195	8.35	0.0001	AB
High	Plain	21	20.25	4.91	195	4.12	0.0001	B

Table A19. Daily maximum and minimum soil temperatures (°C) and precipitation (mm) at the three field testing locations in 1998.

	Misteguay			Metea			Kilmanagh		
Date	Max.	Min.	pptn.	Max.	Min.	pptn.	Max.	Min.	pptn.
04/01	10.2	8.2	3.8	13.3	12.2	19.6	16.1	3.9	28.2
04/02	8.4	7.3	0.8	12.8	10.0	9.9	16.1	3.9	5.8
04/03	7.3	6.3		8.9	8.9	0.8	6.7	2.8	1.3
04/04	8.7	5.3		7.2	9.4	0.5	7.2	1.1	
04/05	9.2	4.4		8.3	6.1		7.8	-1.7	
04/06	9.7	4.5		9.4	6.7		7.2	-5.0	
04/07	10.1	5.4		10.0	7.2		11.1	-5.0	
04/08	8.9	6.8	6.9	10.0	8.3	10.2	12.8	0.0	
04/09	6.8	6.0		6.1	8.3	4.1	5.0	3.9	7.1
04/10	9.0	4.5		8.9	6.7	5.3	8.3	0.6	
04/11	9.9	4.7		7.8	6.1		8.3	-5.0	
04/12	10.4	6.4		10.0	7.2		15.6	-5.0	
04/13	11.4	8.3		11.1	8.3		20.6	4.4	
04/14	11.5	9.9	1.3	10.6	9.4	0.8	21.1	9.4	T
04/15	10.8	8.7		11.1	10.6	2.5	12.8	3.3	8.9
04/16	11.3	8.1	13.2	10.6	10.0	1.0	10.0	2.2	
04/17	10.4	7.4		11.7	10.0	7.4	16.7	1.1	13.7
04/18	11.3	6.2		10.6	8.9	0.5	9.4	1.7	
04/19	11.8	8.1		11.1	8.9		17.2	3.3	
04/20	12.8	7.6		11.1	9.4		13.3	0.6	
04/21	12.6	8.8		12.2	9.4		16.1	0.6	
04/22	14.3	8.9		12.2	11.1		16.1	1.7	
04/23	14.9	9.3		13.3	11.1		17.8	1.7	
04/24	14.2	10.2		13.3	10.6		18.9	2.2	
04/25	13.1	9.2		13.3	11.1		17.2	1.1	
04/26	11.9	9.4		13.3	10.6	24.1	10.0	1.7	
04/27	11.8	6.8		12.2	9.4	10.2	4.4	-1.7	
04/28	13.1	6.9		12.2	8.9		9.4	-3.9	
04/29	12.0	8.3		13.3	9.4		15.6	-3.3	
04/30	13.7	10.2	1.5	12.8	10.6	0.3	16.7	0.6	T
05/01	15.5	12.3		13.3	12.8	17.3	21.1	8.3	
05/02	14.3	12.4		15.6	13.3	21.8	16.7	9.4	8.1
05/03	15.2	11.6		11.7	11.7	1.5	13.9	7.2	1.5
05/04	15.9	11.6		15.0	14.4	1.3	20.0	7.2	
05/05	16.9	11.7		16.7	13.9	2.5	21.1	7.8	
05/06	17.7	13.8		17.2	13.9		23.9	9.4	0.5
05/07	17.9	14.6		18.3	15.6		25.0	10.6	1.8
05/08	16.8	14.8	26.9	18.3	16.7	0.3	23.3	10.6	
05/09	16.5	13.4	8.9	17.2	15.6	1.3	18.3	7.2	
05/10	17.2	12.4		18.3	15.6		15.6	6.1	
05/11	15.9	13.8		17.8	15.0		20.6	6.1	2.5
05/12	18.3	14.2		17.2	15.6	1.8	14.4	11.7	4.1
05/13	19.1	15.3		17.8	15.0	2.3	17.8	12.2	
05/14	21.2	15.2		19.4	16.1		25.0	9.4	
05/15	21.8	16.1		21.1	16.7		26.7	10.0	
05/16	21.2	18.5		21.7	18.9		31.7	15.6	

Table A19. Cont.

	Misteguay			Metea			Kilmanagh		
Date	Max.	Min.	pptn.	Max.	Min.	pptn.	Max.	Min.	pptn.
05/17	21.3	16.4		21.7	18.9		27.2	15.6	
05/18	21.3	16.8		21.7	18.9		27.8	13.9	T
05/19	22.2	17.6		21.7	18.9		31.1	15.0	
05/20	21.9	17.8		22.2	18.9		32.2	12.8	0.5
05/21	20.1	16.3		22.2	19.4		25.6	8.9	
05/22	18.8	14.4		21.7	18.3		15.0	2.2	
05/23	19.0	13.5		21.1	17.2		17.2	2.8	
05/24	17.4	14.3	2.5	21.1	16.7		21.1	5.6	
05/25	15.6	14.3	4.8	18.3	17.8	3.8	22.8	11.1	3.6
05/26	19.2	12.4		17.8	15.6	0.3	17.2	9.4	9.4
05/27	20.4	14.6		20.6	15.0		19.4	7.2	
05/28	19.8	15.7		21.7	17.8		26.1	10.0	
05/29	20.7	17.4	0.8	21.1	18.3		28.3	15.0	1.8
05/30	21.4	16.4		21.7	19.4		26.7	7.2	
05/31	19.8	18.2	5.8	23.3	19.4	15.2	22.8	10.0	0.5
06/01	19.4	14.2		22.8	18.3		23.3	2.8	2.0
06/02	19.1	16.3		22.2	18.3		20.0	5.6	
06/03	17.6	14.2		21.7	17.8		26.1	5.0	
06/04	17.6	12.9		19.4	16.1		15.6	3.9	T
06/05	16.2	13.1		19.4	16.1		17.8	1.1	
06/06	15.4	12.3		17.8	15.6		13.9	3.3	
06/07	16.6	12.4		16.7	15.0		15.6	7.2	0.3
06/08	17.9	12.4		17.8	15.0		17.2	3.9	
06/09	16.5	13.9	1.0	18.9	15.0		19.4	3.9	
06/10	15.7	14.3	5.8	17.8	16.1	9.4	21.1	10.0	T
06/11	17.2	14.9	5.6	18.3	16.1	0.5	19.4	12.2	0.5
06/12	19.9	16.8	1.0	18.3	16.7	7.1	22.2	14.4	18.3
06/13	19.4	16.9	2.5	22.2	18.3	9.4	27.2	14.4	
06/14	21.6	16.1		21.7	18.9	0.5	19.4	12.2	3.6
06/15	23.3	17.3	1.3	22.8	18.9		24.4	11.1	
06/16	23.4	18.6		24.4	20.6	1.8	24.4	12.8	
06/17	23.7	19.1		24.4	21.7	3.6	25.0	14.4	
06/18	24.7	18.9		24.4	21.1		25.0	13.9	
06/19	24.1	20.7		25.0	21.1		26.1	16.1	1.8
06/20	25.4	19.8		26.1	22.8		31.1	17.8	
06/21	25.1	21.1	4.3	26.1	22.2		32.2	18.9	6.1
06/22	25.8	20.3		26.1	23.3		28.9	19.4	
06/23	26.7	22.1	0.5	26.7	23.3		30.0	15.6	
06/24	26.3	21.8		27.8	25.0		32.8	16.7	
06/25	26.9	23.0		27.2	24.4	8.9	33.9	19.4	
06/26	27.3	23.7		27.8	23.9	20.8	33.9	16.7	
06/27	25.7	22.2	5.8	27.8	24.4	1.3	26.7	16.1	1.0
06/28	26.5	21.7		26.7	24.4		30.0	17.8	
06/29	26.6	21.7		26.7	24.4	0.3	31.7	15.6	12.2
06/30	25.1	22.7		27.8	23.9	0.3	30.0	15.6	

Table A20. Daily maximum and minimum soil temperatures (°C) and precipitation (mm) at the three field testing locations in 1999.

	Misteguay			Metea		
Date	Max.	Min.	pptn.	Max.	Min.	pptn.
04/01	9.3	8.1		11.0	8.9	
04/02	10.9	8.4		13.4	9.7	
04/03	12.8	9.4		15.0	11.3	18.8
04/04	12.3	7.9	10.4	13.4	9.5	17.0
04/05	9.5	6.6		12.1	7.5	0.3
04/06	8.9	7.3	0.8	11.3	8.2	0.3
04/07	10.3	6.0	0.3	13.3	6.5	
04/08	12.6	7.7		15.8	8.9	1.5
04/09	11.3	7.4	4.8	12.0	6.8	23.4
04/10	8.9	5.4		11.1	5.1	
04/11	8.1	5.4	21.6	8.0	6.3	7.9
04/12	8.8	4.3		11.9	4.9	
04/13	10.6	4.9		12.5	5.8	
04/14	11.7	5.9		13.8	6.2	
04/15	10.4	7.6		10.3	7.9	
04/16	8.9	7.2	15.0	9.3	7.8	12.7
04/17	8.9	6.1	3.6	10.1	7.1	1.3
04/18	8.3	6.5	0.8	10.4	7.1	1.3
04/19	8.8	6.0		10.9	6.6	2.0
04/20	11.0	6.3		12.7	8.0	0.5
04/21	9.9	8.0		11.8	9.2	
04/22	9.3	8.1	39.9	10.9	9.1	50.0
04/23	8.1	6.6	17.0	9.1	6.6	27.4
04/24	9.5	4.6		11.3	4.8	
04/25	10.8	5.4		12.9	6.0	
04/26	12.3	7.1		13.9	7.6	
04/27	11.4	8.1		13.3	9.0	
04/28	11.7	7.9		13.6	8.5	
04/29	12.2	8.1		13.8	8.7	
04/30	13.1	7.7		14.7	8.5	
05/01	14.4	8.7		13.3	11.1	
05/02	14.9	9.8		13.9	10.0	
05/03	15.8	10.7		14.4	12.8	
05/04	16.7	11.7		14.4	12.8	
05/05	15.6	12.9	0.5	15.0	13.9	
05/06	15.0	13.8	1.3	17.2	15.0	0.3
05/07	14.8	12.2		16.1	15.0	1.3
05/08	14.2	12.5	3.3	16.1	15.0	
05/09	14.9	10.7		15.6	13.9	1.0
05/10	15.3	10.8		13.9	13.9	
05/11	15.6	11.2		14.4	13.3	
05/12	14.4	11.4	5.8			
05/13	13.3	10.1		15.0	13.3	2.0
05/14	14.9	9.8		14.4	13.3	
05/15	15.7	12.5	1.8	13.9	12.8	

Table A20. Cont.

	Misteguay			Metea		
	Max.	Min.	pptn.	Max	Min.	pptn.
05/16	16.9	13.4	5.6	15.6	15.6	
05/17	18.8	15.3	8.6	16.1	12.2	8.9
05/18	17.6	16.3	3.0	20.0	16.1	18.5
05/19	17.3	13.5		18.9	17.2	1.3
05/20	18.7	12.9		18.9	16.7	
05/21	18.7	15.1		18.9	16.1	
05/22	17.8	15.8	1.3	18.9	17.2	1.8
05/23	16.3	13.4	17.3	19.4	17.2	0.3
05/24	15.1	12.3		17.2	16.1	3.8
05/25	12.3	11.1	1.8	16.1	14.4	1.0
05/26	15.8	10.7		13.3	13.3	
05/27	17.6	11.2		16.1	13.9	
05/28	19.7	13.4		16.7	14.4	
05/29	21.2	15.2		18.9	17.8	
05/30	21.6	17.0		18.9	16.1	
05/31	20.3	18.2	1.3	19.4	17.8	7.6
06/01	22.0	18.2	2.5	20.0	17.8	
06/02	20.7	18.6	5.3	21.1	18.9	
06/03	19.7	16.0		21.1	18.9	
06/04	20.3	15.0		18.4	16.8	
06/05	21.9	16.9		21.3	15.7	
06/06	24.3	19.8		24.5	19.9	
06/07	24.2	20.8		25.2	21.4	
06/08	24.7	20.3	1.0	25.6	20.9	
06/09	23.4	20.3		24.6	20.9	
06/10	25.8	20.4		26.6	22.0	
06/11	26.2	22.0		26.9	22.6	
06/12	25.9	22.0	5.3	26.8	22.6	0.3
06/13	24.7	21.7	8.4	24.7	22.4	0.3
06/14	22.3	20.1	9.9	23.3	20.5	2.8
06/15	20.9	16.6		21.8	17.1	
06/16	20.7	17.5		20.8	18.0	
06/17	21.2	16.9	1.0	21.2	17.4	0.3
06/18	22.5	16.4		24.1	16.4	
06/19	22.0	18.0		23.1	18.6	
06/20	22.8	18.3		24.8	18.8	
06/21	24.1	18.6		25.6	19.5	
06/22	23.9	19.1		25.2	20.2	
06/23	24.3	20.2		26.2	21.0	0.5
06/24	23.3	21.6		24.5	22.2	6.6
06/25	26.2	20.1		26.8	20.2	
06/26	26.3	21.3		27.1	20.9	
06/27	25	22.3		25.8	22.5	8.9
06/28	25.8	21.9		27.3	22.2	6.4
06/29	24.8	20.9		24.7	20.8	0.5
06/30	22.9	19.9		22.7	19.5	

REFERENCES

Akeson, W. R. (1981). Relationship of sugar beet fruit size to vigor of commercially processed seed lots and cultivars. Crop Sci. **21**: 61-65.

Akeson, W. R. and Widner, J. N., (1980). Laboratory packed sand test for measuring vigour of sugarbeet seed. Crop Sci. **20**: 641-644.

Asher, M. J. C. and Payne, P.A.(1989). The control of seed and soil borne fungi by fungicides in pelleted seed. Proceedings of the IIRB Winter Congress, Burssels, 179-193. Brussels: IIRB.

Austin, R. B., Longden, P. C. and Hutchinson, J. (1969). Some effects of "hardening" carrot seed. Ann. of Bot. **33**: 833-895.

Baker, E. M., and Rush, C. M. (1988). Reaction of selected sugar beet varieties exposed to two pathogenic *Pytium* spp. (Abstr.) Phytopathology. **78**: 1566.

Bekendam, J., Kraak , H.L. and Vos J. (1987). Studies on field emergence and vigour of onion, sugar beet, flax and maize seed. Acta Hortic. **215**: 83-94.

Bierhuizen, J. F. and Wagenvoort, W. A. (1974). Some aspects of seed germination in vegetables. 1. The Determination an application of heat sums and minimum temperature for germination. Scientia Hortic. **2**: 213-219.

Black, J. N. (1959). Seed size in herbage legumes. Herbage Abstracts.
Bradnock, W. T. (1975). Report of the vigour committee, 1971-1974. Seed Sci. and Technol. **3**:124-127.

Bleasdale, J. K. A. (1966). Plant growth and crop yield. Ann. Appl. Biol. **57**: 173-182.

Buchholtz, W. F. (1944a). Crop rotation and soil drainage effects on sugar beet tip rot and susceptibility of other crops to *Aphanomyces cochlioides*. Phytopathology. **34**:805-812.

Buchholtz, W. F. (1944b). The sequence of infection of a seedling stand of sugar beets by *Pythium debaryanum* and *Aphanomyces cochlioides*. Phytopathology. **34**: 490-496.

Burris, J. S. (1976). Seed/seedling vigor and field performance. J. Seed Technol. **1**: 58-74.

Byford, W. J. (1985). A comparison of fungicide seed treatments to improve sugar beet seedling establishment. Plant Pathol. **34**: 463-466.

Ching, T. M., Saundra Hedtke, Boulger, M. C. and Kronstad, W. E. (1977). Correlation of field emergence rate and seed vigor criteria in barley cultivars. Crop Sci. **17**: 312-314.

Cooke, D. A. and Scott, R. K. (1993). The sugar beet crop (Science into practice). Chapman & Hall, 2-6 Boundary Row, London SE1 8HN.

Côme, D. and Tissaoui, T. (1973). Interrelated effects of imbibition, temperature and oxygen on seed germination. In Seed Ecology (ed. W. Heydecker), p. 157-168. Butterworths, London.

Crop Protection Reference (1995). 11th Ed. C&P Press Inc. New York, NY. p. 385-386.

Delouche, J. C. (1974). Maintaining soybean seed quality. p. 46-61. In Soybean production, marketing and use. Bull. Y-19. TVA, Muscle Shoals, Ala.

Delouche, J. C. and Baskin, C. C. (1973). Accelerated ageing techniques for predicting the relative storability of seed lots. Seed Sci. Technol. **1**: 427-452.

Delouche, J. C. and Caldwell, W. P. (1960). Seed vigor and vigor tests. Proc. Assoc. Off. Seed Anal. **50**: 124-129.

Dunne, C., Moënne-Loccoz, Y., McCarthy, J., Higgins P., Powell, J., Dowling, D. N. and O'Gara, F. (1998) Combining proteolytic and phloroglucinol-producing bacteria for improved biocontrol of *Pythium*-mediated damping-off of sugar beet. Plant Pathol. **47**: 299-307.

Dunning, R. A. (1972). Sugar beet past and disease incidence and damage and pesticide usage. J. I. I. R. B. **6**: 19-34.

Dunning, R. A., Byford W. J. and Durrant, M. J. (1986). Seed treatment. In Monograph 2, (ed. K. A. Jeffs). Collaborative International Pesticides Analytical Council. p. 221-232.

Dunning, R. A., Heijbroek, W. (1981). Improved plant establishment through better control of pest and disease damage. In: Proceedings of the 44th IIRB Winter Congress, Brussels. Brussels, Belgium: IIRB, 37-59.

Durrant, M. J. (1985). Seed quality-tests in the laboratory and performance in the field. British Sugar Beet Review. **53**: 40-42.

Durrant, M. J., Brown, S. J. and Bould, A. (1985). The assessment of quality of sugarbeet seed. J. Agr. Sc., Cambridge. **104**: 71-84.

Durrant, M. J. and Gumerson, R. J. (1990). Factors associated with germination of sugar-beet seed in the standard test and establishment in the field. Seed Sci. Technol. **18**: 1-10.

Durrant, M. J. and Loads, A. H. (1984). Pellet structure and chemical additions. Rothamsted Experimental Station Report for 1983, p. 45.

Durrant, M. J. and Loads, A. H. (1984). Experiments to determine the optimum advancement of sugar beet seed. Seed Sc. Technol. **15**: 185-196.

Durrant, M. J. and Loads, A. H. (1990). Some changes in sugar-beet seeds during maturation and after density grading. Seed Sci. Technol. **18**: 11-21.

Durrant, M. J., Payne, P.A., and McLaren, J. S. (1983). The use of water and some inorganic salt solutions to advance sugar beet seed. II. Experiments under controlled and field conditions. Ann. Appl. Biol. **103**: 517-526.

Durrant, M. J., Payne, P.A., Prince J. W. F., and Fletcher R. (1988). Thiram steep seed treatment to control *Phoma betae* and improve the establishment of the sugar-beet plant stand. Crop Prot. **7**: 319-326.

Durrant, M. J., and Scott, R. K. (1981). Prospects for improving plant establishment. British Sugar Beet Review, **49**: 25-29.

Edje, O. T. and Burris J. S. (1971). Effects of soybean seed vigor on field performance. Agron. J. **63**: 536-538.

Egli, D. B. and TeKrony, D. M. (1979). Relationship between soybean and yield. Agron. J. **71**: 755-758.

Fletcher, R. and Prince, J. W. F. (1987). Seed treatments and dressings. British Sugar Beet Review **55**(2): 25-27.

Fornstrom, K. J. (1980). Planting sugarbeets to stand in Wyoming. J. Am. Soc. Sugar Beet Technol. **20**: 535-543.

Genkel, P. A. (1946). [The resistance of plants to drought and methods of increasing it]. Fiziologiya Rastenii. **5**: 237.

Goyal, M. R. (1982). Soil crusts vs seedling emergence. Review Agricultural Mechanization in Asia, Africa and Latin America Winter 62-78; article No. 1290; J. Univ. P.R., Rio Piedras (USA).

Hampton, J. G. and TeKrony D. M. (1995). Handbook of Vigour Test Methods. 3rd edition. International Seed Testing Association. Zurich, Switzerland.

Harman, G. E., and Taylor, A. G. (1998). Improved seedling performance by integration of biological control agents at favorable pH levels with solid matrix priming. Phytopathology. **78**: 520.525.

Heydecker, W. (1969). The 'vigour' of seeds-a review. Proc. Int. Seed Test. Assoc. **34**:201-219.

Heydecker, W. (1972). Vigour. In. E. H. Roberts (ed.). Viability of seeds. Syracuse University Press, Syracuse, N.Y. p. 209-252.

Heydecker, W., and Coolbear, P. (1977). Seed treatments for improved performance - survey and attempted prognosis. Seed Sc. Technol. **5**: 353-425.

Hibbert, D., Thompson, D. C. and Woodwark, W. (1975). Observations on the effects of different pelleting processes on the laboratory germination and field emergence of sugarbeet seed. J. Int. Insti. Sugar Beet Res. **7**: 24-32.

Hogaboam, C. J. and Snyder F. W. (1964). Influence of size of fruit and seed on germination of a monogerm sugarbeet variety. J. Am. Soc. Sugar Beet Technol. **13**:116-126.

Hunter, J. R. and Dexter, S. T. (1950). Some seed-soil moisture studies with sugar beets. Proc. Amer. Soc. Sugar Beet Technol. **6**: 270-274.

Hunter, J. R. and Erickson, A. E. (1952). Relation of seed germination to soil moisture tension. Agron. J. **44**: 107-109.

Isley, D. (1957). Vigor tests. Proceedings of the association of official seed analysts **47**:176-182.

Jianhua, Z. and McDonald M. B., (1996). The saturated salt accelerated aging test for small-seeded crops. Seed Sci. Technol., **25**: 123-131.

Johnson R. A. and Bhattacharyya G. K. (1996). Statistics Principles and Methods, 3rd Edition. p. 99-164, 491-492.

Johnson R. R. and Wax, L. M. (1978). Relationship of soybean germination and vigor tests to field performance. Agron. J., **70**: 273-278.

Knott, J. E. (1925). Effect of soaking seed of some vegetables before sowing. J. Am. Soc. Agron. **17**: 49-54.

Koller, D. (1972). Environmental control of seed germination. In Seed Biology (ed. T. T. Kozlowski), vol. II, p. 1-101. Academic Press, New York.

Kraak, H. L., Vos, J., (1987). Studies on field emergence and vigour of onion, sugar beet, flax and maize seed. Acta Hortic. **215**: 83-94.

Kraak, H. L., Vos, J., Perry, D. A. and Bekendman, J., (1984). Studies on field emergence and vigour of sugar beet and onion seed. Seed Sci. Technol. **12**: 731-745.

Kuehl, R. O. (1994). Statistical principles of research design and analysis.

Leach, L. D. (1940). Influence of the pathogen, environment, and host response of the efficacy of seed treatment with sugar beets and some vegetable crops. Phytopathology **30**: 788. (Abstr.)

Leach, L. D. (1944). Incidence of Phoma infection on sugar beet seed and the efficacy of seed treatments. Phytopathology **34**: 935 (Abstr.).

Leach, L. D. (1947). Growth rates of host and pathogen as factors determining the severity of pre-emergence damping-off. J. Agric. Res. **75**: 161-179.

Leach, L. D., and Smith, P. G. (1945). Effect of seed treatment on protection rate of emergence and growth of garden peas. Phytopathology. **35**: 191-206.

Lexander, K. (1981). Physical and physiological seed characteristics influencing field emergence of sugar beet. Proceedings of the 44th Winter Congress of the International Institute for Sugar Beet Research, p. 21-36.

Ljungars, A. (1977). Olika faktorers betydelse für traktorenas jordpachnings-verkan. Mätningar 1974-1976 (with English summary). Agricultural college of Sweden, Uppsala, reports from the division of soil management, no. 52, 43 pp.

Longden, P. C. (1971). Advanced sugar beet seed. J. Agric. Sci. (Cambridge), **77**:43-46.

Longden, P. C. and Johnson, M. G. (1974). Predicting sugar beet seedling emergence in the field. Seed Sci. Technol. **2**: 337-342.

Longden, P. C. (1986). Influence of seed crop environment on the quality of sugar beet seed. Proceedings of the 49th Winter Congress of the International Institute for Sugar Beet Research, p. 1-16.

Longden, P. C. and Johnson, M. G., and Salter, P. J. (1979). Establishment and growth of sugar beet as affected by seed treatment and fluid drilling. J. Agric. Sci. **93**:541-552.

Lovato, A. and Cagalli, S. (1992). Sugar beet (*Beta vulagaris L.*) seed vigour compared laboratory and field tests. Seed Sci. Technol. **21**: 61-67.

Maude, R. B. (1966). Pea seed infection by *Mycosphaerella pinodes* and *Ascochyta pisi* and its control by seed soaks in thiram and captan suspensions. Ann. App. Biol., **57**: 193-200.

Maude, R. B. (1983). Eradicative seed treatments. Seed Sci. Technol. **11**: 907-920.

Maude, R. B. (1986). Treatment of vegetable seeds. In: Seed Treatment, p 244 (ed. by K. A. Jeffs). Croydon: BCPC.

Maude, R. B., Vizor, A. S. and Shuring, C. G. (1969). The control of fungal seed-borne diseases by means of a thiram seed soak. Ann. App. Biol., **64**: 245-257.

McKeen, W. E. (1949). A study of sugar beet rootrot in southern Ontario. Can. J. Res. **27**:284-311.

McLachlan J. B. (1972). Effect of seed size on yield of monogerm sugarbeet (*Beta vulgaris*). Irish J. Agric. Sci. **11**: 233-236.

Miles, D. F. Jr. (1980). Relationship between laboratory vigor tests and field emergence of soybeans (*Glycine max* (*L.*) Merril) in Michigan. M. S. thesis. Michigan State University, East Lansing.

Moore, R. P. (1963). What, how and why of germination energy. Virginia-Carolina Peanut News. **9**: 6-12.

Orioli, F., Bonsetti, A. and Rosso, F. (1979). La germinazione del seme di barbabietola. Correlazione tra dati di laboratorio ed emergenza in campo. Sementi Elette. **28**: 39-45.

Osburn, R. M., and Schroth, M. N. (1988). Effect of osmopriming sugar beet seed on exudation and subsequent damping-off caused by *Pythium ultimum.* Phytopathology. **78**:1246-1250.

Osburn, R. M., and Schroth, M. N. (1989). Effect of osmopriming sugar beet seed on germination rate and incidence of *Pythium ultimum* damping-off. Plant Dis. **73**:21-24.

Papavizas, G. C., Ayers, W. A. (1974). *Aphanomyces species* and their root diseases in pea and sugar beet - A review. Washington DC, USA: Department of Agriculture; USDA Technical Bulletin 1485.

Payne, P. A., Asher M. J. C. and Kershaw C. D. (1994). The incidence of *Pythium spp.* and *Aphanomyces cochlioides* associated with the sugar-beet growing soils of Britain. Plant Pathology. **43**: 300-308.

Payne P. A. and Williams G. E. (1990). Hymexazol treatment of sugar-beet seed to control seedling disease caused by *Pythium* spp. and *Aphanomyces cochlioides*. Crop Prot. **9**: 371-377.

Perry, D. A. (1972). Seed vigour and field establishment. Horticultural Abstracts. **42**: 334-342.

Perry, D. A. (1978). Report of the vigour test committee 1974-1977. Seed Sci. Technol. **6**: 159-181.

Pollock, B. M. and E. E. Roos. (1972). Seed and seedling vigor. In T. T. Kozlowski (ed.). Seed Biology. Vol. I. Academic Press, New York. p. 313-387.

Rush C. M (1987). First report of *Aphanomyces cochlioides* on sugar beets in Texas. Plant Dis. **72**:79.

Rush C. M (1991). Comparison of seed priming techniques with regard to seedling emergence and Pythium damping-off in sugar beet. Phytopathology. **81**(8): 878-882.

Rush C. M (1992). Stand establishment of sugar beet seedlings in pathogen-infested soils as influenced by cultivar and seed-priming technique. Plant disease. **76**(8):800-805.

Rush C. M. and Vaughn K. M. (1992). Effect of irrigation, soil matric potential, and seed priming on sugar beet seed germination and damping-off caused by *Aphanomyces cochlioides*. Phytopathology **83** (2): 202-206.

Savitsky, V. F. (1954). Relation between the weight of fruit and weight of germ in monogerm and multigerm beets. J. Am. Soc. Sugar Beet Technol. **8** (2): 16-21.

Schoore, A. F. (1956). Report of the activities of the committee on seedling vigour. Proc. Int. Seed Test. Assoc. **21**:282-286.

Scott, R. K., Harper, R., Wood, D. W., and Jaggard K. W. (1974). Effect of seed size on growth, development and yield of monogerm sugar beet. J. Agric. Sci. **82**:517-530.

Skuderna A. W. and Doxtator C. W. (1938). Germination Tests with Sugar Beet Seed. J. Am. Soc. Agro. **30**(4): 323-333.

Snyder, F. W. and Filban C. (1970). Relation of sugarbeet seedling emergence to fruit size. J. Am. Soc. Sugar Beet Technol. **15**: 703-708.

Snyder, F. W. and Zileke R. C. (1973). Water requirement for maximum germination and emergence of sugar beet seeds. J. Am. Soc. Sugar Beet Technol. **17**: 323-331.

Steen, R. A. (1987). Results of American Crystal's 1986 coded variety trials. 1986 North Dakota-Minnesota Sugarbeet Res. Ext. Rept. **17**: 203-269.

Stehlik, V. and Neuwirth, F. (1928). Ökologie der aufgehenden Zuckerrübe mit besonderer Berücksichtigung ihrer Krankheiten. Z. Zuckerind. Cechoslov. Republik. **53**: 429-453.

Stout, M. and Tolman B. (1944). Field and greenhouse tests with synthetic growth-regulating substances applied to sugar beet seeds and plants. J. Am. Soc. Agro. **36**(2): 141-146.

Soil survey of Ingham County, Michigan (1979). United States Department of Agriculture, Soil Conservation Service. p. 51, 127.

Takayanagi, K. and Murakami, K. (1968). Rapid germinability test with exudates from seed. Nature Lond., **218**: 493-494.

Tao, K.-L. J. (1978). Factors causing variations in the conductivity test for soybean seeds. J. Seed Tech. **3**(1): 10-18.

Taylor, A. G., Klein, D. E., and Whitlow, T. H. (1988). SMP: Solid matrix priming of seeds. Scientia Hortc. **37**: 1-11.

TeKrony, D. M. and Hardin, E. H. (1968). The problem of under-developed seeds occurring in monogerm sugar beets. J. Am. Soc. Sugar Beet Technol. **15**: 623-639.

TeKrony, D. M. and Hardin, E. H. (1969). Germination potential of monogerm sugarbeet seed as determined by field emergence and laboratory germination. J. Am. Soc. Sugar Beet Technol. **13**: 607-616.

Vanstallen, R. (1971). The effect of humidity on pelleted seed germination. Institut Belge pour amelioration de la Betterave, Trimestrielle **4**: 97-115.

Verveka, K. (1983). Effect of pelleting on water uptake and the germination of sugar beet seed. Acta Agronomica Academiae Scientiarium Hungaricae. **32**: 173-179.

Wanjura, D. F. and Buxton D. R. (1972). A systematic method for studying seedling emergence. J. Am. Soc. Sugar Beet Technol. **19**: 207-218.

Wilson, R. G. (1979). Survey of pesticide use in irrigated regions of the Nebraska Panhandle. Nebr. Agric. Stn. Bull. 544. p. 19.

Woltz, J. M., TeKrony, D. M., Egli, D. M. and Vincelli, P. (1998). Corn cold test germination as influenced by soil moisture, temperature, and pathogens. Seed Technol. **20**(1): 56-70.

Woodstock, L. W. (1969). Seedling growth as a measure of seed vigor. Proc. Int. Seed Test. Assoc. **34**:273-280.

Woodstock, L. W. (1973). Physiological and biochemical tests for seed vigour. Seed Sci. Technol. **1**: 127-157.

Yaklich, R. W., Kulik, M. J. and Aderson, J. D. (1979). Evaluation of vigor tests in soybean seeds: relationship of ATP, conductivity, and radioactive tracer multiple criteria laboratory tests to field performance. Crop Sci. **19**: 806-810.

Yamaguchi T. (1977). Studies on the seedling diseases of sugar beets-especially disease pathogens of genus *Pythium*. Research Bulletin of the Hokkaido National Agricultural Experimental Station. **118**: 1-52.