Relationship between seed vigor tests and field performance in winter and spring wheat (Triticum aestivum L.)
by Chandgi Ram

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Crop and Soil Science
Montana State University

Abstract:
Field emergence and plant density may greatly influence grain yield in wheat (Triti-cum aestivum L.). Seed vigor tests have been developed to assess seed quality in crops. However, the relationship of these vigor tests with field performance in wheat has not been studied extensively. The objectives of these studies were to evaluate several seed vigor tests and to determine their relationship with field performance of wheat. Standard germination, speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity tests were used to evaluate 10 winter wheat seed lots. Field performance of these lots was evaluated by determining emergence rate index, stand establishment, and grain yield. Emergence rate index was related to accelerated aging and respiration rate values of the seed lots (R = 0.83*). Stand establishment was related to accelerated aging, electrical conductivity, and respiration rate (R = 0.90*); and grain yield was related to the accelerated aging test (R = 0.73*).

Two spring wheat cultivars, ‘Lew’ and ‘Newana’, were evaluated using the same laboratory tests as used for winter wheat. In the cultivar Lew, emergence rate index was related to respiration rate (R = 0.72*) and grain yield to respiration rate (R = 0.66**). In Newana, emergence rate index was related to cold test and acclerated aging (R = 0.90**); stand establishment to cold test and respiration rate (R = 0.89**); and grain yield to respiration rate and standard germination (R = 0.84*).

In the second year, the sensitivity of certain vigor tests on several seed lots of Newana spring wheat was evaluated. Emergence rate index was related to standard germination and accelerated aging (R = 0.81**); stand establishment to speed of germination index (R = 0.79**); and grain yield to standard germination, glutamic acid decarboxylase activity, and respiration rate (R = 0.86**). Another study was conducted to evaluate the performance of several vigor tests on artificially aged seed lots, when seed quality was variable. Emergence rate index of these seed lots was related to accelerated aging (R = 0.98**); stand establishment to cold test (R = 0.93**); and grain yield to respiration rate and standard germination (R = 0.93**).

In general, field performance in winter wheat was related to accelerated aging, respiration rate and electrical conductivity and in spring wheat to respiration rate, cold test, standard germination, and accelerated aging tests.

RELATIONSHIP BETWEEN SEED VIGOR TESTS AND FIELD PERFORMANCE IN WINTER AND SPRING WHEAT (*Triticum aestivum* L.)

by

Chandgi Ram

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APPROVAL

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Chandgi Ram

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for admission to the College of Graduate Studies.

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Date 15 March, 1983.

Dedicated to my wife Bimla and our children
Yogesh, Anupma and Suresh

VITA

Chandgi Ram was born on December 20, 1949, to Shrimati Hero Devi and Shri Kehri Ram, in Popran (Jind), Haryana, India. He graduated from Government High School, Pundri (Kurukshetra) Haryana in 1966. In 1967, he was awarded a medal for his outstanding achievement of standing first in Pre-University (Ag) by Kurukshetra University. He studied for five years at College of Agriculture, Kaul (Kurukshetra University) and earned a B.Sc. (Ag) degree majoring in Cytogenetics and Plant Breeding in 1971.

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ABSTRACT

Field emergence and plant density may greatly influence grain yield in wheat (*Triticum aestivum* L.). Seed vigor tests have been developed to assess seed quality in crops. However, the relationship of these vigor tests with field performance in wheat has not been studied extensively. The objectives of these studies were to evaluate several seed vigor tests and to determine their relationship with field performance of wheat. Standard germination, speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity tests were used to evaluate 10 winter wheat seed lots. Field performance of these lots was evaluated by determining emergence rate index, stand establishment, and grain yield. Emergence rate index was related to accelerated aging and respiration rate values of the seed lots (R = 0.83*). Stand establishment was related to accelerated aging, electrical conductivity, and respiration rate (R = 0.90*); and grain yield was related to the accelerated aging test (R = 0.73*).

Two spring wheat cultivars, 'Lew' and 'Newana', were evaluated using the same laboratory tests as used for winter wheat. In the cultivar Lew, emergence rate index was related to respiration rate (R = 0.72*) and grain yield to respiration rate (R = 0.66**). In Newana, emergence rate index was related to cold test and acclerated aging (R = 0.90**); stand establishment to cold test and respiration rate (R = 0.89**); and grain yield to respiration rate and standard germination (R = 0.84*).

In the second year, the sensitivity of certain vigor tests on several seed lots of Newana spring wheat was evaluated. Emergence rate index was related to standard germination and accelerated aging (R = 0.81**); stand establishment to speed of germination index (R = 0.79**); and grain yield to standard germination, glutamic acid decarboxylase activity, and respiration rate (R = 0.86**). Another study was conducted to evaluate the performance of several vigor tests on artificially aged seed lots, when seed quality was variable. Emergence rate index of these seed lots was related to accelerated aging (R = 0.98**); stand establishment to cold test (R = 0.93**); and grain yield to respiration rate and standard germination (R = 0.93**).

In general, field performance in winter wheat was related to accelerated aging, respiration rate and electrical conductivity and in spring wheat to respiration rate, cold test, standard germination, and accelerated aging tests.

INTRODUCTION

Traditionally seed quality is measured by purity and germination. Seed germination has been defined as, "the emergence and development, from the seed embryo, of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions" (AOSA, 1978). However, field conditions are not always favorable or optimum, therefore, the standard germination test often overestimates field performance. The seed should be more than alive and thence the need for vigor testing has developed. Other synonymous terms for seed vigor found in the literature are, "pushing power," driving force (Heydecker, 1965), vitality (Munn, 1935), "field" or "planting value," physiological predetermination (Kidd and West, 1918), potential low planting value (Matthews and Bradnock, 1967), and field emergence potential (Bradnock and Matthews, 1970).

Several attempts have been made to define seed vigor which have been reviewed by Heydecker (1972), Perry (1973), Woodstock (1973), and McDonald (1975, 1980). The International Seed Testing Association (ISTA) defined seed vigor as the "sum of those properties of the seed which determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence" (Perry, 1978). However, AOSA has defined seed vigor as, "Seed vigor comprises those seed properties which determine the potential for rapid uniform emergence and development of normal seedlings under a wide range of field conditions" (McDonald, 1980).

Several vigor tests have been developed to measure the phenomenon of seed vigor. Successful seed vigor tests should be reproducible, correlate with emergence under certain field conditions, and be rapid, objective, simple, and economically practical (AOSA, 1983).

Woodstock and Combs (1964) stated that the ultimate proof of any vigor test is the reliability in predicting field stand under a variety of conditions and over a period of years. Grabe (1965) suggested it is not logical to expect a single vigor test to evaluate all factors of agronomic significance.

Field emergence rate and stand establishment can be of great importance to achieve optimum plant density which may influence grain yield in wheat (*Triticum aestivum* L.). Seed vigor tests have been developed to assess seed quality of crops. However, relationship of those vigor tests with field performance has not been studied extensively in wheat. The objective of this study was to evaluate several vigor tests in the laboratory and determine their relationship with field performance of wheat.

REVIEW OF LITERATURE

Significance of Vigor Testing in Cereals

In modern agriculture, precision sowing is being introduced, seeding rates are being reduced, and more attention is being given to achieving maximum possible yields. These practices have enhanced the need to identify and sow high-vigor seed, particularly in adverse soil conditions (Perry, 1976).

Darwinkel (1978) studied the effects of plant density on the growth and productivity of winter wheat. Maximum grain yield was achieved at 100 plants m^{-2}, which corresponded to 430 ears m^{-2} and to about 19,000 grains m^{-2}.

The compensatory ability of cereals is well known and is usually demonstrated experimentally by sowing seed at different rates. Wheat, and barley (*Hordeum vulgare* L.), plants at low populations will produce more heads, more seeds $head^{-1}$, and larger seeds. This type of compensation results in equal yields from seeding rates as far apart as 39.2 to 313.6 kg ha^{-1} (Perry, 1976). He also observed that the effects of low population derived from planting low vigor seed into poor soil conditions were very different from those stands obtained by planting sound seed at low rates into good soil conditions.

Stormonth and Doling (1979) have shown that 10 seed lots of 'Hobbit' winter wheat ranging in vigor between 2.5 and 8.5 produced yields ranging from 17.1 to 19.1 kg $plot^{-1}$, a 10% yield difference. Seed lots classified as possessing low vigor produced the lower yields. Another experiment using seed of a similar vigor range, several seeding rates and the cultivar 'Atou', indicate a positive relationship between vigor and yield. The yield differences between high and low vigor seed lots was 10%.

Likhachev (1973) studied germination and field emergence in wheat, rye (*Secale cereale* L.), triticale (*Triticale hexaploid* L.), barley, and oats (*Avena sativa* L.) in the laboratory and under field conditions. Seedling emergence depended more on seed quality than on the environment; environmental effects increased with the growth of seedlings and with plant development. He also concluded that emergence depended more on seedling vigor than on germination energy.

Ayre (1980) has shown that seed vigor affects plant growth of cereal throughout the season. Two seed lots of Hobbit winter wheat with 90% germination and with different vigor scores were sown at equal rates on 27 October 1978. In the spring of 1978, low-vigor seed plots contained 146 plants m^{-2} as compared to 257 plants m^{-2} for high vigor seeds. These values represent field establishment of 40 and 70% of the live seeds, respectively. Weekly examination of the plots between 17 April and 12 June, showed that plants from low vigor seed were always less advanced, were shorter and produced more vegetative tillers $plant^{-1}$ than did the plants from high vigor seeds. Microscopic comparisons of the early developmental stages of the wheat showed that growing points of low-vigor plants were smaller and took much longer to develop than those of high-vigor plants. Spikelet numbers increased more quickly in plants from high vigor seed; however, from 15 May onwards the developing head from the low-vigor plants contained more spikelets ear^{-1} than those of the high vigor plants. Yields from plots sown with low vigor seeds were 11% less than those from high vigor seed.

Gul and Allan (1976) reported that wheat emergence rate indices of field trials were correlated with each other but not with laboratory tests. Rapid emergence was positively correlated with high stand numbers and with coleoptile length, seedling height and culm length under conditions of deep sowing and high soil water potentials. Under low water potential and with shallow sowing, emergence rate was positively correlated with root development.

Perry (1976) observed that with the traditional constant weight sowing method for cereals, little attention is paid to the proportion of seedlings which emerged. Seeding rates are often excessive and the loss of 20 to 40% of seedlings has no effects upon grain yield. Hampton et al. (1981) have shown the significance of plant populations in cereal production. Seeding rates calculated on a seed number basis provide predictable and reliable emergence which is important in establishment of the crop.

Rennie (1979) reported that vigor tests did not give a better indication of potential field emergence than the standard laboratory germination tests. Anderson and Anderson (1979) found that seed lots of winter wheat with low germination percentages were slow to emerge and under unfavorable seedbed conditions dry matter production plant^{-1} was reduced. They emphasized the need to provide good seedbed conditions for cereal seed which have poor vigor unless yield reductions are expected. Keydel et al. (1979) pointed out that germination capacity, vigor, and the percentage of abnormal seedlings were positively correlated with seed yield of hybrid wheat.

Hutchings and Hicks (1972) evaluated establishment and grain yield of wheat on a conventional seedbed and with minimal till. Lower grain yield was attributed to lack of seedling vigor caused by residual effects of herbicide. Perry (1977) observed that wet conditions reduced emergence and final yield of low vigor barley and these reductions were most pronounced at the earlier sowing dates.

Bakumenko et al. (1975) found that heavy frost (up to -9.0 C) at the seedling, flowering or milk stages of spring wheat cultivars adversely affected germination percentage and seedling vigor of seed produced.

Lindstrom (1974) concluded that days to stand establishment in winter wheat can be predicted if average seed zone temperature is known. Stormonth and Doling (1977) have shown that laboratory tests can predict winter wheat emergence. Vigor scores ranged from 1.5 to 8.5 and plant emergence was 40% and 100%, respectively.

Don et al. (1981) described methods for several laboratory vigor tests that have been standardized to give a reproducible evaluation of certain aspects of winter wheat seed quality. They studied three different aspects of the vigor complex, one physical and two physiological and found that no individual test provided information on more than one aspect. They further suggested that if a full evaluation of winter wheat seed quality was required a combination of several different laboratory test methods might be necessary.

Physical Characteristics

Physical characteristics of seeds, e.g., size, weight, and density, have been shown to be associated with vigor for many crop species. Generally speaking, large, heavier or denser seeds are the most vigorous. Several researchers have shown that large seeds of wheat produce more vigorous seedlings. Using only the large seeds, within a seed lot results in a more rapid and higher emergence rate and percentages. Occasionally the large seeds do not outperform small seeds. Large seeds generally have greater embryo size, more carbohydrate reserves, and early photosynthesis which results in larger seedlings and sometimes increased yields. The advantage of large seeds is even greater for short growing season crops or where economic yield is a storage organ or the seed. Increases in yield are most likely to be obtained where specific yield components are determined during early growth (Wood et al., 1977).

Kittock and Law (1968) studied the effect of age and seed size on wheat seedling vigor. They separated wheat seed into five size classes with screens. They reported with different seed size classes significant positive correlation were found between seed weight and tetrazolium reduction, and between shoot weight and tetrazolium reductions. Scott (1961) assessed the relative importance of embryo and endosperm size in winter wheat. Kernels of uniform (80 mg) weight were either left intact or part of the endosperm was removed to give kernel weight of 60, 40, or 20 mg; with similar sized embryos (0.64

mg). Emergence was delayed with the 20 mg kernels and fewer seedlings emerged. Seedling weight was closely related to the weight of reserves contained and not the size of embryo. In another study, kernel weighing 40, 60 and 80 mg were selected, those kernels had different embryo size (0.31, 0.47 and 0.64 mg respectively). One half of the kernels weighing 60 and 80 mg had endosperm removed until each kernel weighed 40 mg. Half of the kernels weighing 40 mg were cut down to 20 mg weight. Emergence for all kernels was completed two days after the first seedlings appeared and seedling numbers were decreased only for those kernels having the largest embryo and smallest endosperm. Embryo size had little effect on plant growth and the amount of reserve material available to the embryo was the dominant factor affecting seedling size.

Chang and Robertson (1968) stated that large seeds of barley produced taller plants with broader leaves and they attributed the superiority of large seeds to the greater amount of stored energy compounds in the endosperm. DasGupta and Austenson (1973a) found that variation in yield between seed lots of spring wheat were related primarily to seed size in 1968 samples and to germination in 1969 samples.

Seed size has been shown to affect cereal yields (Kaufmann and McFadden, 1963; Whitcomb, 1936). Austenson and Walton (1970) and Knott and Takuldar (1971) found seed weight to have a positive correlation with yield. Voronin et al. (1970) reported that large, medium, and small seed of spring wheat produced 6, 5, and 4 seminal roots, respectively.

Evans and Bhatt (1977) conducted greenhouse experiments to study the influence of seed size, protein content and cultivar on seedling vigor of wheat measured as seedling dry weight at 20 days. The simple and partial correlation coefficients among the variables were all positive and significant. They suggested that genotypic differences in seedling vigor may lead to its use as a selection criterion in wheat breeding programs.

Grabe and Garay (1975) studied the effects of seed source and size on wheat yields. They found that large seed outyielded unsized seed by 3.36 kg ha^{-1}, while small seed yielded 3.36 kg ha^{-1} less than unsized seed. A positive relationship between seed size and vigor in wheat has been shown by Bremner et al. (1963), Geiszler and Hoag (1967), Lopez and Grabe (1973), Evans and Bhatt (1977). In barley, seed size and vigor relationship has been studied by Boyd et al. (1971), Kaufmann and Guitard (1967), and with seed weight by McDaniel (1969) and Ching et al. (1977).

Pinthus and Osher (1966) reported that seed size had no effect on seedling emergence in wheat and barley varieties, although plants grown from large seeds grew higher and produced more kernels. McNeal and Berg (1960) noted little effect of source, protein content, and test weight of seed on yield. Demirlicakmak et al. (1963) studied the influence of seed size on yield and yield components of barley. They observed that there was no effect of seed size on emergence, although the culm counts and yields were highest for large seed and lowest for small seed.

Speed of Germination

Speed of germination is one of the oldest seed vigor concepts. Vigorous seeds have been shown to germinate rapidly. Speed of germination has been measured by various techniques and given many different names such as: emergence rate index (Allan et al., 1962), germination rate (Maguire, 1962), germination value/peak value (Czabator, 1962; Djavanshir and Pourbeik, 1976), and speed of germination (Lawrence, 1963). Several methods for determining germination rate have been used (Nicholas and Heydecker, 1968; Tucker and Wright, 1965; Timson, 1965). Belcher and Miller (1974) measured speed of germination with criterion of the number of days a lot required to reach 90% germination.

Speed of germination tests have important advantages. They are inexpensive, rapid, require no specialized equipment, most importantly do not necessitate additional technical

training. The disadvantages are that moisture and temperature are difficult to standardize among laboratories, yet they have a profound effect upon speed of germination. A speed of germination is more stringent and requires the analyst to have a well-defined concept of a germinated seed (McDonald, 1975). Speed of germination has been shown to be positively correlated with seed vigor in wheat, rye and barley (Germ, 1960), barley (Cobb and Jones, 1966), corn (*Zea mays* L.) (Gill and Delouche, 1973; Mian and Coffey, 1971a; Rajanna and de La Cruz, 1975), rice (*Oryza sativa* L.) (Mian and Coffey, 1971b).

Bobkova and Pashkevich (1980) found correlation between the initial growth vigor of wheat seeds and grain yields, indicating a possibility of determining the yielding ability of seeds from their initial growth vigor. Berezkin et al. (1978) reported in wheat and barley that the growth rate was the most reliable index for predicting yield. Other factors evaluated were 1000 seed weight, protein content, embryo weight, endosperm weight, and field germination. They also stated that criteria for an indirect estimation of barley yield were not found.

Cold Test

A cold test is a stress test which tries to duplicate spring field conditions in the laboratory by placing the seed in cold, wet, pathogen-infested soil for a specified period followed by warm conditions which allow the seeds to germinate. Germination counts indicate how a seed lot will perform in the field (AOSA, 1983). The ability of seeds to germinate in cold, wet soil is affected by heredity, mechanical injury, seed treatment and physiological condition of the seeds. The cold test measures the combined effect of all of these factors and others (AOSA, 1976).

The cold test is the most widely used vigor test currently available in the United States. This vigor test has received widespread acceptance for corn (Clark, 1953, 1954; Rice, 1960; Grabe, 1965; Svien and Isley, 1955; Crosier, 1957). During the past two

decades, this test has been used to vigor test other species, for example; soybean [*Glycine max* (L.) Merr.] (Rice, 1960; Byrd and Delouche, 1971), cotton (*Gossypium hirsutum* L.) (Mehdi et al., 1971; Bishnoi and Delouche, 1975), and sorghum [*Sorghum bicolor* (L.) Moench] (Pinthus and Rosenblum, 1961).

DasGupta and Austenson (1973b) reported in spring wheat that field stands at all locations were positively correlated with standard, cold, and modified cold germination percentages. Grain yields in all tests were positively correlated with all estimates of germination and with their respective field stands. Hampton (1981) examined the relationship between field emergence and both laboratory germination percentages and several vigor tests for wheat. Results of field emergence trials were more closely correlated with direct stress vigor tests than laboratory germination when soil conditions were unfavorable, but no advantage was gained from vigor testing when soil conditions were good. Field emergence was closely correlated with soil temperature at a depth of 5 cm. He proposed the use of a vigor test involving germination at 5 C for seven days, then 20 C for four days for vigor testing of New Zealand's cereals.

Accelerated Aging Test

This test was first developed to measure the relative storability of seeds (Delouche, 1965; Delouche and Baskin, 1973). Seed samples are placed under stress conditions of high temperature (40-45 C) and high relative humidity ($\sim$ 100%) for a certain period of time. A standard germination test is conducted after seeds have been stressed. The decline in germination during this accelerated aging is related to the initial degree of deterioration of the seed lots viz. high vigor germination remains high; low vigor lots show a marked decline in germination. The basic assumption of this test is that the germination percentage after accelerated aging is correlated with vigor of the lot and hence to the lot's capacity to perform well under field conditions (AOSA, 1976).

Helmer et al. (1962) observed the germinative response of crimson clover (*Trifolium incarnatum* L.) following several days' exposure to high levels of relative humidity (≈ 100%) and temperature (35-40 C) was closely associated with seed vigor and seedling emergence under field conditions.

Pili (1967) used accelerated aging technique to evaluate the storability of alfalfa (*Medicago sativa* L.), wheat, corn, and cotton. She observed differential responses among seed lots of each kind. She concluded that this test was efficient in evaluating storability of alfalfa and corn, but was less efficient for wheat and cotton. Although accelerated aging test responses were significantly correlated. Pili (1967) used several exposure period (3 to 6 days) and found that three days was optimum for wheat. Therefore, short period of exposure to accelerated aging may improve effectiveness of the test for wheat.

Herrera (1969) reported on a study in which seeds of five cultivars of wheat grown at three locations in Mississippi were subjected to 40 C and 100% relative humidity for 0, 5, 6 and 7 days. Significant reductions in germination percentage were obtained following seven days of exposure. He concluded that the accelerated aging test was the best indicator of seed deterioration of the five methods evaluated. Omar (1980) indicated that germination was substantially reduced by four days aging at 40 C and 100% relative humidity and by two days at 45 C and 100% relative humidity in wheat.

Baskin (1977) suggests the use of wire-mesh baskets as seed containers and jars as accelerated aging chamber. The AOSA vigor handbook (1976) suggests using small plastic seed containers and a large plexiglass box as the aging chamber. McDonald (1977) working with soybean and barley showed that seed moisture influenced the accelerated aging test. McDonald and Phaneendranath (1978) suggested using a single layer of seed in wire mesh trays placed in a small plastic box. These techniques are important steps in the standardization of this test.

Tao (1979) confirmed McDonald's conclusions that initial seed moisture influenced the rate of accelerated aging in soybean seeds. He also found that sealed jars were superior to large accelerated aging chambers. The height of seed samples above the water affected the results. He further suggested that square plastic germination box be used instead of jars to save space.

Accelerated aging tests have been used to forecast stand establishment in several crops, for example: pea (*Pisum sativum* L.) (Caldwell, 1960), peanut (*Arachis hypogaea* L.) (Baskin, 1971), soybean (Byrd and Delouche, 1971; Tekrony and Egli, 1977), bean (*Phaseolus vulgaris* L.) (Roos and Manalo, 1971), and cotton (Bishnoi and Delouche, 1980).

Respiration Test

Seed respiration is the process of degrading stored foods reserves to provide metabolic energy for seed germination and seedling growth. The correlation between respiration and vigor is based upon the fact that vigorous seeds which germinate and grow rapidly require more energy which is supplied by increased respiratory activity. If the mitochondria are not functional due to loss of membrane structure, then respiratory activity decreases, resulting in little or no embryonic axis elongation (McDonald, 1975).

The respiration test is quantitative, rapid, easy to standardize and perform, well suited for routine testing of large numbers of seed samples and, with suitable precautions, reliable (Woodstock, 1966). Several factors can influence the rate of respiration, for example, temperature as reported by Bailey (1918) in wheat. Carbon dioxide production in the respiration process was found increasing regularly with the increase in relative humidity in stored wheat, barley and oats (Robertson and Lute, 1939); presence of microflora on and in the stored wheat seed (Oxley and Jones, 1944). However, Denney (1948) and Ragai and Loomis (1954) concluded that surface microorganisms did not effect respiration results significantly.

Mechanical injury in seeds complicates the interpretation of respiration results, which may increase rather than decrease respiration rates (Woodstock, 1969). Respiration rates measured during the first 18 hours of germination detected injury caused by gamma radiation in corn, sorghum, wheat and radish (*Raphanus sativus* L.) (Woodstock and Combs, 1965; Woodstock, 1968).

Woodstock and Grabe (1967) observed a significant positive correlation between rates of O_2 uptake during imbibition and later stages of germination and seedling growth in corn. They also noted a highly negative correlation between respiration quotients and seedling growth.

Kittock and Law (1968) studied the relationship of seedling vigor and respiration in wheat. Significant positive correlations were found between rate of emergence and vigor (ability to emerge from deep seeding), emergence and rate of respiration, and between vigor and both tetrazolium chloride reduction and rate of respiration for seeds of different ages. Anderson and Adbul-Baki (1971) observed glucose metabolism of embryos and endosperm from deteriorating barley and wheat seeds. They found that excised embryos from deteriorated wheat seeds had reduced respiration and glucose utilization into ethanol-insoluble material but not into CO_2. Accelerated aging treatments had no effects on respiration of excised endosperms, although they reduced utilization of glucose into ethanol-insoluble material and CO_2. Changes in metabolic activity of whole seeds in response to deterioration treatments are difficult to interpret because they represent the sum of the changes that take place in the embryos and endosperms. They concluded that changes in respiration and glucose utilization in these two parts of the seed neither proceed at the same rate nor go in the same direction during deterioration.

In a study of 75 spring wheat genotypes, no relationship was found between seedling vigor, field establishment and ATP content of dry seed, or seedling (Briggs and Horak, 1980). They suggested that in any search for genotypic variability for stand establishment

in spring wheat, differential seedling mortality rates and dry weight accumulation at the five leaf stage appear to be useful characteristics to measure.

DasGupta and Austenson (1973b) reported that spring wheat yield variations among samples were most consistently dependent on standard germination, O_2 uptake and field emergence. They concluded that the rate of O_2 uptake by seed during the 8th and 9th hours of imbibition was a satisfactory indicator of seed vigor.

Correlation between seed lot shoot lengths and respiration were not significant ($r = 0.20$), nor were correlations between respiration and grain yield ($r = 0.03$). In all cases there was a highly significant inverse correlation between respiration and seed lot test weight. To further understand why respiration was negatively correlated with test weight, a water uptake study was performed. Water uptake was found to be positively correlated with test weight and protein content of the planted seed ($r = 0.63^*$, $r = 0.68^*$ respectively). Because of this, respiration was negatively correlated with winter uptake ($r = -0.60$, varieties pooled) (Delaney, 1980).

Matthews and Collins (1975) observed that field emergence of seed lots of 'Golden Promise' barley, was directly related to the rate of emergence. The rates of O_2 uptake were directly related to both rate of emergence and ultimate emergence.

Ching et al. (1977) reported that spring and winter barley seed weight, three-day-old seedling ATP content, TAP content of the hydrated embryo, and seven-day-old seedling dry weight were good seedling-vigor indices for predicting field emergence rate.

Ellis and Hanson (1974) found significant correlation between scutellar O_2 uptake rate from germinating seed and grain yield of greenhouse-grown plants. They also observed relationship between scutellar O_2 uptake and percentage germination. Percentage germination was correlated with field emergence. However, other researchers who have reported that respiration was not correlated with vigor in wheat and barley (Abdul-Baki, 1969; Anderson, 1970; Lopez and Grabe, 1973).

Electrical Conductivity Test

The conductivity test measures the amount of electrolytes which leach from seeds as they deteriorate. Presley (1958) used this test to measure seed viability. The test was later developed into a vigor test for the prediction of field emergence of wrinkle garden peas (Matthews and Bradnock, 1967, 1968). Poor membrane structure and leaky cells are usually associated with deteriorating and low vigor seed.

Koostra (1973) reported the loss of selective permeability of cell membranes by measuring the electrical conductivity of seed leachates. During imbibition, water soluble substances such as peptides, enzymes, carbohydrates, and amino acids leaked out of the cells of deteriorated seed. Abdul-Baki and Anderson (1970) observed that leaching of sugars from mechanically injured barley seed was higher than from whole seed with equal viability. They also concluded that increased leaching of glucose was related to changes in membrane permeability which was also associated with low viability. The quantity of glucose leached depended on glucose concentration in the seed and the rate at which it was utilized in metabolic processes. In high quality seed, the rate of glucose utilization was faster and, therefore, the concentration of glucose in the leachate was less.

The integrity of membranes is important for many biochemical reactions in living cells. Changes in membrane ultrastructure and permeability in aged seeds have been observed (Gill and Delouche, 1973; Harman and Granett, 1972). The extent of leakage from low vigor seeds also causes secondary effects. Nutrients exuded from seeds during germination stimulate microorganism activity and secondary infection (AOSA, 1983). Hibbard and Miller (1928) reported that the electrical resistance of the seed leachates of peas, timothy (*Phleum pratense* L.), and wheat decreased as viability decreased.

Omar (1980) made measurements on conductivity in wheat with an ASA 610 seed analyzer. He observed that germination values predicted on the basis of conductivity

did not correspond closely with actual germination percentages. The partition operational mode did not detect the lower vigor of lots as established by accelerated aging and storage. He suggested plotting population conductivity profiles on the basis of individual seed readings which provides more meaningful information than simple categorization of the seed as germinable or nongerminable in the partition operational mode.

Conductivity test results in AOSA vigor referee programs were significantly correlated with field emergence for field corn and soybean and also was a vigor test which was repeatable among laboratories (Tao, 1980a, 1980b).

The conductivity test has been shown to correlate with vigor in seeds of barley (Abdul-Baki and Anderson, 1970), rice (Agrawal, 1977), corn (Gill and Delouche, 1973; Tao, 1980a, 1980b), pea (Matthews and Bradnock, 1967; Carver and Matthews, 1975; Scott and Close, 1976), bean (*Phaseolus vulgaris* L.) (Matthews and Bradnock, 1967), soybean (Abdul-Baki and Anderson, 1973a; Yaklich et al., 1979; Tao, 1980a, 1980b).

Glutamic Acid Decarboxylase Activity (GADA)

Measurement of the activity of specific enzymes was one of the earliest biochemical techniques used to assess deterioration and predict seed viability. As seeds germinate, proteolytic enzymes increase and hydrolyze proteins to provide carbon and nitrogen necessary for assimilatory growth processes. Glutamic acid, an amino acid is present in large quantities in seed protein (for example, 31% in wheat (FAO, 1970)), is converted by the enzyme glutamic acid decarboxylase into γ-aminobutyric acid and CO_2. Glutamic acid decarboxylase activity (GADA) has been shown to be highly active in vigorous seeds and less active in seeds of lower vigor (McDonald, 1975). Cheng et al. (1958) observed significant differences in the activity of glutamic acid decarboxylase in different varieties of wheat seed.

Linko and Milner (1959) studied the effect of water on enzyme activation in wheat. They found seed moisture levels as low as 18% activated enzyme systems. The activity of these systems increases rapidly with increasing moisture content. Glutamic acid decarboxylase is located almost entirely in the embryo. In intact seed, other metabolic reactions overcome the decarboxylation of glutamate at moisture levels higher than 18% resulting in a net production of glutamate.

Linko and Sogn (1960) observed that the GADA of 25 commercial wheat samples was highly correlated with percentage of germ-damaged seed ($r = -.88^{**}$) and with germination percentage ($r = .92^{**}$). With 19 samples of new crop wheats of little germ damage and high germination percentage, the correlation between glutamic acid decarboxylase activity and viability was insignificant, largely due to differences in decarboxylase activity of wheats from various locations and of different variety. They concluded that though glutamic acid decarboxylase activity seemed to have little value in examining new crop wheats of high viability, either alone or together with other tests it may give a good picture of the storage ability of wheat.

In 1961, Linko developed a simple and rapid manometric method for determining glutamic acid decarboxylase activity as quality index of wheat. He measured the CO_2 evolution due to the decarboxylation of glutamic acid and found a highly significant correlation between germination percentages and the observed pressure increases. He also observed that the estimate of the storage conditions of wheat by GADA was equal to or better than that by fat acidity determination.

Grabe (1964) evaluated glutamic acid decarboxylase activity (GADA) as an index of seed deterioration and seedling vigor of corn and oats. Of the various measurements compared, GADA was the most sensitive, followed in order by root length, cold test performance, and germination. Early stages of seed deterioration did not affect the stand producing ability of the seed. Vigor tests based on germination performance thus appear better

suited for predicting field emergence, while tests based on measurement of enzyme activity appear more adapted for measuring other aspects of vigor.

Grabe (1965) used GADA, seedling growth rate, germination, and the cold test to predict relative storability of corn seed lots. He concluded that longevity was associated with prestorage conditions, GADA, and seedling growth rate. However, field emergence was not related to GADA.

Bautisa et al. (1964) used glutamic acid decarboxylase activity as a viability index of artificially dried and stored rice. They concluded GADA was a more reliable index than fat acidity method. Azizul Islam et al. (1973) reported GADA was the most sensitive measure of the progress of deterioration in rice seed but was closely followed by germination responses after accelerated aging. They also noted that deterioration was not reflected in a decrease in germination percentage—the traditional index of the physiological quality of seed—until it had substantially advanced.

Abdul-Baki and Anderson (1973b) studied the relationship between decarboxylation of glutamic acid and vigor in soybean seed. They reported that vigor of soybean lots is highly correlated with the ability of the excised embryonic axes to incorporate glutamic acid into water-soluble protein and maintain a relatively high rate of respiration. The decreased O_2 uptake and CO_2 production by the low vigor lots, was pronounced in the axes and negligible in cotyledons. They suggested that a search for biochemical indices to measure seed vigor should be focused on embryonic axes rather than on whole seeds.

Burris et al. (1969) observed little relationship between GADA and seedling vigor in soybean and James (1968) found GADA high while germination decreased in bean seeds. Bautisa and Linko (1962) reported that GADA provided a quick and reliable way to estimate storage deterioration of corn. This method also detected damage caused to proteins by operations such as drying at excessively high temperature.

MATERIALS AND METHODS

Laboratory Studies

Standard Germination Test

Fifty seeds were counted per lot for each replication. Seed were placed in (10 X 10 cm) plastic germination boxes with moistened blue filter paper and kept at 15 C in the germinator for seven days. Normal seedlings were counted according to rules for testing seed (AOSA, 1978) and expressed as percentage germination.

Speed of Germination

Speed of germination index was calculated as described by Maguire (1962).

$$x = \frac{\text{number of normal seedling}}{\text{days of first count}} + \ldots + \frac{\text{number of normal seedlings}}{\text{days of final count}} .$$

Cold Test

The cold test was conducted as suggested in AOSA (1983). Fifty seeds were counted for each replication and germinated in soil in plastic boxes. The germination medium used for this test was the soil which was brought from the field where the crop was planted. Moisture percent and water holding capacity of the soil were determined. Enough water (temp 10 C) was added to the soil to reach 70% of the water holding capacity (WHC ≈ 54%). Seed boxes were covered and placed in a 10 C chamber. After seven days boxes were transferred to 25 C chamber. Eleven days after the start of cold test, emerged seedlings were counted and reported as percentages.

Accelerated Aging Test

Seeds were exposed to 41 C and approximately 100% relative humidity for six days based on a preliminary study. The aging chamber used was a 28 X 24 X 13 cm plastic box, with two shelves of plexiglass with numerous holes were used to facilitate water vapor movement to maintain uniform relative humidity in the chamber. Distilled water was placed in the bottom of the chamber at depth of 2.5 cm. The water level was 2 cm from the lower shelf. Disposable plastic petri dishes were used as seed containers. A single layer of $\sim$ 200 seeds were placed in each petri dish. The chamber was closed with heavy duct tape to make it water and airtight and then transferred to an incubator at 41 C. After six days (144 hrs), the aging chamber was removed from the incubator and the seeds were germinated as described for the standard germination test. Mean percentage germination of 200 seeds was considered as one replication of accelerated aging. These procedures were repeated at least four times for each accelerated aging study.

Respiration Rate

Oxygen uptake was measured by Gilson Differential Respirometer. Twenty seeds were weighed, soaked in 50 ml distilled water for three hours and placed with 2 ml water in a reaction flask and 0.2 ml KOH 10% in center well. The reaction flasks were placed in a 25 C water bath and were shaken to 78 oscillations min^{-1}. The system was equilibrated for 30 min. Readings were taken three times at an interval of 30 min. Respiration rate was reported as microlites of oxygen absorbed per gram per minute ($\mu LO_2\ g^{-1}\ min^{-1}$) as well as microliters of oxygen per seed per minute ($\mu LO_2\ seed^{-1}\ min^{-1}$) at standard temperature and pressure.

Electrical Conductivity Test

Two electrical conductivity tests were used; one using the procedure suggested by AOSA (1976) and the second using the ASA-610.

Method 1. Four replicates of 50 seeds each were weighed. The replicates were placed in 500 ml flasks and 250 ml of deionized water were added to each. The flasks were placed in an incubator at a constant temperature of 20 C for 24 hours, after which time the contents of the flask were gently stirred. The electrical conductivity was measured with a Wescon conductivity meter and reported as μmhos per cm per gram of seed weight (μmhos cm^{-1} g^{-1}).

Method 2. Conductivity Index—An index was developed from the readings obtained from the Automatic Seed Analyzer (ASA 610) developed by AgroSciences, Inc., Ann Arbor, Michigan. Seeds were soaked for 22 hours at 25 C. The conductivity index was calculated as follows:

$$\text{Electrical Conductivity Index} = \frac{\text{number of seeds } < 60\ \mu\text{ amp}}{1} + \frac{\text{number of seeds } 60\text{-}64\ \mu\text{ amp}}{2} + \ldots + \frac{\text{number of seeds } 115\text{-}119\ \mu\text{ amp}}{13} + \frac{\text{number of seeds } > 120\ \mu\text{ amp}}{14}$$

Glutamic Acid Decarboxylase Activity (GADA)

Glutamic acid decarboxylase activity was determined as described by Linko (1961). The Gilson Differential Respirometer was used to determine the enzyme activity. The substrate solution used was 0.1 M glutamic acid in 0.067 M phosphate buffer at pH 5.8. This was prepared as follows: 9.08 g of dry monobasic potassium phosphate (KH_2PO_4) was dissolved in one L of distilled water (Solution A); a second solution was prepared by dissolving 9.47 g of dry dibasic sodium phosphate (Na_2HPO_4) in one L of water (Solution B); then 193.5 milliliters of solution A was mixed with 16.5 milliliters of solution B to give 200 milliliters of 0.067 M phosphate buffer solution with a pH of 5.8. The reaction mixture was prepared by dissolving 1.471 g of glutamic acid crystals in 100 ml of the buffer

solution. The buffer solution was stored in the refrigerator but the reaction mixture was prepared fresh each day.

Approximately 25 g of seed were finely ground in a Udy cyclone mill equipped with a 1 mm screen. Approximately one g of ground seed samples were weighed up to three decimals and placed in the reaction flask with 2.5 ml of reaction mixture based on a preliminary study. The contents were thoroughly mixed by stirring with a glass rod. Reaction flasks were placed in a 30 C water bath and were shaken at 78 oscillations min^{-1}. System was equilibrated for 10 min. Carbon dioxide evolution was measured every 15 min three times. The enzyme activity was measured as microliters of CO_2 per gram per minute ($\mu LCO_2\ g^{-1}\ min^{-1}$) at standard temperature and pressure.

Field Studies

The residual seeds from all seed lots of winter and spring wheat evaluated in the laboratory were planted at the Arthur H. Post field research laboratory near Bozeman, Montana. The soil at the field research laboratory is classified as Amsterdam variant of silt loam (fine-silty, mixed family of Typic Haploborolls). All field experiments were laid out in a randomized complete block design with four replications. Plot size was 3.05 m X 1.83 m (10' X 6') and each plot contained 6 rows, spaced 0.305 m, giving a total plot size of 5.57 m^2.

After planting and before emergence of seedlings, 0.5 m length was marked off from each of the two central rows of each plot. Emergence rate, stand establishment, plants m^{-1} of row and heads $plant^{-1}$ were recorded from this sampling unit. Other variables including grain yield were determined from the four central rows excluding two border rows of each plot.

Emergence rate index was calculated similarly to the speed of germination index. The emergence rate index was calculated as follows:

$$x = \frac{\text{number of seedlings emerged}}{\text{days of first count}} + \ldots + \frac{\text{number of seedlings emerged}}{\text{days of final count}}$$

Stand establishment was determined by counting the total number of seedlings emerged in one m of row, once emergence was complete. Upstretched seedling height of winter wheat seedlings was measured seven months after seeding and was reported in cm.

Plant height was measured as the distance from the soil surface to the top of the spike, excluding awns. Heading date was determined as the number of days after January 1 required until 50% of tillers had their spike emerged from the boot. Plants m^{-1} was determined as the total number of plants m^{-1} of row at maturity, which was also considered to be the mature plant population. Heads $plant^{-1}$ was calculated by dividing the number of heads m^{-1} of row by the number of plants m^{-1} of row. Seeds $head^{-1}$ was determined by selecting 25 heads at random from the harvested area of each plot. These 25 heads were threshed, seeds counted with an electronic counter and total number of seeds divided by 25 to determine the number of seeds $head^{-1}$.

One thousand seed weight was calculated by converting the seed number and weights of the seed from the 25 heads to 1000 seed weight and reported in g. Grain yield was determined based on the harvested samples which were harvested with a chain combine, cleaned and dried before sample weight was determined and reported as kg ha^{-1}.

Statistical Analysis

All variables of the laboratory studies and field studies were subjected to analysis of variance. Means were separated using protected least significant difference (LSD). Simple correlations were computed from the mean values, using 'MSUSTAT' (Lund, 1979). A multiple stepwise regression procedure (forward selection and backward elimination) using BMDP (Dixon and Jennrich, 1981) analysis was used to select a battery of seed vigor tests which, from those tests performed, would predict field performance. Scatter diagrams

comparing field performance and each vigor test were plotted. The validity of the multiple regression was further verified by plotting the residuals against predicted values and also by preparing normal probability plots. Predicted values of field performance variables were plotted against observed values to show the magnitude of multiple correlation. Quadratic terms were also used to explore the possibility of nonlinear relation.

Winter Wheat

First Year Studies (1980-81)

Ten seed lots from five cultivars, two lots of each, constituted the seed source for this study. Most of these lots were from the winter wheat breeding program which were stored in the Plant and Soil Science seed room for various length of time. The storage conditions were temperature $\approx$ 10 C and $\approx$ 50% relative humidity. The specific details of these lots are given in Appendix Table 22.

Laboratory Studies. All seed lots were sized to obtain uniform seed size. Seeds which passed through 7/64 X 3/4 screen and did not pass through 6/64 X 3/4 were used for this study. Seed was sized to eliminate the effect of seed size on vigor tests. All seed samples were subjected to the following seed vigor tests: standard germination, speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity (ASA 610).

Field Studies. Once seed vigor status was evaluated, field studies were planted on 24 September, 1980 as explained earlier at seeding rate of 67.2 kg ha^{-1} pure live seed. The field performance was evaluated as: emergence rate index, stand establishment, seedling height, plant height, heading date, number of plants m^{-1} row, number of heads $plant^{-1}$, number of seeds $head^{-1}$, 1000 seed weight, and grain yield.

Second Year Studies (1981-82)

Twelve different seed lots of the cultivar 'Redwin' were obtained from the state seed testing laboratory. These seed lots had a high percentage germination and were all of the certified seed class or better. The specific details concerning these seed lots are given in Appendix Table 23.

Laboratory Studies. All seed lots were subjected to the following vigor tests: standard germination, accelerated aging, and glutamic acid decarboxylase activity (GADA).

Field Studies. Field studies were planted on 20 September, 1981 at seeding rate 67.2 kg ha^{-1} pure live seed. Field performance of seed lots was evaluated as: emergence rate index, stand establishment, plant height, number of plants m^{-1}, number of heads $plant^{-1}$, number of seeds $head^{-1}$, 1000 seed weight, and grain yield.

Spring Wheat

First Year Studies (1981)

Five lots each of hard red spring wheat cultivars 'Lew' and 'Newana' were obtained from the state seed testing laboratory. These seed lots had a high percentage germination and were all certified classes or better. These seed lots were divided into sized and unsized seeds. Seeds which passed through 7/64 X 3/4 screen and did not pass through 6/64 X 3/4 screen were designated sized seed, whereas original seeds were considered as unsized seeds which included large, medium and small seeds. The specific details of seed sources are given in Appendix Table 24.

Laboratory Studies. All seed lots were subjected to the following vigor tests: standard germination, speed of germination, accelerated aging, cold test, respiration rate, and electrical conductivity (ASA 610).

Field Studies. Field studies were planted on 24 April, 1981 at seeding rate 67.2 kg ha^{-1} pure live seed. Field performance of the seed lots was evaluated as: emergence rate index, stand establishment, plant height, heading data, number of plants m^{-1}, number of heads $plant^{-1}$, number of seeds $head^{-1}$, 1000 seed weight, and grain yield.

Second Year Studies (1982)

Experiment I. Twelve different lots of cultivar Newana were the seed source for this study. These lots included certified seed, common seed and lots from spring wheat breeding program. The specific details of these lots are given in Appendix Table 25.

Laboratory Studies. Field studies were planted on 7 May, 1982 at seeding rate of 56 kg ha^{-1}. All seed lots were subjected to the following seed vigor tests: standard germination, speed of germination, accelerated aging, respiration rate, and glutamic acid decarboxylase activity (GADA).

Field Studies. Field performance of the seed lots was evaluated as: emergence rate index, stand establishment, plant height, heading date, number of plants m^{-1}, heads $plant^{-1}$, seeds $head^{-1}$, 1000 seed weight, and grain yield.

Experiment 2. Twelve different lots of cultivars Lew and Newana were created by artificial aging. Temperature = 50 C and R.H $\approx$ 100% for certain period of time. The specific details of seed sources are given in Appendix Table 26.

Laboratory Studies. All seed lots were subjected to the following seed vigor tests: standard germination, speed of germination, cold test, accelerated aging, respiration rate, electrical conductivity, and glutamic acid decarboxylase activity (GADA).

Field Studies. Field performance of seed lots was evaluated as: emergence rate index, stand establishment, plant height, heading date, number of plants m^{-1}, heads $plant^{-1}$, seeds $head^{-1}$, 1000 seed weight, and grain yield.

RESULTS AND DISCUSSION

Winter Wheat (First Year Studies, 1980-1981)

When comparing field emergence rate index and various vigor tests, accelerated aging was first selected by stepwise multiple linear regression. The 0.52 correlation value is not significant at 0.05 level. However, when respiration rate is added, the magnitude of the multiple correlation is increased to 0.83.* These two tests together explained 69% of the variability among seed lots for emergence rate index. Other tests evaluated included standard germination, speed of germination, cold test, and electrical conductivity. The accelerated aging values and respiration rate along with observed and predicted values of emergence rate index are shown in Table 1. Predicted values of emergence rate index using accelerated aging and respiration rate have been plotted against observed values (Fig. 1). This figure shows the relationship between the seed vigor tests (accelerated aging and respiration rate together) with the emergence rate index. Multiple correlation coefficient (R = 0.83*) is equivalent to the simple correlation between the observed and predicted value of emergence rate index using these two vigor tests. The slope of this line is also equivalent to the simple correlation and multiple correlation discussed above. Therefore, as the relationship between vigor tests and field performance variable increases, the slope of this line also increases to unity and vice versa.

When stand establishment was compared with various vigor tests, accelerated aging entered first into the regression equation. The 0.48 correlation value is not significant. However, when electrical conductivity values are added the magnitude of multiple correlation to 0.81* which is significant. Adding respiration rate to the above two tests increases the

*$P \leq 0.05$; **$P \leq 0.01$.

Table 1. Means of Vigor Tests, Observed and Predicted Values of Emergence Rate Index for Various Seed Lots of Winter Wheat (First Year Studies, 1980-81).

	Vigor Tests		Emergence Rate (index)	
Lot No.	Acc Aging (%)	Resp (μLO_2 $seed^{-1}$ min^{-1})	Observed	Predicted
1	58 ab	0.0261 f	8.90	10.47
2	62 ab	0.0240 def	12.50	10.14
3	66 b	0.0207 bc	9.30	9.01
4	67 b	0.0180 a	8.60	7.82
5	58 ab	0.0250 ef	10.00	9.88
6	48 a	0.0248 ef	8.00	7.98
7	68 bc	0.0185 ab	7.10	8.34
8	85 c	0.0223 cd	13.10	13.24
9	68 bc	0.0225 cde	10.30	10.36
10	62 ab	0.0209 bc	7.90	8.48
Mean	64	0.0223	9.57	9.57
LSD (0.05)	17	0.0026	NS	

correlation to 0.90*. Combining of data from these three laboratory tests explained 80% of the variability among seed lots for stand establishment. Other tests evaluated included standard germination, speed of germination, and cold test. None of these tests were important in predicting stand establishment. Accelerated aging values, electrical conductivity index, and respiration rate values along with the observed and predicted values of stand establishment are shown in Table 2. Predicted values of stand establishment using accelerated aging, electrical conductivity index, and respiration rate have been plotted against the observed values of stand establishment (Fig. 2). This figure shows that the relationship between these vigor tests and stand establishment is strong (R = 0.90*). The slope of this line (which is the R value) also indicates that this prediction is accurate by these tests.

For determining the relationship of grain yield with vigor tests, accelerated aging was selected by the stepwise regression. The 0.73* correlation is significant ($P \leq 0.05$). Accelerated aging test accounted for 53% of the variability among seed lots for yield. Other tests evaluated included standard germination, speed of germination, cold test, respiration rate, and electrical conductivity. Accelerated aging values along with observed and predicted