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

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Crop and Soil Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

March 1983

APPROVAL

of a thesis submitted by

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.

3-14-1983 — Loren E. Wiesner
Date — Chairperson, Graduate Committee

Approved for the Major Department

3/15/83 — Dwane G. Miller
Date — Head, Major Department

Approved for the College of Graduate Studies

3-15-83 — Michael Malone
Date — Graduate Dean

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for a doctoral degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. I further agree that copying of this thesis is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for extensive copying or reproduction of this thesis should be referred to University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106, to whom I have granted "the exclusive right to reproduce and distribute copies of the dissertation in and from microfilm and the right to reproduce and distribute by abstract in any format."

Signature Zhang Qimu

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.

Mr. Ram was awarded 'Junior Fellowship' by Indian Council of Agricultural Research, New Delhi, India to pursue a M.Sc. in Ag. Botany. In 1974, he obtained the M.Sc. (Plant Breeding) from Haryana Agricultural University, Hissar, India. He served as Agricultural Inspector for about two years (1973-1975) in the Department of Agriculture, Haryana.

Mr. Ram joined Haryana Agricultural University, Hissar in 1975, where he has been working as an Assistant Scientist in the Department of Plant Breeding. He is a 'Fellow' of Indian Society of Genetics and Plant Breeding, New Delhi.

Mr. Ram was nominated by the Indian Council of Agricultural Research, New Delhi as a candidate for advanced training in Seed Technology abroad under the National Seed Project of India financed by the World Bank. In March 1980, he came to Montana State University to pursue Ph.D. program. Mr. Ram is married to Bimla Devi and they have three children.

ACKNOWLEDGMENTS

I would like to thank the following people who directly and indirectly contributed in making my Ph.D. program successful. Dr. L. E. Wiesner, my major advisor, for his valuable advice, friendship, constructive criticism and encouragement throughout the course of this program and who was always available for consultation and direction. Dr. J. H. Brown and Dr. G. A. Taylor, members of my committee, for their constructive criticisms and help in conducting laboratory and field studies, respectively. Dr. R. E. Lund, advisor from minor area (Statistics), and Dr. J. M. Martin, members of my committee, for their statistical consultation. Dr. D. L. Smith, graduate representative, for his advice and favorable comments. Ms. Georgia Ziemba for her help in statistical analysis and computor programming. Dr. D. G. Miller, Head, Plant & Soil Science Department, Dr. J. R. Sims, Coordinator, International Agricultural Program, and Mrs. Stephanie Becker, International Student Advisor, for their concern for an international student.

Other scientists: Dr. D. F. Grabe, Oregon State University; Dr. L. O. Copeland, Michigan State University; Dr. J. C. Delouche, Mississippi State University; and Dr. M. B. McDonald Jr., Ohio State University, for their suggestions and help in my research.

Haryana Agricultural University, Hissar and the Indian Council of Agricultural Research, New Delhi, who sponsored this program under the National Seed Project financed by World Bank.

My parents, teachers, brothers and sisters, relative and friends in India and abroad for being my well wishers whose blessings have brought me up to this level.

My wife, Bimla, and our children Yogesh, Anu and Suresh for their love, sacrifice and great understanding during this entire program.

Mrs. Jean Julian for typing this manuscript.

TABLE OF CONTENTS

TABLE OF CONTENTS—Continued

LIST OF TABLES

Tables | Page

Tables Page

Tables Page

LIST OF FIGURES

Figures | Page

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 × 24 × 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 ∿ 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 (μLO_2 g^{-1} min^{-1}) as well as microliters of oxygen per seed per minute (μLO_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 (μLCO_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 ≈ 10 C and ≈ 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

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

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 ($P \leqslant 0.05$). 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

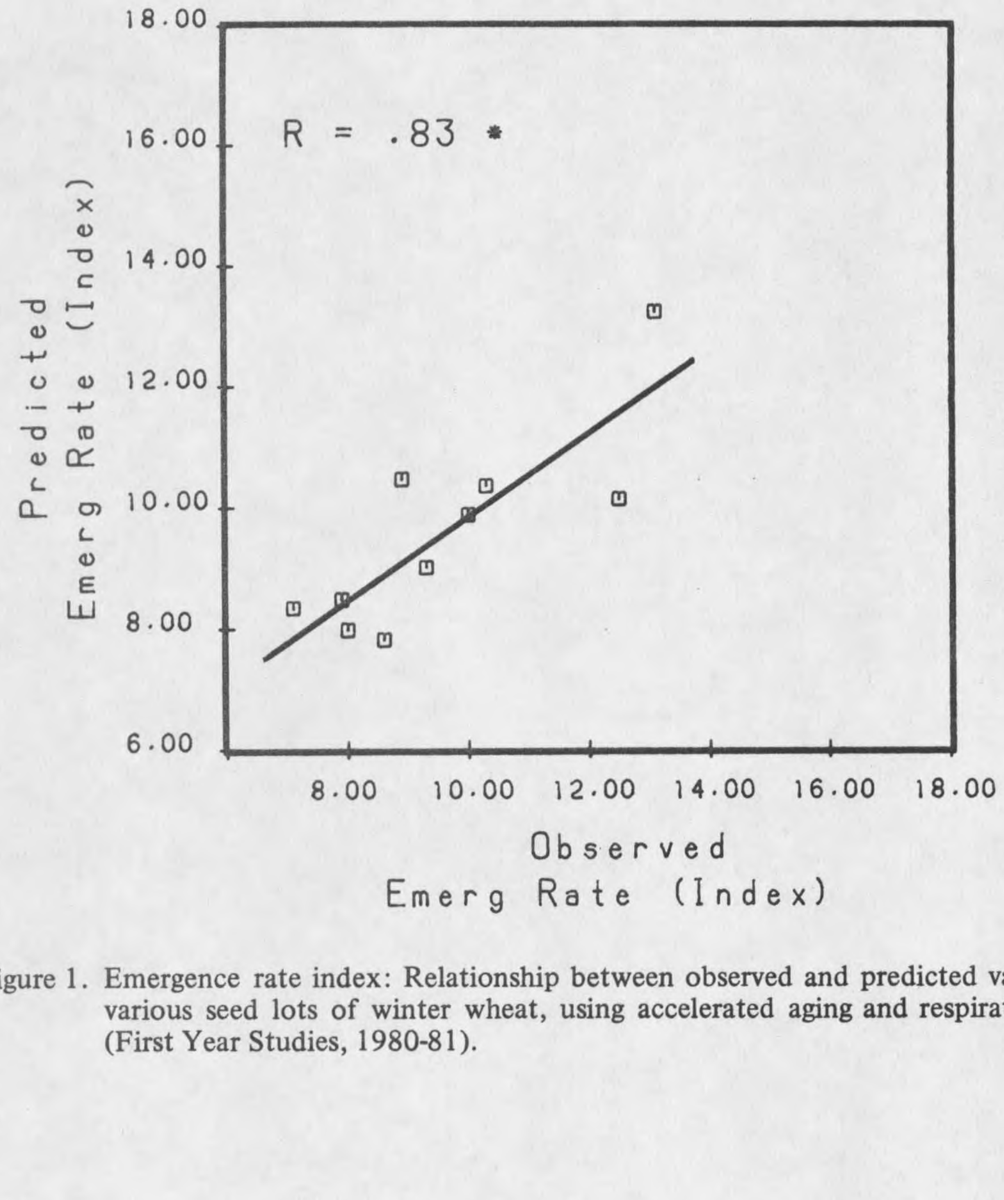

Figure 1. Emergence rate index: Relationship between observed and predicted values for various seed lots of winter wheat, using accelerated aging and respiration rate (First Year Studies, 1980-81).

Table 2. Means of Vigor Tests, Observed and Predicted Values of Stand Establishment for Various Seed Lots of Winter Wheat (First Year Studies, 1980-81).

	Vigor Tests			Stand Estab (seedling m^{-1})	
Lot No.	Acc Aging (%)	Cond Index	Resp (μLO_2 $seed^{-1}$ min^{-1})	Observed	Predicted
1	58 ab	33.10 e	0.0261 f	37	41
2	62 ab	30.20 de	0.0240 def	45	40
3	66 b	16.60 ab	0.0207 bc	33	31
4	67 b	22.80 abcde	0.0180 a	34	33
5	58 ab	21.30 abcd	0.0250 ef	34	32
6	48 a	27.50 bcde	0.0248 ef	28	29
7	68 bc	17.60 abc	0.0185 ab	29	31
8	85 c	12.30 a	0.0223 cd	43	43
9	68 bc	22.00 abcde	0.0225 cde	38	38
10	62 ab	28.50 cde	0.0209 bc	35	36
Mean	64	23.19	0.0223	36	36
LSD (0.05)	17	11.64	0.0026	NS	

values of grain yield are shown in Table 3. Predicted values of grain yield using accelerated aging have been plotted against the observed values of grain yield (Fig. 3).

Table 3. Means of Vigor Tests, Observed and Predicted Values of Grain Yield for Various Seed Lots of Winter Wheat (First Year Studies, 1980-81).

	Vigor Tests	Grain Yield (kg ha^{-1})	
Lot No.	Acc Aging (%)	Observed	Predicted
1	58 ab	5316 bc	4706
2	62 ab	5482 c	5032
3	66 b	5431 c	5276
4	67 b	5206 bc	5350
5	58 ab	3568 a	4706
6	48 a	3794 a	3966
7	68 bc	6673 d	5461
8	85 c	6199 d	6675
9	68 bc	5223 bc	5446
10	62 ab	4737 b	5010
Mean	64	5163	5163
LSD (0.05)	17	613	

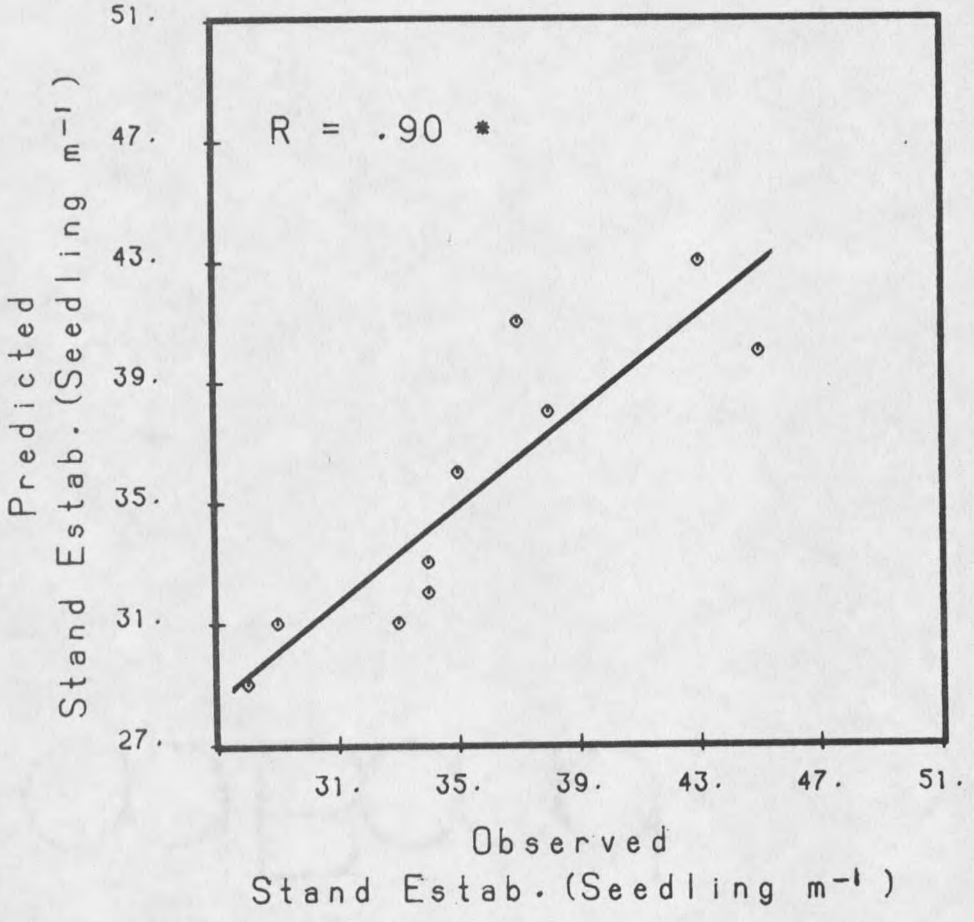

Figure 2. Stand establishment: Relationship between observed and predicted values for various seed lots of winter wheat, using accelerated aging, electrical conductivity, and respiration rate (First Year Studies, 1980-81).

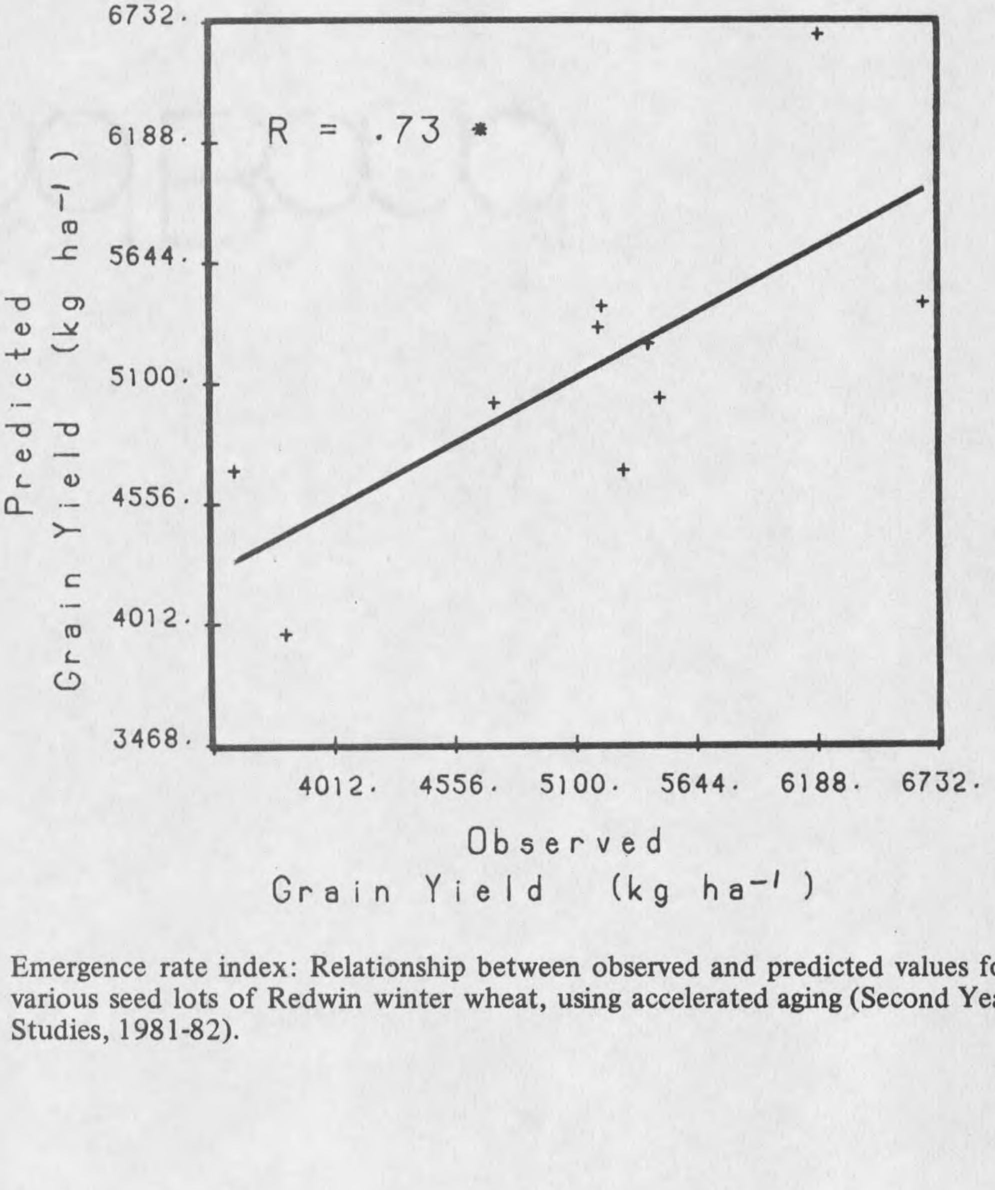

Figure 3. Emergence rate index: Relationship between observed and predicted values for various seed lots of Redwin winter wheat, using accelerated aging (Second Year Studies, 1981-82).

Mean squares and mean comparisons for all vigor tests are given in Tables 27 and 28, respectively. Accelerated aging results are reported in percentage of seeds which germinate after being exposed to a stress condition. Mean values ranged from 48 to 85 with an average of 64%, and there were significant differences among seed lots (Table 1). The philosophy of this test is that germination of a seed lot after accelerated aging is related to vigor and the capacity of the seed lot to perform well under stress in the field. Respiration rate ranged from 0.0180 to 0.0261 with an average of 0.0223 μLO_2 seed^{-1} min^{-1} (Table 2). Respiration rates for seed lots evaluated were significantly different. Vigorous seeds which germinate and grow rapidly require more energy which is supplied by increased respiratory activity. Therefore, the higher the respiratory rate, the better the seed quality. Mean values of electrical conductivity index ranged from 12.30 to 33.10 with an average of 23.19 (Table 2). Seed lots evaluated were significantly different for electrical conductivity index. The electrical conductivity index is high, when the seed lot has a low electrical conductivity due to low cell permeability. Therefore, the higher the index value, the better the seed quality.

Mean squares and mean comparisons for all field performance variables are given in Tables 29 and 30, respectively. Emergence rate index values ranged from 7.10 to 13.10 with an average of 9.57 (Table 1). Stand establishment values ranged from 28 to 45 with an average of 36 seedling m^{-1} (Table 2). Seed lots did not differ in their emergence rate index ($P = 0.09$) or stand establishment ($P = 0.12$). Their coefficients of variation (29.5, 23% respectively) were also high which might explain the nonsignificance. Seeding rate was 67.2 kg ha^{-1} which is the recommended rate for farmers in Montana under irrigated conditions. Moreover, these seeding rates were adjusted so that each seed lot had an equal number (63 seeds m^{-1}) of pure live seeds. These seed lots were screened to bring to uniform seed size, which eliminated a major component of seed vigor. All these factors contributed to nonsignificant differences among seed lots for both emergence rate index and stand establishment. One might expect significant differences among seed lots if planted under suboptimum conditions, e.g., dryland situations with low seeding rates. Grain yield ranged from 3568 to 6673 with an average of 5163 kg ha^{-1} (Table 3). Seed lots differed significantly for grain yield ($P < 0.01$).

Simple correlations among all the vigor tests and field performance variables are given in Table 49. Accelerated aging was not significantly correlated with emergence rate index or stand establishment (r = 0.52, 0.48 respectively). Accelerated aging had a significant positive correlation (r = 0.79**, 0.73*) with plants m^{-1} row and grain yield and negative correlation with conductivity index (r = −0.72*). Respiration rate μLO_2 g^{-1} min^{-1} was positively correlated with respiration rate μLO_2 $seed^{-1}$ min^{-1} (r = 0.98**) and both were significantly correlated with seedling height (r = 0.71*, 0.69* respectively).

Emergence rate index and stand establishment were significantly correlated (r = 0.87**). Accelerated aging test was related with most of the parameters of field performance evaluated, but the relationship was not significant for emergence rate index and stand establishment. However, with the addition of other vigor test, this relationship (multiple correlation) was significant. These results agree with the concept of evaluating seed quality suggested by Don et al. (1981). They suggested a combination of several tests were needed to fully evaluate winter wheat seed quality. Accelerated aging has shown promise in predicting stand establishment of other crops like peanuts (Baskin, 1971), cotton (Bishnoi and Delouche, 1980), pea (Caldwell, 1960), bean (Roos and Manalo, 1971), and soybean (Byrd and Delouche, 1971; Tekrony and Egli, 1977).

Respiration rate and electrical conductivity were important in predicting field emergence and stand establishment and should be used in conjunction with accelerated aging to improve field performance predictions. Respiration has been shown to be correlated with seed vigor in wheat (Kittock and Law, 1968; Woodstock and Justice, 1967; DasGupta and Austenson, 1973b) and in barley (McDaniel, 1969; Matthews and Collins, 1975; Ellis and

Hanson, 1974; Ching et al., 1977). However, some reports show that respiration rate does not always correlate with vigor (Abdul-Baki, 1969; Anderson, 1970; Lopez and Grabe, 1973; Delaney, 1980).

Electrical conductivity tests have shown promise in measuring seed vigor in wrinkle-seeded garden peas, rice, corn, barley, garden bean and soybean seeds, etc., however, AOSA vigor referee program results were not significantly correlated with field emergence for field corn and soybean (AOSA, 1983). Hampton (1981) observed in wheat significant (0.63*) and nonsignificant correlation with field emergence in two different studies.

Winter Wheat (Second Year Studies, 1981-82)

Evaluation of Redwin Seed Lots

The objective of this study was to evaluate the sensitivity of accelerated aging on different seed lots of the cultivar ‘Redwin’ winter wheat. Based on our first year studies accelerated aging was the single most important vigor test to predict field performance. In this study field emergence rate index was not predicted by any of the vigor tests evaluated even though stepwise regression selected accelerated aging as an important vigor test. The nonsignificant correlation value was 0.48. Twenty-three percent of the variability among seed lots for emergence rate was explained by this test. Other tests evaluated included standard germination, and glutamic acid decarboxylase activity. None of these tests contributed to predicting field emergence rate index. Accelerated aging values along with observed and predicted values of emergence rate index are shown in Table 4. Predicted values of emergence rate using accelerated aging have been plotted against observed values (Fig. 4). This plot indicates that this relationship is not dependable, as shown by nonsignificant correlation (R = 0.48).

Stand establishment was not predicted by any of the vigor tests evaluated. Glutamic acid decarboxylase activity and accelerated aging together explained 29% of the variability

Table 4. Means of Vigor Tests, Observed and Predicted Values of Emergence Rate Index for Various Seed Lots of Redwin Winter Wheat (Second Year Studies, 1981-82).

	Vigor Tests	Emergence Rate (Index)	
Lot No.	Acc Aging (%)	Observed	Predicted
1	85 e	53.56	45.98
2	75 de	45.27	43.87
3	69 cd	32.64	42.65
4	80 de	34.00	44.82
5	68 cd	48.40	42.36
6	79 de	41.44	44.73
7	38 a	38.04	35.96
8	74 de	43.93	43.64
9	46 ab	34.24	37.74
10	87 e	49.56	46.38
11	54 bc	40.37	39.51
12	66 cd	47.59	42.01
Mean	69	42.47	42.47
LSD (0.05)	16	NS	

among seed lots. Standard germination was also not important in predicting stand establishment. Glutamic acid decarboxylase activity, accelerated aging values, and the observed and predicted values of stand establishment are shown in Table 5. The predicted values of stand establishment using glutamic acid decarboxylase activity and accelerated aging have been plotted against the observed values (Fig. 5). This figure indicates that prediction is not reliable by these two vigor tests as shown by nonsignificant multiple correlation (R = 0.54).

Grain yield was not predicted by any of the tests evaluated. However, glutamic acid decarboxylase activity was selected first by step-wise regression even though the correlation (0.44) was not significant. Glutamic acid decarboxylase activity values along with observed and predicted values of grain yield are shown in Table 6. Predicted values of grain yield using glutamic acid decarboxylase activity have been plotted against observed values (Fig. 6). The slope and correlation (R = 0.44) of this plot indicates that this prediction is not reliable.

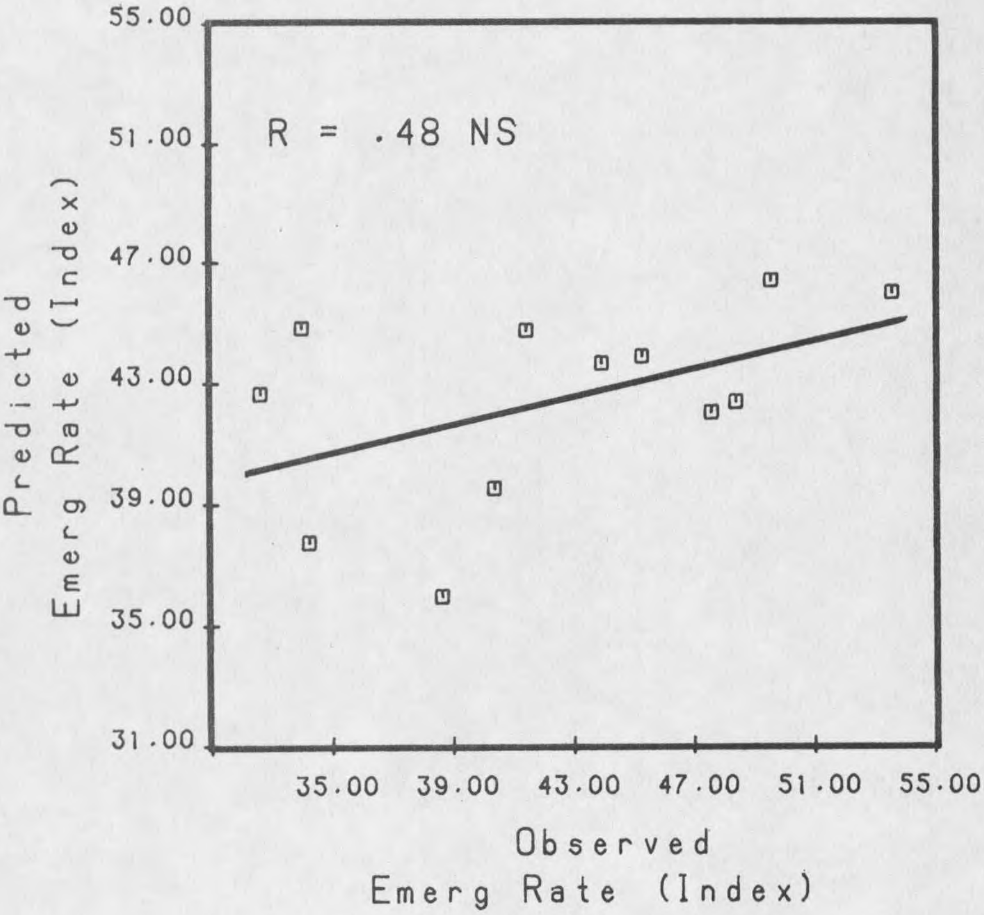

Figure 4. Emergence rate index: Relationship between observed and predicted values for various seed lots of Redwin winter wheat, using accelerated aging (Second Year Studies, 1981-82).

Table 5. Means of Vigor Tests, Observed and Predicted Values of Stand Establishment for Various Seed Lots of Redwin Winter Wheat (Second Year Studies, 1981-82).

	Vigor Tests		Stand Estab (seedling m^{-1})	
Lot No.	GADA (μLCO_2 g^{-1} min^{-1})	Acc Aging (%)	Observed	Predicted
1	8.45	85 e	78	68
2	8.56	75 de	62	67
3	8.99	69 cd	59	69
4	8.11	80 de	50	64
5	8.55	68 cd	69	65
6	7.86	79 de	63	62
7	8.02	38 a	55	56
8	8.05	74 de	67	62
9	8.02	46 ab	60	57
10	8.48	87 e	70	68
11	8.55	54 bc	61	63
12	9.06	66 cd	75	69
Mean	8.39	69	64	64
LSD (0.05)	NS	16	NS	

Table 6. Means of Vigor Tests, Observed and Predicted Values of Grain Yield for Various Seed Lots of Redwin Winter Wheat (Second Year Studies, 1981-82).

	Vigor Tests	Grain Yield (kg ha^{-1})	
Lot No.	GADA (μLCO_2 g^{-1} min^{-1})	Observed	Predicted
1	8.45	5297	5462
2	8.56	5313	5437
3	8.99	5185	5338
4	8.11	5454	5541
5	8.55	5260	5439
6	7.86	5615	5599
7	8.02	5603	5561
8	8.05	5537	5556
9	8.02	5540	5561
10	8.48	5599	5457
11	8.55	5912	5440
12	9.06	5398	5323
Mean	8.39	5476	5476
LSD (0.05)	NS	NS	

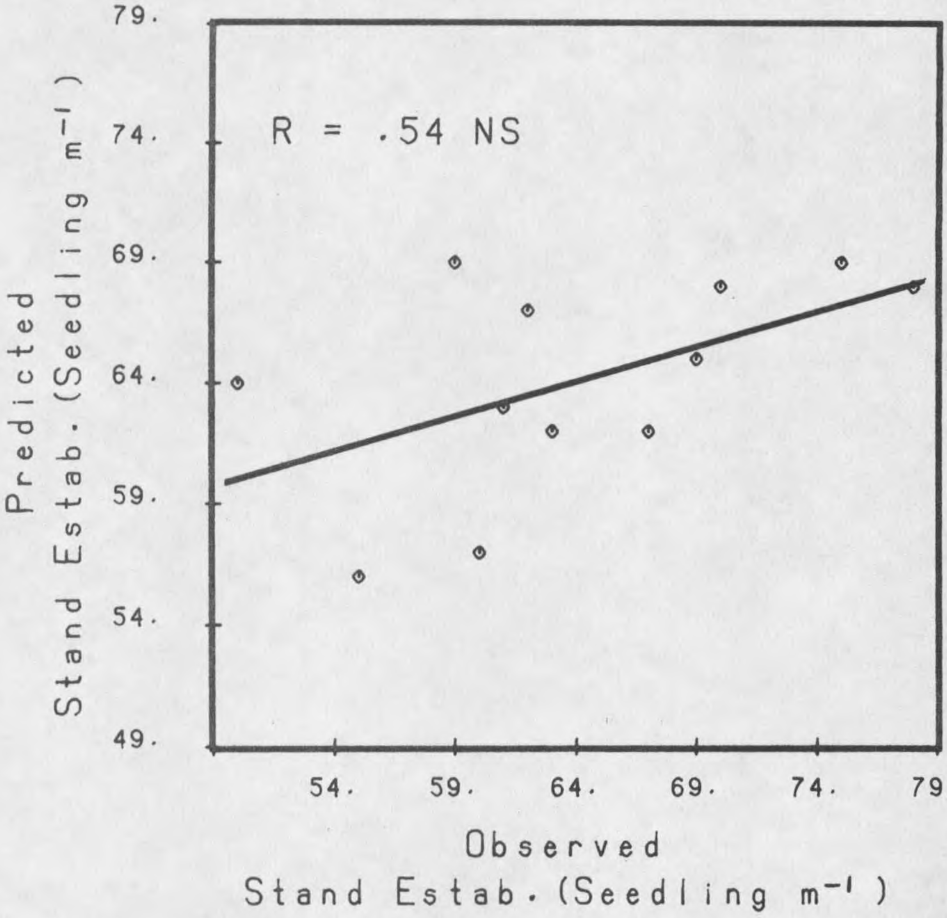

Figure 5. Stand establishment: Relationship between observed and predicted values for various seed lots of Redwin winter wheat, using glutamic acid decarboxylase activity and accelerated aging (Second Year Studies, 1981-82).

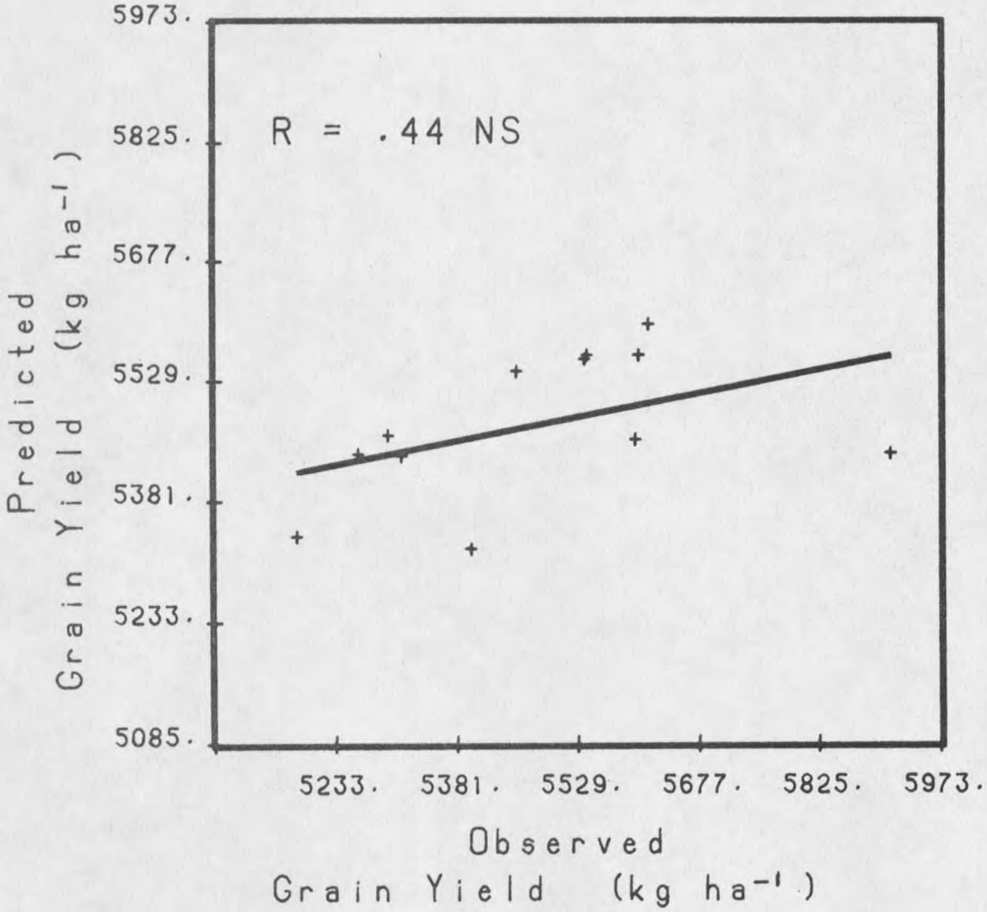

Figure 6. Grain yield: Relationship between observed and predicted values for various seed lots of Redwin winter wheat, using glutamic acid decarboxylase activity (Second Year Studies, 1981-82).

Mean squares and mean comparisons for all vigor tests and field performance variables are given in Tables 31 and 32 respectively. Accelerated aging reduced germination percentage to values that ranged from 38 to 87% with an average of 69% (Table 4). Accelerated aging values for seed lots evaluated were significantly different. Glutamic acid decarboxylase activity has been shown to be highly active in vigorous seeds and less active in seeds of lower vigor (McDonald, 1975). Mean values of glutamic acid decarboxylase activity ranged from 7.86 to 9.06 with an average of 8.39 μLCO_2 g^{-1} min^{-1} (Table 5). Glutamic acid decarboxylase activity values for seed lots were not significant (Table 5). As indicated earlier, these seed lots were of good quality. Linko and Sogn (1960) also concluded that glutamic acid decarboxylase activity was of little value in examining wheat seed from the last growing season.

Emergence rate index varied from 32.64 to 53.56 with an average of 42.47 (Table 4). Emergence rates among seed lots were not different ($P = 0.14$). Stand establishment values ranged from 50 to 78 with an average of 64 seedling m^{-1} (Table 5). Stand establishment values for seed lots were not significantly different ($P = 0.08$). Grain yield varied from 5185 to 5912 with an average of 5476 kg ha^{-1} (Table 6). Seed lots evaluated were also not significantly different for grain yield ($P = 0.63$).

Simple correlations among these three vigor tests and field performance variables have been given in Table 50. Accelerated aging was positively correlated with standard germination ($r = 0.68$*) and negatively correlated with heads $plant^{-1}$ and 1000 seed weight ($r = -0.62$*, -0.58* respectively). Glutamic acid decarboxylase activity was negatively correlated with heads $plant^{-1}$ ($r = -0.62$*). Emergence rate index was significantly correlated with stand establishment ($r = 0.87$**).

In the second year study (1981-82) the correlation coefficients were not significant probably because of less variation in seed source as recently grown seed of one cultivar, Redwin, was used for this study. Therefore, there was no genotypic variation among seed lots. We did not observe significant differences for any variables of field performance because: (1) all of these seed lots were produced under the certification program and were of high quality and (2) field conditions were optimum. Seeding rate used was 67.2 kg ha^{-1}. These seeding rates were based on pure live seeds. Plantings for each of the seed lots had equal number of viable seeds (69 live seeds m^{-1}). Field emergence was 85% in 1981-82 as compared to 53% in 1980-81.

Standard germination did not predict any of the field performance variables for either year's studies. The emergence rate index was significantly correlated with stand establishment for both years (r = 0.87**, 0.87** respectively). The quadratic terms of all the vigor tests were also used in stepwise regression to explore the possibilities of non-linear relationship. Since there was no substantial increase in R^2, therefore, results are reported for linear multiple regression.

Spring Wheat (First Year Studies, 1981)

Evaluation of Lew Seed Lots

When field emergence rate index was compared with various vigor tests, only respiration rate was selected by stepwise regression (R = 0.72*). Fifty-two percent of variability among seed lots was explained by this vigor test. Other tests evaluated included standard germination, speed of germination, cold test, accelerated aging, and electrical conductivity. However, none of these tests contributed toward predicting emergence rate index. Means of respiration rate, and the observed and predicted values of emergence rate index are given in Table 7. Predicted values of emergence rate index using respiration rate have been plotted against the observed values (Fig. 7). The figure shows the correlation between respiration rate and emergence rate index (0.72*) which is significant.

Stand establishment was not related significantly with any of the vigor tests evaluated. These tests include standard germination, speed of germination, cold test, accelerated aging

Table 7. Means of Vigor Tests, Observed and Predicted Values of Emergence Rate Index for Various Seed Lots of Lew Spring Wheat (First Year Studies, 1981).

	Vigor Test	Emergence Rate (Index)	
Lot No.	Resp (μLO_2 seed^{-1} min^{-1})	Observed	Predicted
1	0.0328 c	25.82	25.28
2	0.0297 ab	21.81	21.91
3	0.0307 bc	20.38	23.02
4	0.0274 a	20.37	19.38
5	0.0277 a	21.04	19.72
6	0.0307 bc	25.05	22.93
7	0.0294 ab	19.80	21.61
8	0.0275 a	19.35	19.52
9	0.0285 ab	18.03	20.60
10	0.0297 ab	24.22	21.91
Mean	0.0294	21.59	21.59
LSD (0.05)	0.0027	NS	

respiration rate, and electrical conductivity. Though cold test was selected by the stepwise regression, however, this correlation value (0.43) is not significant. Means of cold test along with observed and predicted values of stand establishment are given in Table 8. Predicted values of stand establishment using cold test have been plotted against observed values (Fig. 8).

Table 8. Means of Vigor Tests, Observed and Predicted Values of Stand Establishment for Various Seed Lots of Lew Spring Wheat (First Year Studies, 1981).

	Vigor Test	Stand Estab (seedling m^{-1})	
Lot No.	Cold test (%)	Observed	Predicted
1	85	76	75
2	85	73	75
3	90	72	73
4	91	79	72
5	96	68	69
6	92	75	72
7	91	69	72
8	91	69	72
9	90	69	72
10	88	75	74
Mean	90	73	73
LSD (0.05)	NS	NS	

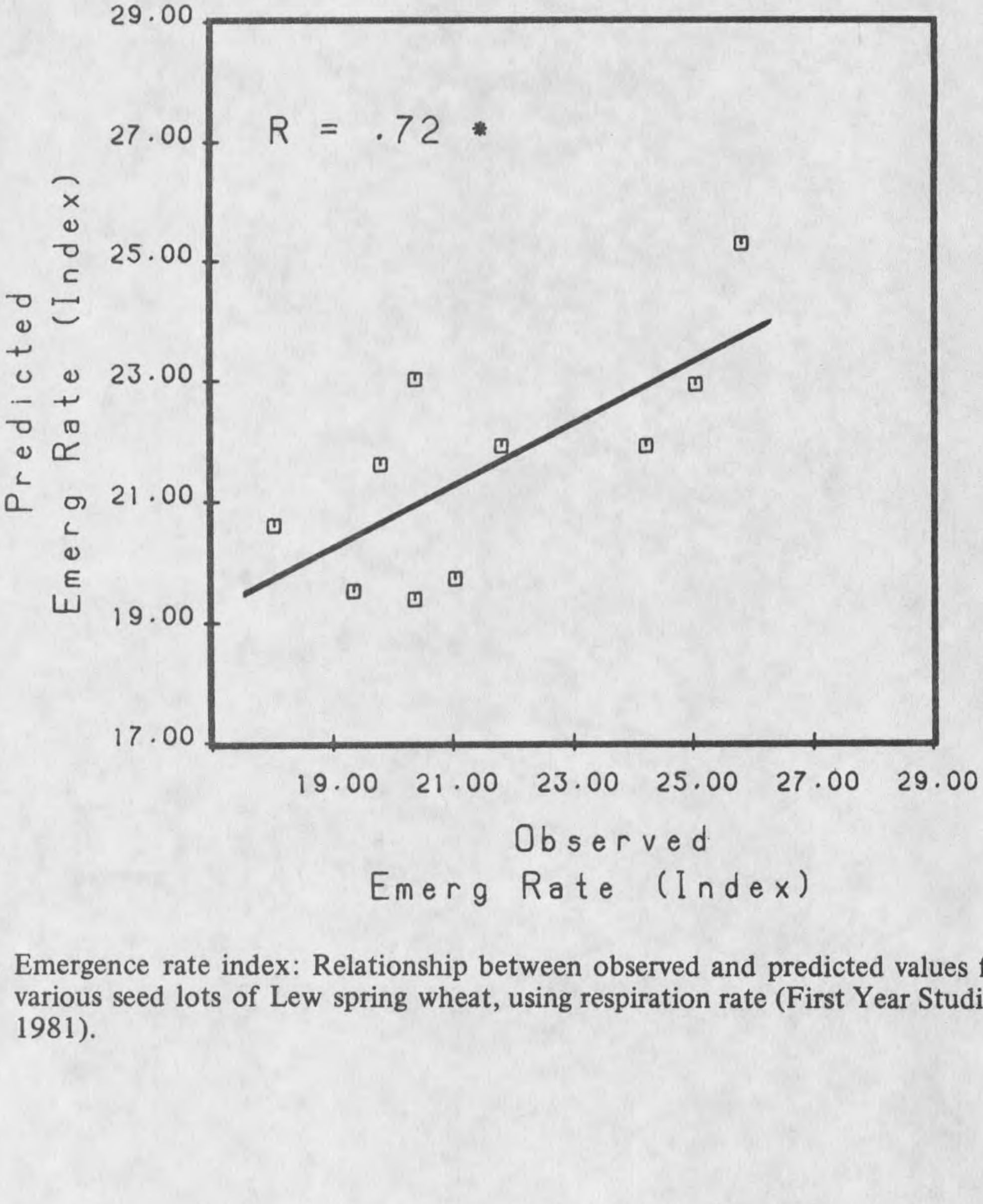

Figure 7. Emergence rate index: Relationship between observed and predicted values for various seed lots of Lew spring wheat, using respiration rate (First Year Studies, 1981).

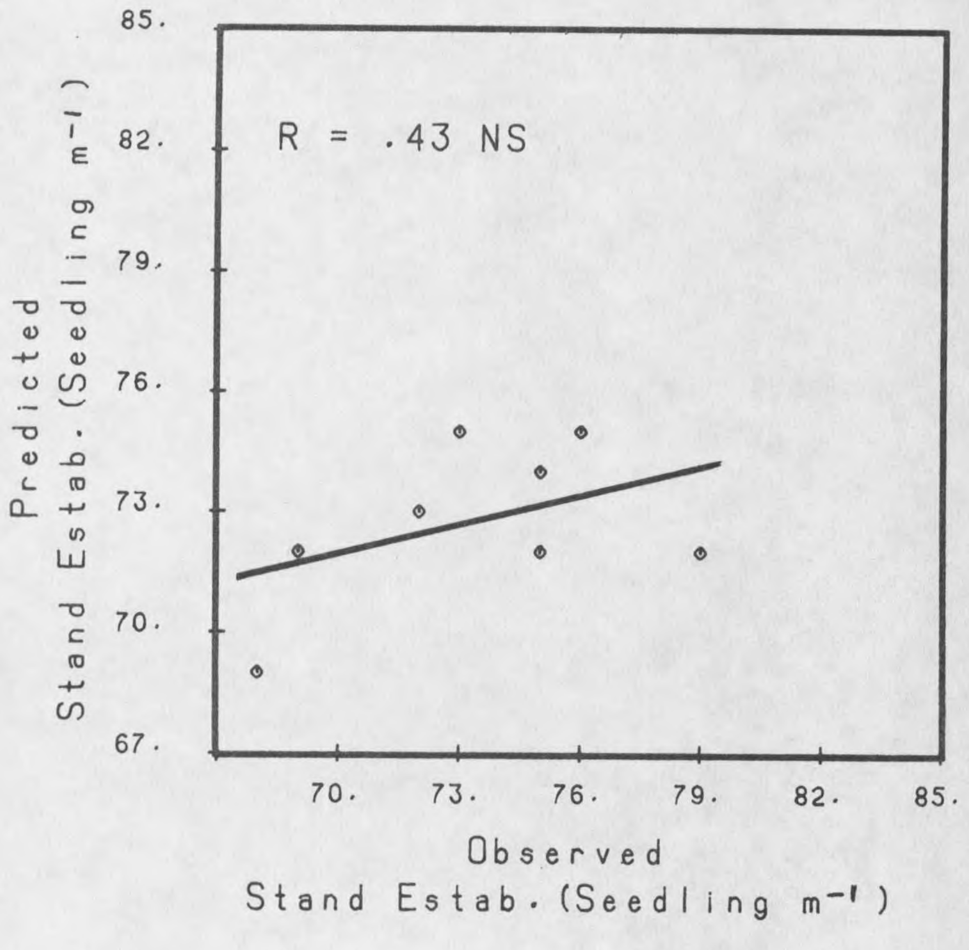

Figure 8. Stand establishment: Relationship between observed and predicted values for various seed lots of Lew spring wheat, using cold test (First Year Studies, 1981).

When grain yield was compared with several vigor tests, respiration rate was selected by stepwise regression and the correlation coefficient of 0.66* was significant. Other tests evaluated included standard germination, speed of germination, cold test, accelerated aging, and electrical conductivity. However, none of these tests were important in predicting grain yield. Means of respiration rate along with observed and predicted values of grain yield are given in Table 9. Predicted values of grain yield using respiration rate have been plotted against the observed values (Fig. 9).

Table 9. Means of Vigor Tests, Observed and Predicted Values of Grain Yield for Various Seed Lots of Lew Spring Wheat (First Year Studies, 1981).

	Vigor Test	Grain Yield (kg ha^{-1})	
Lot No.	Resp (μLO_2 $seed^{-1}$ min^{-1})	Observed	Predicted
1	0.0328 c	4844	4858
2	0.0297 ab	4812	4734
3	0.0307 bc	4827	4775
4	0.0274 a	4526	4640
5	0.0277 a	4735	4653
6	0.0307 bc	4766	4771
7	0.0294 ab	4652	4722
8	0.0275 a	4649	4645
9	0.0285 ab	4782	4685
10	0.0297 ab	4624	4734
Mean	0.0294	4722	4722
LSD (0.05)	0.0027	NS	

Respiration rate ranged from 0.0274 to 0.0328 with an average of 0.0294 μLO_2 $seed^{-1}$ min^{-1} (Table 7). There were significant differences among seed lots for respiration rate. Cold test values varied from 85 to 96% with an average of 90% (Table 8). Seed lots were not different for cold test evaluation. Emergence rate index varied from 18.03 to 25.82 with an average of 21.59 (Table 7). Stand establishment varied from 68 to 79 with an average of 73 seedlings m^{-1} of row (Table 8). Grain yield ranged from 4526 to 4844 with an overall mean of 4722 kg ha^{-1} (Table 9). There were no significant differences at 0.05 level among these 10 seed lots for emergence rate index (P = 0.31), stand establish-

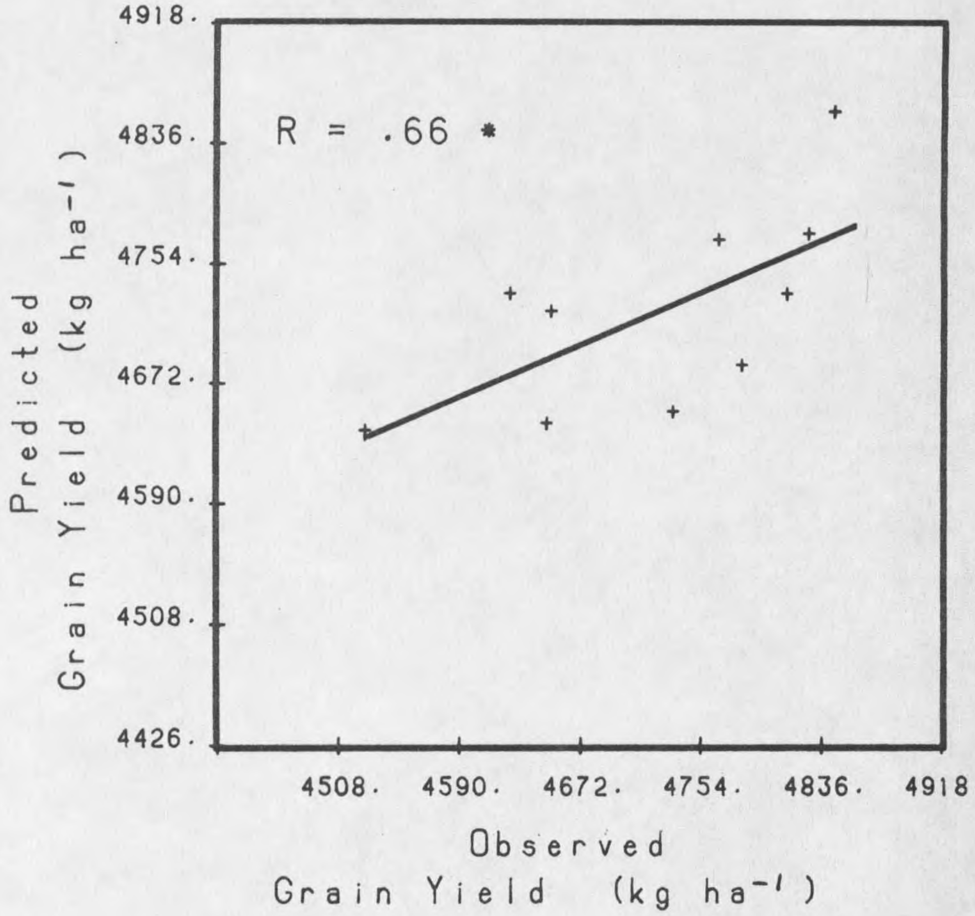

Figure 9. Grain yield: Relationship between observed and predicted values for various seed lots of Lew spring wheat, using respiration rate (First Year Studies, 1981).

ment (P = 0.68), and grain yield (P = 0.34). These seed lots were planted in field at seeding rate equivalent to 67.2 kg ha^{-1} but seed rates were adjusted to pure live seed such that each lot had equal number of viable seeds per unit area (60 live seeds m^{-1}). Since all these seed lots were of one cultivar (Lew) there was no genotypic variation.

Simple correlations among various vigor tests and field performance variables are given in Table 51. Standard germination was correlated with cold test (r = 0.71*) and had negative correlation with respiration rate (μLO_2 g^{-1} min^{-1}) (r = -0.85**). Cold test was negatively correlated with both respiration rate (μLO_2 g^{-1} min^{-1} and μLO_2 $seed^{-1}$ min^{-1}) (r = -0.67*, -0.64*, respectively). Accelerated aging did not correlate with any of the field performance variables. Respiration rate (μLO_2 seed^{-1} min^{-1}) was correlated with electrical conductivity, emergence rate index, and grain yield (r = 0.65*, 0.72*, 0.66* respectively). There was no correlation between respiration rate (μLO_2 g^{-1} min^{-1}) and respiration rate (μLO_2 seed^{-1} min^{-1}). Stand establishment was correlated with plants m^{-1} at maturity (r = 0.75*).

Another objective of this study was to determine the effect of seed sizing on vigor testing. Five lots of cultivar Lew were divided into sized and unsized seeds. These lots were evaluated using standard germination, speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity. Sizing of seed did not change the vigor tests evaluation of seed lots. The lot × size interactions in general for vigor tests and field performance variables were also not significant (Tables 33 and 35, respectively).

Evaluation of Newana Seed Lots

When emergence rate index was compared with various vigor tests, cold test was first selected by stepwise regression. However, the correlation was not significant (R = 0.56). When accelerated aging was added, the correlation increased to a significant coefficient of 0.90**. Other tests evaluated included standard germination, speed of germination, respiration rate, and electrical conductivity. Mean values of cold test, accelerated aging along with observed and predicted values of emergence rate index are given in Table 10. Predicted values of emergence rate index using cold test and accelerated aging have been plotted against the observed values of emergence rate index (Fig. 10). It is apparent from this figure that the relationship between vigor tests (cold tests and accelerated aging together) with emergence rate index is very strong.

When stand establishment was compared with various vigor tests, cold test was selected first and had a correlation coefficient of 0.85**. When respiration rate was added by the stepwise regression the correlation increased to 0.89**. Both of these tests together

Table 10. Means of Vigor Tests, Observed and Predicted Values of Emergence Rate Index for Various Seed Lots of Newana Spring Wheat (First Year Studies, 1981).

	Vigor Tests		Emergence Rate (Index)	
Lot No.	Cold Test (%)	Acc Aging (%)	Observed	Predicted
1	95	94 c	19.87	19.35
2	95	92 bc	16.20	18.32
3	98	81 ab	24.53	22.74
4	95	91 bc	19.92	17.82
5	97	80 ab	16.89	18.33
6	96	76 a	15.11	15.28
7	96	90 bc	19.75	20.21
8	97	90 bc	22.09	23.18
9	95	92 bc	19.98	19.72
10	94	90 bc	15.50	14.89
Mean	95	88	18.98	18.98
LSD (0.05)	NS	12	NS	

explained 79% of the variability among seed lots. Other tests evaluated included standard germination, speed of germination, accelerated aging, and electrical conductivity. However, none of these tests contributed in predicting stand establishment. Means of cold test and accelerated aging along with observed and predicted values of stand establishment are given in Table 11. Predicted values of stand establishment using cold test and respiration rate have been plotted against the observed values of stand establishment (Fig. 11). This figure

Table 11. Means of Vigor Tests, Observed and Predicted Values of Stand Establishment for Various Seed Lots of Newana Spring Wheat (First Year Studies, 1981).

	Vigor Tests		Stand Estab (seedling m^{-1})	
Lot No.	Cold Test (%)	Resp (μLO_2 seed^{-1} min^{-1})	Observed	Predicted
1	95	0.0242 abc	69	71
2	95	0.0231 ab	69	70
3	98	0.0228 a	81	81
4	95	0.0229 a	72	70
5	97	0.0226 a	75	76
6	96	0.0251 bc	75	77
7	96	0.0226 a	70	73
8	97	0.0229 a	80	76
9	95	0.0256 c	77	75
10	94	0.0231 ab	68	67
Mean	95	0.0235	74	74
LSD (0.05)	NS	0.0020	NS	

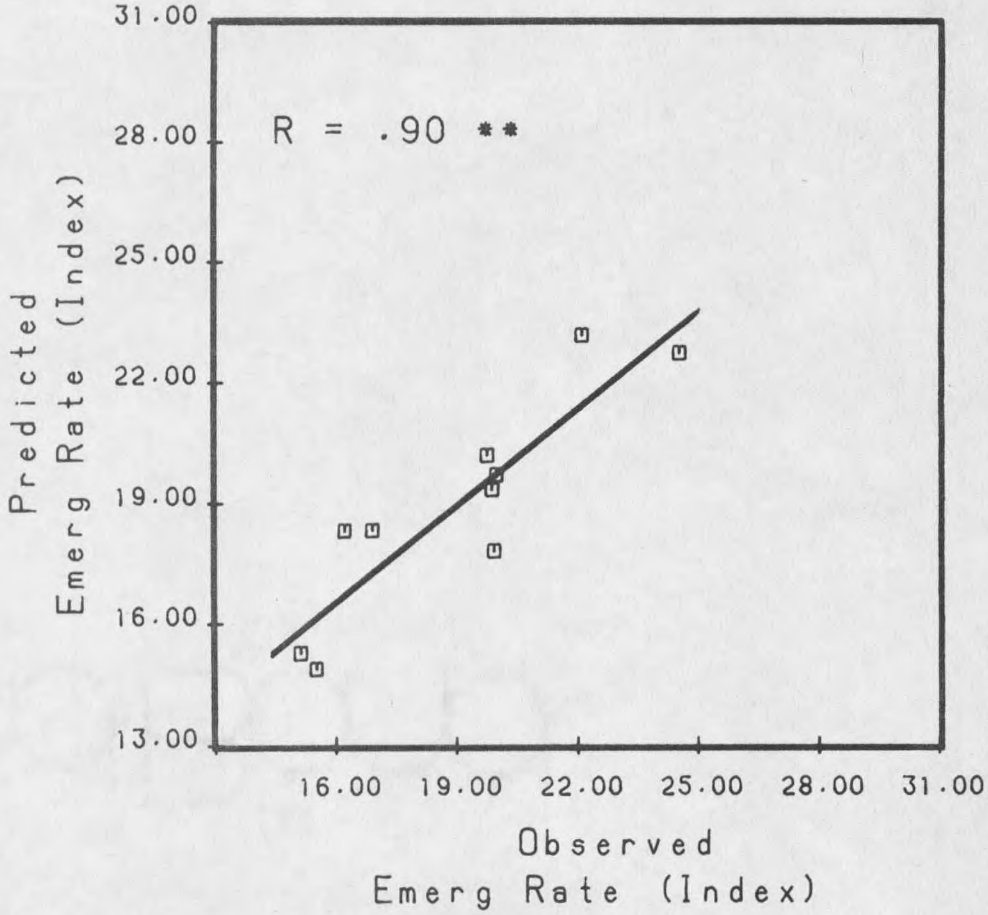

Figure 10. Emergence rate index: Relationship between observed and predicted values for various seed lots of Newana spring wheat, using cold test and accelerated aging (First Year Studies, 1981).

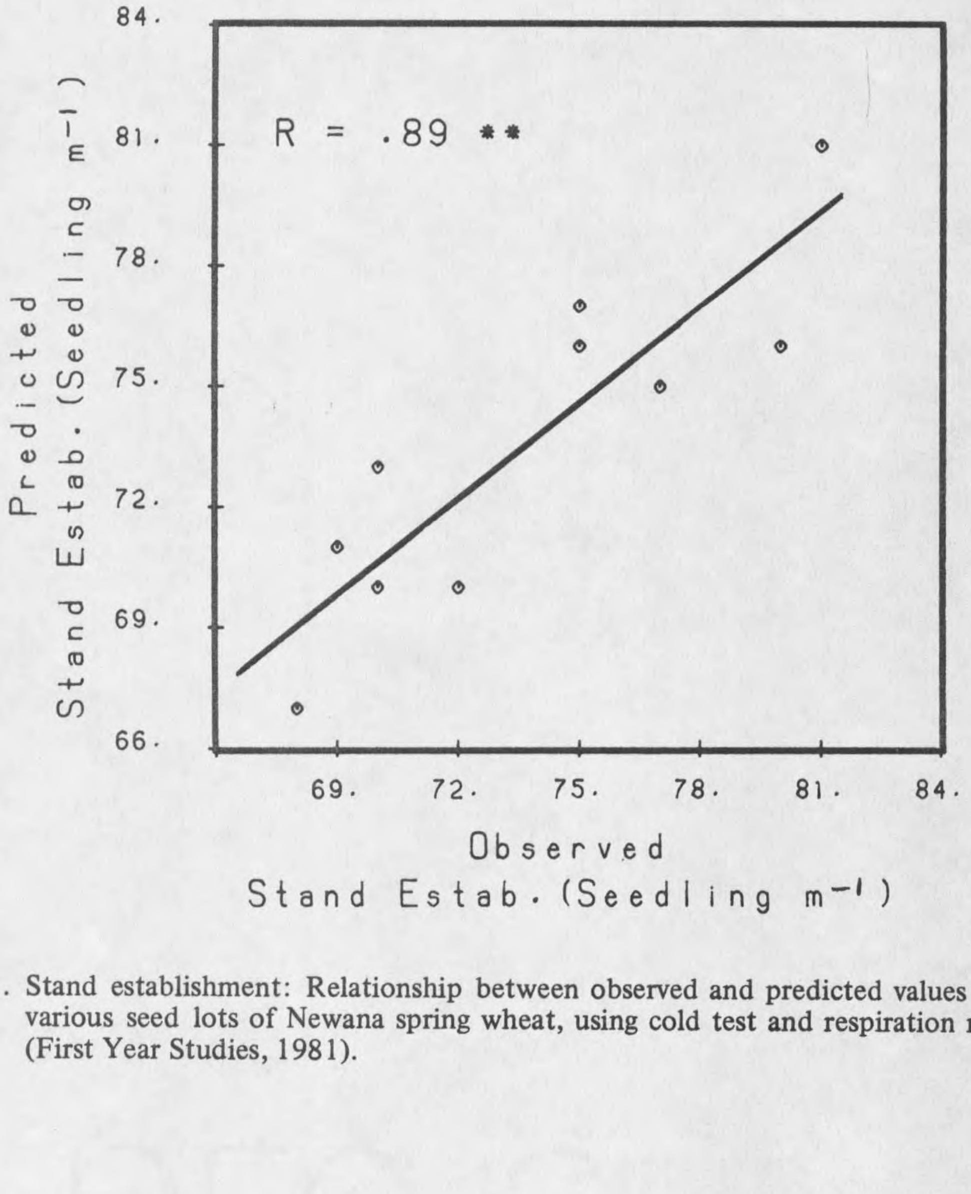

Figure 11. Stand establishment: Relationship between observed and predicted values for various seed lots of Newana spring wheat, using cold test and respiration rate (First Year Studies, 1981).

shows that the relationship between vigor tests (cold test and respiration rate together) with stand establishment is very strong.

When grain yield was compared with various vigor tests by stepwise regression, respiration rate was selected first and the correlation coefficient was 0.79**. When standard germination was added the magnitude of this correlation increased to 0.84*. These tests together explained 71% of the variability among seed lots. Other tests evaluated included speed of germination, cold test, accelerated aging, and electrical conductivity. None of these tests contributed in predicting grain yield. Means of respiration rate and standard germination along with observed and predicted values of grain yield are given in Table 12. Predicted values of grain yield using respiration rate and standard germination have been plotted against the observed values of grain yield (Fig. 12). This figure shows that there is strong relationship (R = 0.84*) between vigor tests and grain yield.

Table 12. Means of Vigor Tests, Observed and Predicted Values of Grain Yield for Various Seed Lots of Newana Spring Wheat (First Year Studies, 1981).

	Vigor Tests		Grain Yield (kg ha^{-1})	
Lot No.	Resp (μLO_2 $seed^{-1}$ min^{-1})	Std Germ (%)	Observed	Predicted
1	0.0242 abc	91 b	5791	5666
2	0.0231 ab	92 b	5616	5542
3	0.0228 a	94 b	5511	5523
4	0.0229 a	90 b	5538	5491
5	0.0226 a	95 b	5469	5509
6	0.0251 bc	83 a	5760	5684
7	0.0226 a	91 b	5431	5469
8	0.0229 a	91 b	5494	5506
9	0.0256 c	91 b	5711	5840
10	0.0231 ab	83 a	5345	5435
Mean	0.0235	90	5567	5567
LSD (0.05)	0.0020	6	NS	

Mean values of cold test ranged from 94 to 98 with an average of 95%. There were no significant differences among seed lots for cold test evaluation (Table 10). Probably there was not enough stress for these seed lots. Accelerated aging values ranged from 76 to 94

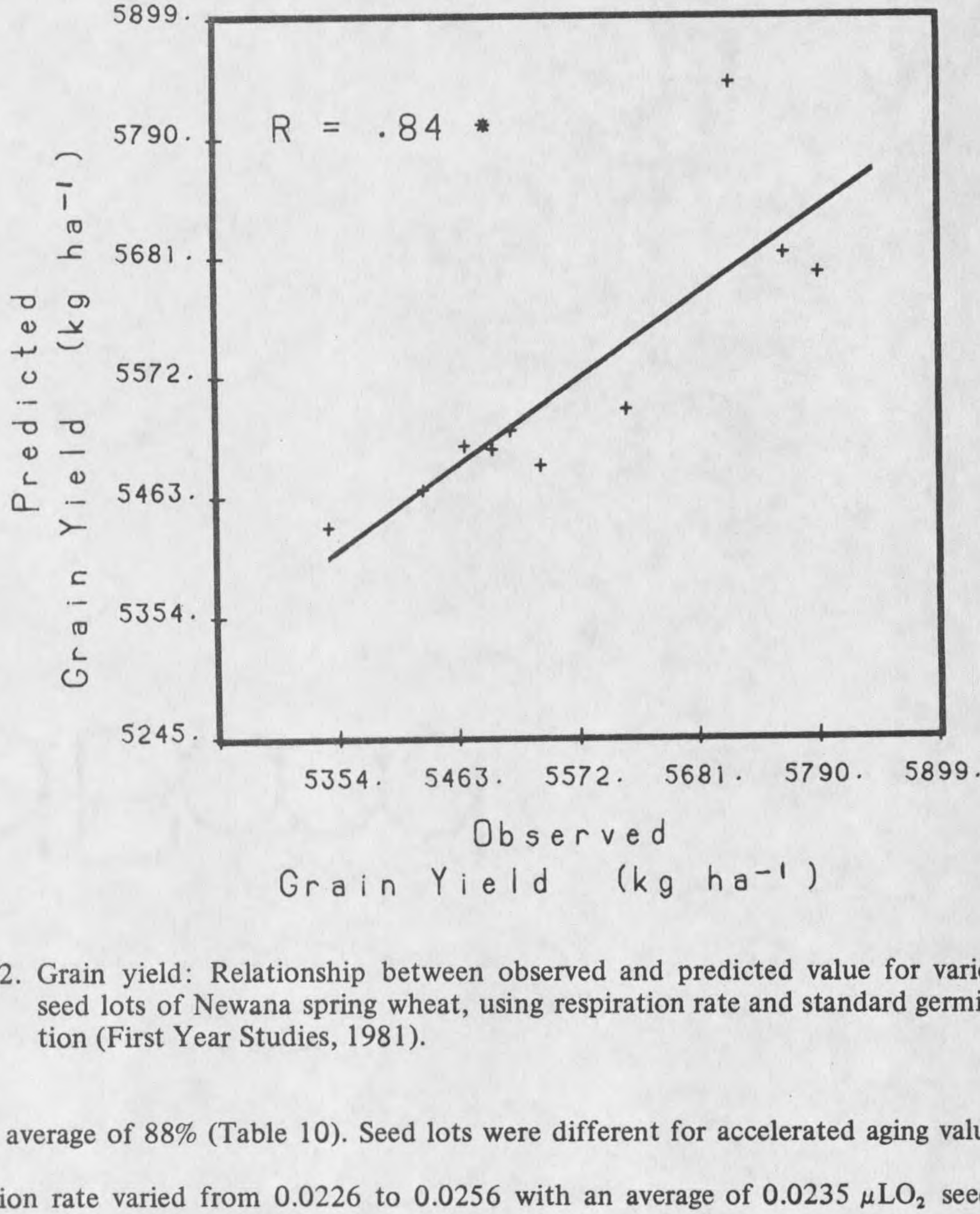

Figure 12. Grain yield: Relationship between observed and predicted value for various seed lots of Newana spring wheat, using respiration rate and standard germination (First Year Studies, 1981).

with an average of 88% (Table 10). Seed lots were different for accelerated aging values. Respiration rate varied from 0.0226 to 0.0256 with an average of 0.0235 μLO_2 seed^{-1} min^{-1} (Table 11). There were significant differences among seed lots for respiration rate. Emergence rate index varied from 15.11 to 24.53 with an average of 18.98 (Table 10). Seed lots were not different for emergence rate index (P = 0.07). Stand establishment varied from 69 to 81 with an average of 74 seedling m^{-1} of row (Table 11). Seed lots were not different for stand establishment (P = 0.10). Grain yield varied from 5345 to 5791 with an average of 5567 kg ha^{-1} (Table 12). Seed lots did not differ for grain yield (P = 0.70). These seed lots were planted in field at a seeding rate of 67.2 kg ha^{-1}. Equal numbers of seeds (60 live seeds m^{-1}) were planted for each lot based on pure live seeds. Genotypic effects were also removed for field performance variables by using one cultivar.

Simple correlation among various vigor tests and field performance variables are given in Table 52. Cold test had negative correlation with accelerated aging and respiration rate μLO_2 g^{-1} min^{-1} (r = -0.67*, -0.72* respectively). There was no correlation between respiration rate μLO_2 g^{-1} min^{-1} and respiration rate μLO_2 $seed^{-1}$ min^{-1}. Standard germination did not correlate with any variables of field performance. Respiration rate μLO_2 $seed^{-1}$ min^{-1} had positive correlation with grain yield (r = 0.79**).

Another objective of this study was to determine the effect of seed sizing on vigor testing. Five lots of Newana cultivar were divided into sized and unsized seeds. These lots were evaluated using standard germination, speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity. Sizing of seed did not change the vigor test evaluation of seed lots. The lots × size interaction were not significant for most of vigor tests except standard germination and respiration rate μLO_2 $seed^{-1}$ min^{-1} (Tables 37 and 39).

Spring Wheat (Second Year Studies, 1982)

Evaluation of Newana Seed Lots (Experiment I)

When emergence rate index was compared with various vigor tests, standard germination was selected first. The correlation value of 0.73** was significant. When accelerated aging was added, the magnitude of the correlation increased to 0.81**. These two tests accounted for 66% of the variability among seed lots. Other tests evaluated included speed of germination, respiration rate, and glutamic acid decarboxylase activity. None of these tests contributed significantly in predicting emergence rate index. Means of standard germination and accelerated aging along with observed and predicted values of emergence rate index are given in Table 13. Predicted values of emergence rate index using standard germination and accelerated aging have been plotted against the observed values of emergence rate index (Fig. 13). This figure shows that the relationship between vigor tests (standard germination and accelerated aging together) with emergence rate index is strong (R = 0.81**).

Table 13. Means of Vigor Tests, Observed and Predicted Values of Emergence Rate Index for Various Seed Lots of Newana Spring Wheat (Second Year Studies, 1982).

	Vigor Tests		Emergence Rate (index)	
Lot No.	Std Germ (%)	Acc Aging (%)	Observed	Predicted
1	91 bc	56 cde	31.73 bcd	30.27
2	88 b	39 ab	34.88 d	31.28
3	98 d	43 abc	33.41 cd	33.96
4	57 a	41 ab	22.32 ab	21.02
5	87 b	64 ef	32.86 cd	28.04
6	96 cd	58 def	25.03 abc	31.65
7	97 d	95 h	27.60 bcd	27.44
8	93 bcd	67 efg	29.49 bcd	29.48
9	90 b	72 fg	24.00 abc	27.88
10	49 a	31 a	17.48 a	19.78
11	96 cd	79 g	31.23 bcd	29.13
12	97 cd	47 bcd	33.08 cd	33.17
Mean	86	57	28.59	28.59
LSD (0.05)	6	14	9.77	

When stand establishment was compared with several vigor tests, speed of germination index was selected first (R = 0.79**). This test accounted for 62% of the variability among seed lots. Other tests evaluated included standard germination, accelerated aging, respiration rate, and glutamic acid decarboxylase activity. However, none of these tests were important in predicting stand establishment. Means of vigor tests along with observed and predicted values of stand establishment are given in Table 14. Predicted values of stand

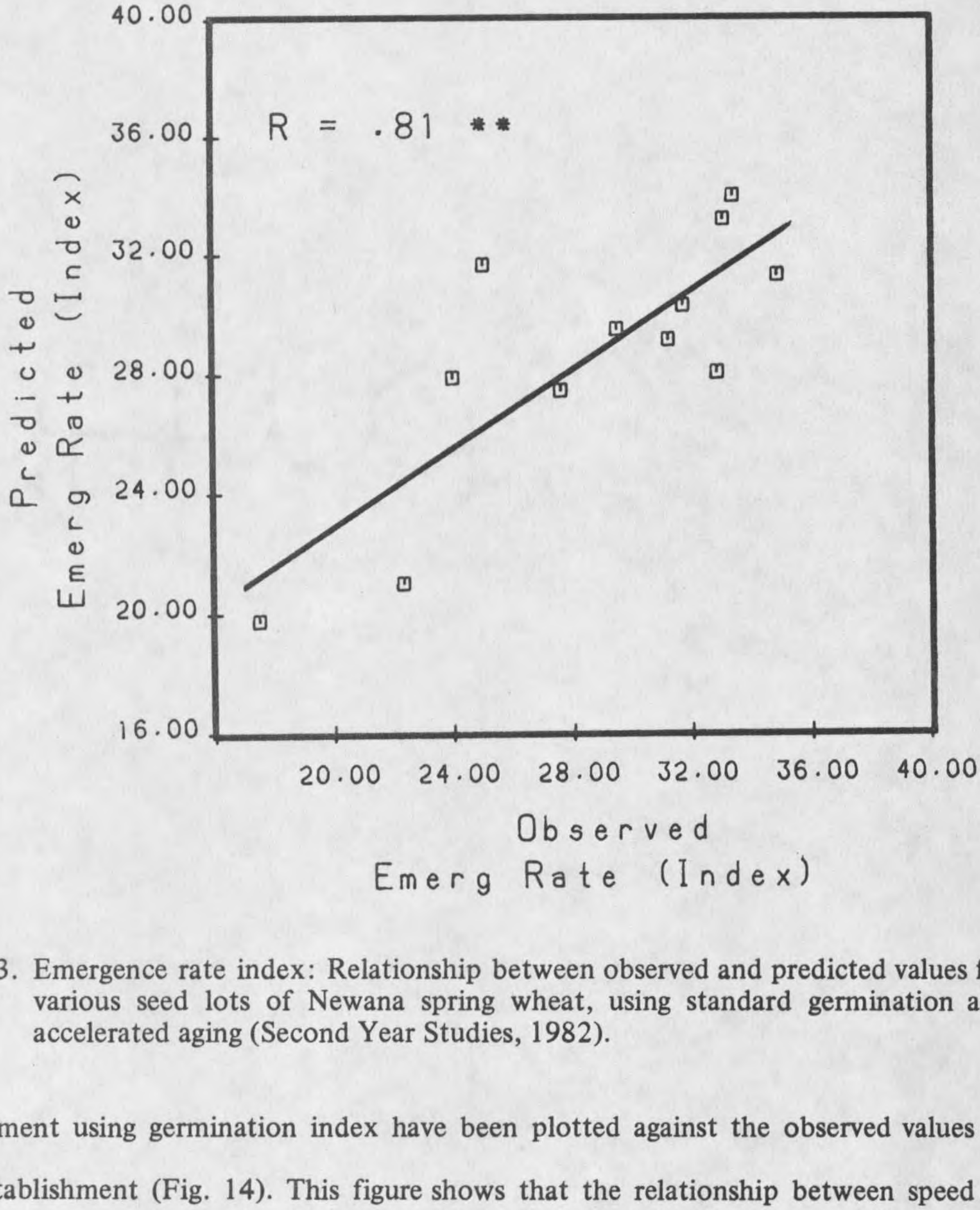

Figure 13. Emergence rate index: Relationship between observed and predicted values for various seed lots of Newana spring wheat, using standard germination and accelerated aging (Second Year Studies, 1982).

establishment using germination index have been plotted against the observed values of stand establishment (Fig. 14). This figure shows that the relationship between speed of germination index and stand establishment is strong (R = 0.79**).

When grain yield was compared with several vigor tests, standard germination test was selected by stepwise regression (R = 0.63*). Glutamic acid decarboxylase activity was

Table 14. Means of Vigor Tests, Observed and Predicted Values of Stand Establishment for Various Seed Lots of Newana Spring Wheat (Second Year Studies, 1982).

	Vigor Test	Stand Estab (seedling m^{-1})	
Lot No.	Germ Index	Observed	Predicted
1	30.05 bc	48 bcde	47
2	27.45 bc	47 bcd	45
3	42.50 d	55 de	57
4	18.47 a	31 a	38
5	28.27 bc	55 de	46
6	29.55 bc	39 ab	47
7	32.27 c	43 bc	49
8	43.17 d	59 e	58
9	24.75 b	53 cde	43
10	17.25 a	38 ab	37
11	40.02 d	57 de	55
12	40.25 d	56 de	55
Mean	31.17	48	48
LSD (0.05)	18.22	11	

selected next and correlation value increased to 0.76*, when respiration rate was added to the above tests, magnitude of correlation increased to 0.86**. These three tests explained 74% of the variability among seed lots for grain yield. Mean values of vigor tests along with observed and predicted values of grain yield are given in Table 15. Predicted values of grain yield using standard germination, glutamic acid decarboxylase activity, and respiration rate have been plotted against observed values of grain yield (Fig. 15). This figure shows that the relationship between vigor tests (standard germination, glutamic acid decarboxylase activity, and respiration rate together) with grain yield is significant.

Mean squares and mean comparisons of all the vigor tests are given in Tables 41 and 42 respectively. Mean values of standard germination ranged from 49 to 98% with an average of 86% (Table 13). Speed of germination index values varied from 17.25 to 43.17 with an average of 31.17 (Table 14). Mean values of accelerated aging ranged from 31 to 95 with an average of 57% (Table 13). Glutamic acid decarboxylase activity ranged from 3.07 to 5.23 with an overall mean of 4.57 μLCO_2 g^{-1} min^{-1} (Table 15). Respiration rate varied from 0.0162 to 0.0231 with an average of 0.0206 μLO_2 $seed^{-1}$ min^{-1} (Table 15).

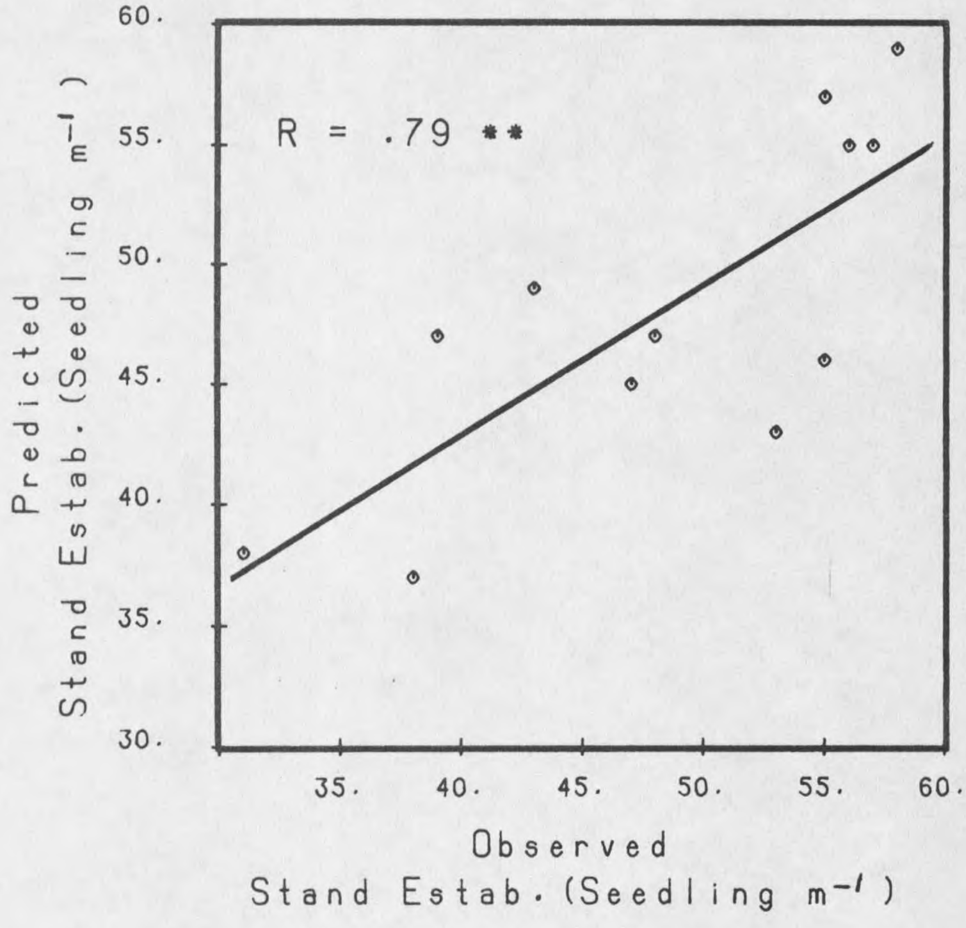

Figure 14. Stand establishment: Relationship between observed and predicted values for various seed lots of Newana spring wheat, using germination index (Second Year Studies, 1982).

Table 15. Means of Vigor Tests, Observed and Predicted Values of Grain Yield for Various Seed Lots of Newana Spring Wheat (Second Year Studies, 1982).

	Vigor Tests			Grain Yield ($kg\ ha^{-1}$)	
Lot No.	Std Germ (%)	GADA ($\mu LCO_2\ g^{-1}\ min^{-1}$)	Resp ($\mu LO_2\ seed^{-1}\ min^{-1}$)	Observed	Predicted
1	91 bc	4.61 b	0.0204 bc	6256	6152
2	88 b	5.22 d	0.0212 cde	5846	5983
3	98 d	5.23 d	0.0206 bcd	6041	6042
4	57 a	3.78 a	0.0191 b	5977	5945
5	87 b	4.92 c	0.0231 e	6255	6194
6	96 cd	4.81 bc	0.0224 de	6358	6279
7	97 d	4.95 c	0.0216 cde	6077	6192
8	93 bcd	4.60 b	0.0215 cde	6208	6243
9	90 b	4.95 c	0.0198 bc	6128	5989
10	49 a	3.07 a	0.0162 a	5838	5882
11	96 cd	4.61 b	0.0216 cde	6199	6281
12	97 cd	4.12 a	0.0198 bc	6310	6312
Mean	86	4.57	0.0206	6124	6124
LSD (0.05)	6	0.04	0.0019	NS	

Seed lots were significantly different for all the vigor tests conducted (Table 42). These lots included certified seed, and common seed. Common seed lots were selected purposely because all farmers do not plant certified seed. The objective was to evaluate the vigor tests over a wide range of seed quality. Mean squares and mean comparisons for all the field performance variables are given in Tables 43 and 44, respectively. There were significant differences among seed lots for emergence rate index and stand establishment. From first year studies, we did not observe significant differences for emergence rate index and stand establishment. Therefore, seeding rate was reduced from 67.2 to 56.0 kg ha^{-1} (50 live seeds m^{-1}). Moreover, these seeding rates were not adjusted for pure live seeds. Emergence rate index ranged from 17.48 to 34.88 with an average of 28.59 (Table 13), whereas stand establishment varied from 31 to 59 with an average of 48 seedling m^{-1} (Table 14). Grain yield ranged from 5838 to 6358 with an average of 6124 kg ha^{-1} (Table 15), but yield differences among seed lots were not significant ($P = 0.34$).

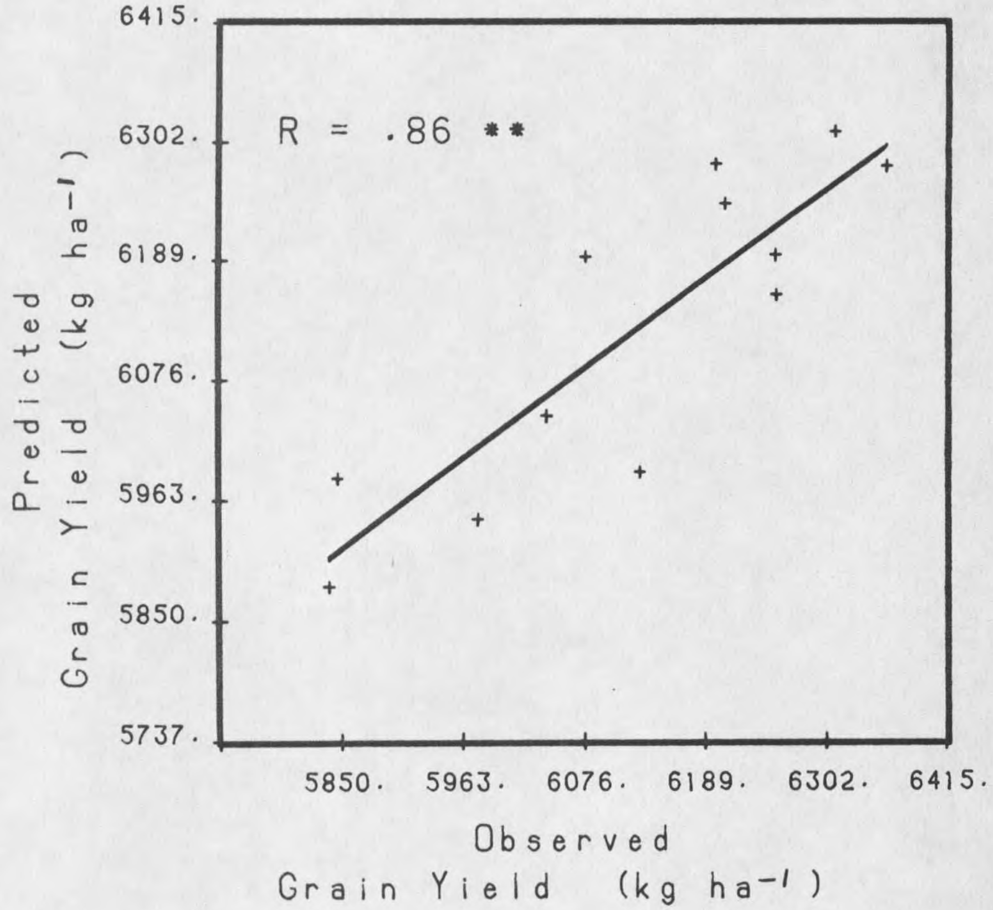

Figure 15. Grain yield: Relationship between observed and predicted values for various seed lots of Newana spring wheat, using standard germination, glutamic acid decarboxylase activity, and respiration rate (Second Year Studies, 1982).

In spite of the differences in emergence rate index and stand establishment among seed lots, there were no differences for grain yield. This is mainly attributed to the compensation mechanism. Those lots which had fewer plants per unit area, produced more heads $plant^{-1}$ and seeds $head^{-1}$, e.g., lots 4 and 10 (Table 44).

Simple correlations among all the vigor tests and field performance variables are given in Table 53. Standard germination was correlated with most of the vigor tests and field performance variables. Speed of germination index was correlated with respiration rate μLO_2 g^{-1} min^{-1} (r = 0.59*). Respiration rate μLO_2 $seed^{-1}$ min^{-1} was correlated with accelerated aging, and respiration rate μLO_2 g^{-1} min^{-1} (r = 0.57* and 0.64* respectively). Glutamic acid decarboxylase activity was correlated with respiration rate μLO_2 seed^{-1} min^{-1} (r = 0.79**). Emergence rate index was correlated with stand establishment (r = 0.67*) and with plants m^{-1} (r = 0.63*). Stand establishment was correlated with plants m^{-1} (r = 0.90**) which in turn correlated with grain yield (r = 0.61*).

Spring Wheat (Second Year Studies, 1982)

Evaluation of Artificially Aged Seeds (Experiment 2)

Comparing emergence rate index with several vigor tests, stepwise regression selected accelerated aging first and 96% of the variability among seed lots was explained by this test. Other tests evaluated included standard germination, speed of germination, cold test, respiration rate, electrical conductivity, and glutamic acid decarboxylase activity. None of these tests were important in predicting emergence rate index. Mean values of vigor tests along with observed and predicted values of emergence rate index are given in Table 16. Predicted values of emergence rate index using accelerated aging have been plotted against the observed values of emergence rate index (Fig. 16). This figure indicates that the relationship between accelerated aging and emergence rate index is acceptable (R = 0.98**).

When stand establishment was compared with various vigor tests only cold test (r = 0.93**) was selected. Eighty-six percent of the variability among seed lots was explained by this test. Other tests evaluated included: standard germination, speed of germination, accelerated aging, respiration rate, and electrical conductivity. None of these tests were important in predicting stand establishment. Mean values of vigor tests along with observed and predicted values of stand establishment are given in Table 17. Predicted values of stand establishment using cold test and observed values of stand establishment have been plotted (Fig. 17). This figure indicates (R = 0.93**) that the relationship between cold test and stand establishment is significant.

Table 16. Means of Vigor Tests, Observed and Predicted Values of Emergence Rate Index for Various Artificially Aged Seed Lots of Spring Wheat (Second Year Studies, 1982).

	Vigor Tests	Emergence Rate (index)	
Lot No.	Acc Aging (%)	Observed	Predicted
1	92 f	31.79 d	28.38
2	93 f	29.99 d	28.55
3	44 d	9.10 ab	12.71
4	2 a	1.15 a	0.00
5	97 f	28.25 d	29.82
6	97 f	29.01 d	29.82
7	79 e	18.33 c	24.03
8	16 b	5.96 ab	3.90
9	95 f	31.37 d	29.34
10	24 bc	4.61 ab	6.44
11	96 f	31.44 d	29.69
12	32 c	10.08 b	9.06
Mean	64	19.3	19.3
LSD (0.05)	10	8.01	

Table 17. Means of Vigor Tests, Observed and Predicted Values of Stand Establishment for Various Artificially Aged Seed Lots of Spring Wheat (Second Year Studies, 1982).

	Vigor Test	Stand Estab (seedling m^{-1})	
Lot No.	Cold Test (%)	Observed	Predicted
1	83 ef	47 d	53
2	66 de	53 de	45
3	35 bc	36 c	30
4	0 a	7 a	14
5	76 ef	52 de	50
6	92 f	54 de	57
7	75 ef	58 e	49
8	45 cd	33 c	35
9	79 ef	51 de	51
10	18 ab	22 b	22
11	94 f	51 de	58
12	37 bc	35 c	32
Mean	58	41	41
LSD (0.05)	25	7	

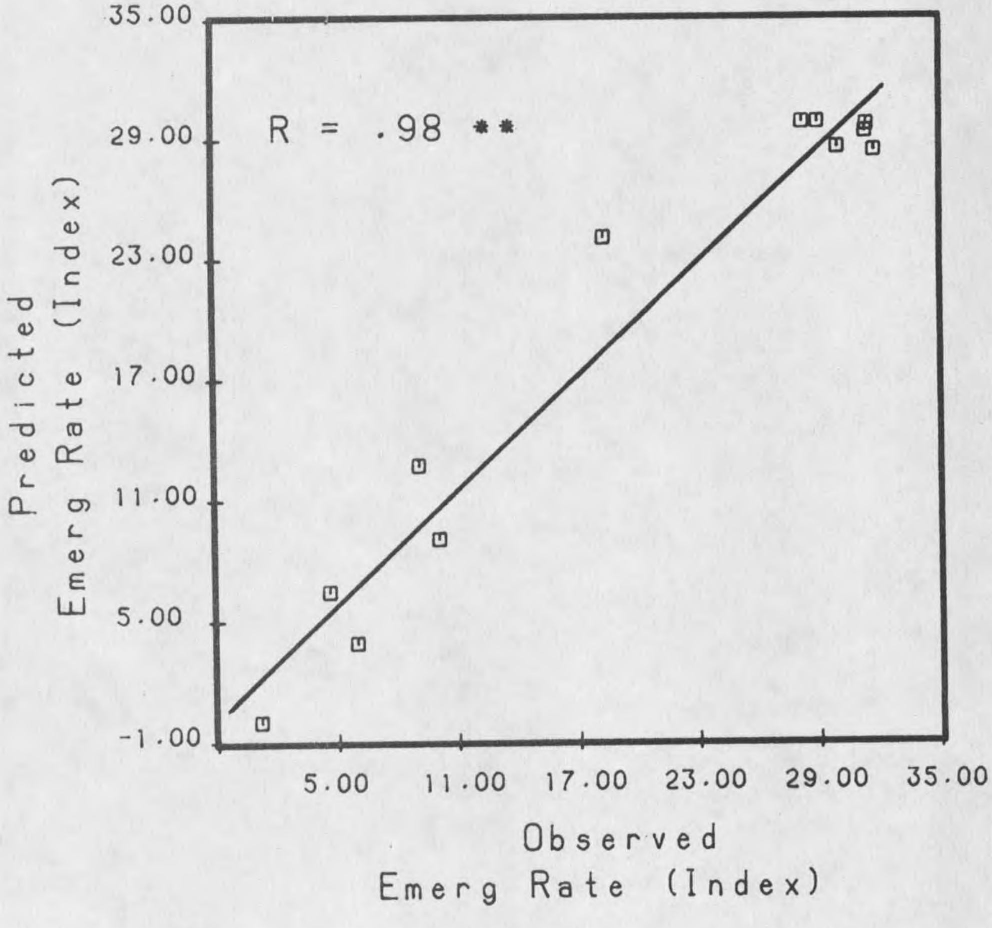

Figure 16. Emergence rate index: Relationship between observed and predicted values for various artificially aged seed lots of spring wheat, using accelerated aging (Second Year Studies, 1982).

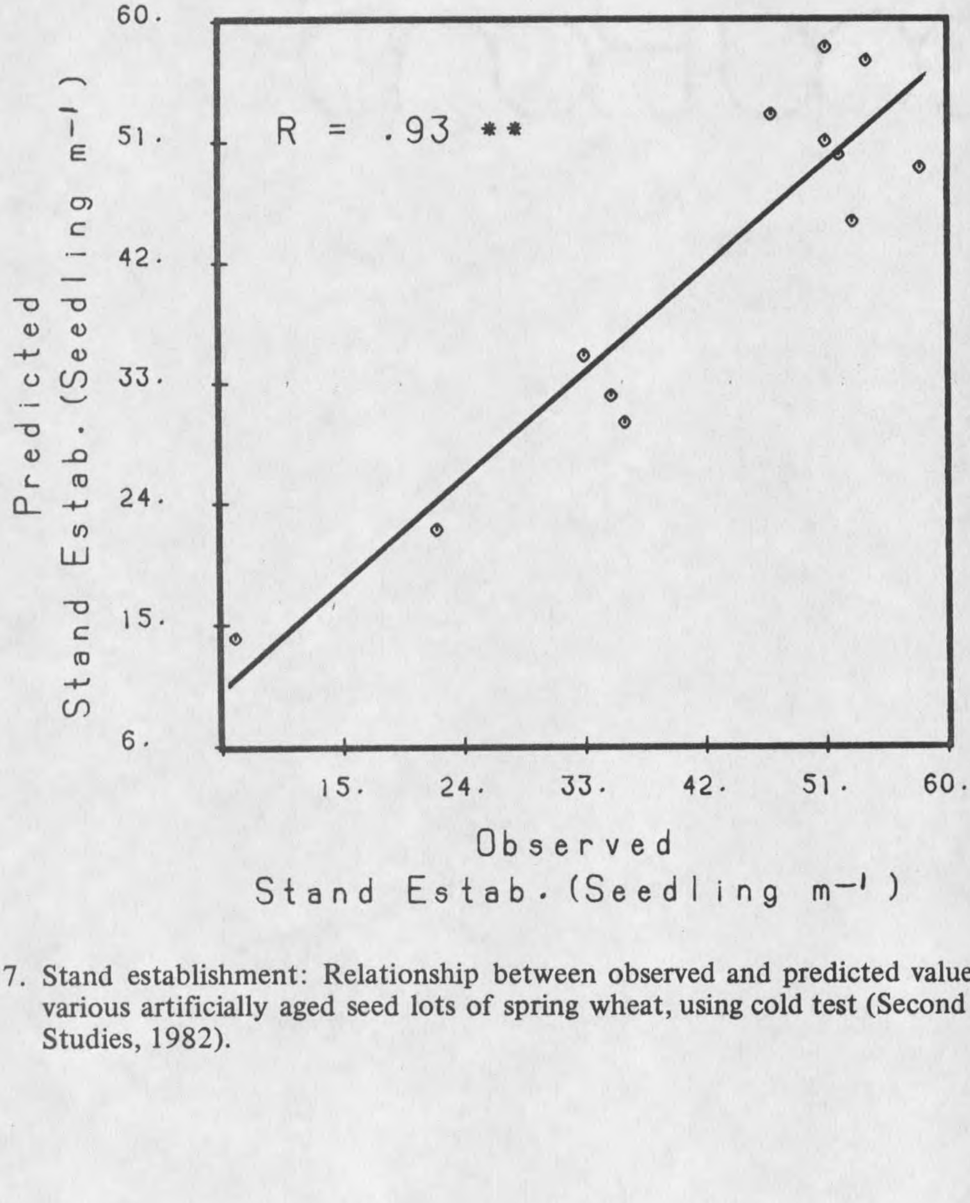

Figure 17. Stand establishment: Relationship between observed and predicted values for various artificially aged seed lots of spring wheat, using cold test (Second Year Studies, 1982).

When grain yield was compared with various vigor tests, stepwise regression selected respiration rate and the correlation value of 0.71* was significant. When standard germination was added this multiple correlation increased to a coefficient of 0.93**. These tests together explained 86% of variability among seed lots. Mean values of vigor tests along with observed and predicted values using respiration rate and standard germination are given in Table 18. Predicted values of grain yield have been plotted against the observed values of grain yield (Fig. 18). This figure shows that the relationship between vigor tests (respiration rate and standard germination together) with grain yield is strong (R = 0.93**).

Table 18. Means of Vigor Tests, Observed and Predicted Values of Grain Yield for Various Artificially Aged Seed Lots of Spring Wheat (Second Year Studies, 1982).

	Vigor Tests		Grain Yield (kg ha^{-1})	
Lot No.	Resp (μLO_2 $seed^{-1}$ min^{-1})	Std Germ (%)	Observed	Predicted
1	0.0273 d	97 fg	4433 b	4621
2	0.0226 d	95 defg	4362 b	4683
3	0.0277 d	88 c	4473 b	4001
4	0.0263 d	62 a	2679 a	2742
5	0.0218 c	96 efg	6104 d	5584
6	0.0189 ab	98 g	6341 d	6290
7	0.0209 bc	91 cdef	6264 d	5492
8	0.0211 bc	89 cd	5440 c	5316
9	0.0254 d	96 efg	4393 b	4926
10	0.0178 a	90 cde	5476 c	6026
11	0.0188 ab	98 fg	6122 d	6275
12	0.0205 bc	70 b	4182 b	4311
Mean	0.0227	89	5022	5022
LSD (0.05)	0.0025	7	436	

Quadratic terms for all the vigor tests were also used in stepwise regression to explore the possibility of nonlinear relationship. However, there was no substantial increase in R^2. Therefore, linear relationships have been reported.

Mean squares and mean comparisons for all the vigor tests are given in Tables 45 and 46 respectively. These lots were artificially aged to create variability among seed lots. Standard germination percentage ranged from 62 to 98% with an average of 89% (Table

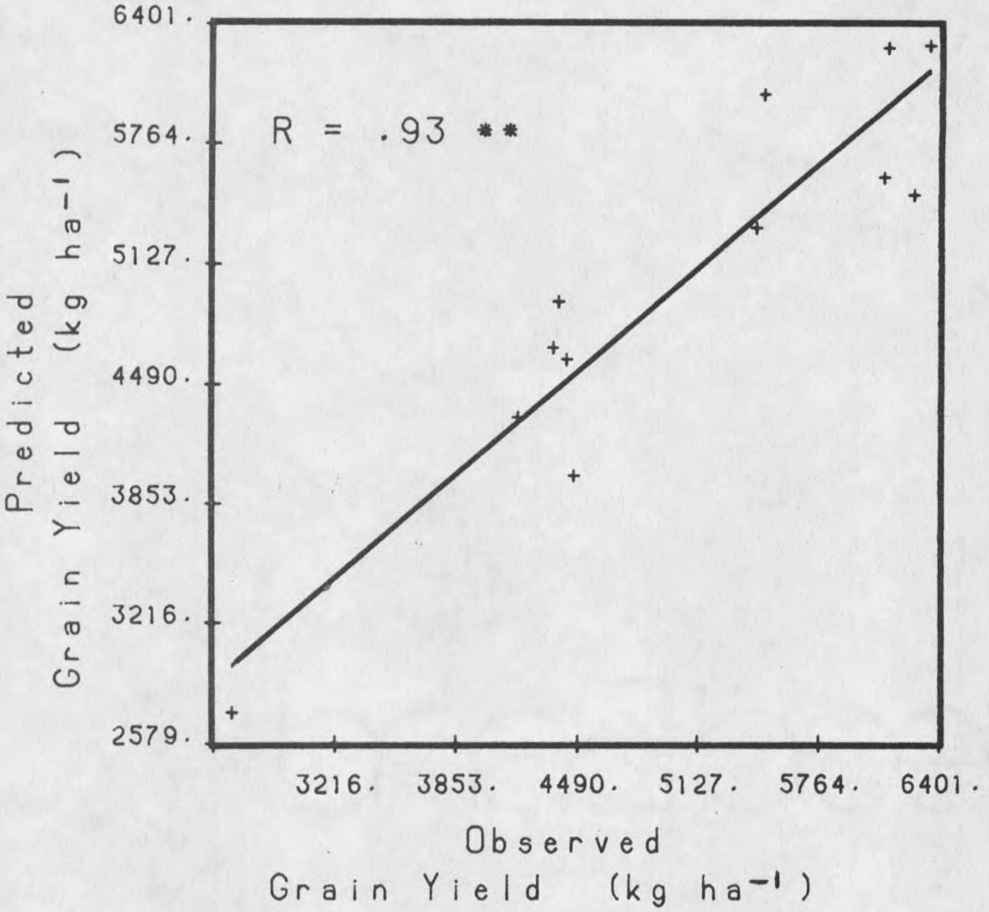

Figure 18. Grain yield: Relationship between observed and predicted values for various artificially aged seed lots of spring wheat, using respiration rate and standard germination (Second Year Studies, 1982).

18). Mean values of accelerated aging ranged from 2 to 97% with an average of 64% (Table 16). Cold test values varied from nil to 94 with an average of 58% (Table 17) and respiration rate ranged from 0.0178 to 0.0277 with an average of 0.0227 μLO_2 $seed^{-1}$ min^{-1} (Table 18). Seed lots were significantly different for all the vigor tests evaluated. Mean squares and mean comparisons for all the field performance variables are given in Tables 47 and 48 respectively. Emergence rate index values ranged from 1.15 to 31.79 with an average of 19.3 (Table 16). Stand establishment values ranged from 7 to 58 with an average of 41 seedling m^{-1} (Table 17). Grain yield varied from 2679 to 6341 with an average of 5022 kg ha^{-1} (Table 18). Seed lots were significantly different for all the variables of field performance. In this study seeding rate used was 56.0 kg ha^{-1} (50 live seeds m^{-1}) which were not adjusted to pure live seed. Also there was appreciable variation among seed lots for quality by artificially aging. Seeding rates recommended for dryland conditions range from 50.4 to 67.2 kg ha^{-1} in Montana.

Simple correlation among all the vigor tests and field performance variables are given in Table 54. Standard germination was correlated with cold test and accelerated aging (r = 0.81** and 0.79** respectively). Accelerated aging was correlated with germination index and cold test (r = 0.87**, 0.93** respectively). Respiration rate μLO_2 g^{-1} min^{-1} was correlated with respiration rate μLO_2 $seed^{-1}$ min^{-1} (r = 0.97**) and both were negatively correlated with grain yield (r = -0.58*, -0.71**). Emergence rate index was correlated with stand establishment and plants m^{-1} (r = 0.86** and 0.77** respectively). Stand establishment was correlated with plants m^{-1} (final stand) at maturity and grain yield (r = 0.95**, 0.63* respectively). Plants m^{-1} was also correlated with grain yield (r = 0.63*). Emergence rate index was not correlated with grain yield directly for both experiments but indirectly it was associated with yield.

Respiration rate μLO_2 $seed^{-1}$ min^{-1} was the most important vigor test in predicting field performance in several experiments for both years. This agrees with the results of other workers. For example, DasGupta and Austenson (1973b) reported in spring wheat that yield variations were most closely related to standard germination, O_2 uptake, and field emergence. Matthews and Collins (1975) have also shown that rates of O_2 uptake were directly related to both rate of emergence and ultimate emergence. The second most important test was the cold test. Accelerated aging was not as important as in winter wheat for predicting field performance, instead standard germination was important. Other tests, e.g., electrical conductivity, glutamic acid decarboxylase activity, and speed of germination did not play a significant role in predicting field performance. Therefore, the combination of respiration rate, cold test, standard germination, and accelerated aging tests should be used to evaluate spring wheat seed quality. These tests are complementary, i.e., there is minimal duplication in terms of evaluating the same seed quality component. One test is not enough to measure overall seed quality.

In the first year spring wheat study (1981), two cultivars Lew and Newana were evaluated. Although significant relationships were observed by stepwise regression between seed vigor tests and field performance, it should be mentioned here that field emergence rate index and stand establishment were not significant for both cultivars. Equal numbers of seeds were planted which had been adjusted to pure live seeds and seeding rate was 67.2 kg ha^{-1}. However, in the second year spring wheat studies (1982), seed sources had more variability. Seeding rates were reduced from 67.2 to 56 kg ha^{-1} and were not adjusted for pure live seeds. This was important to determine the relationship of seed vigor tests with field performance over a wide range of seed quality.

SUMMARY AND CONCLUSIONS

During the past decade, seed vigor testing of crops has gained importance in seed quality programs. However, before these vigor tests can be used in quality control, they must meet certain criteria. Most important among those criteria is that a vigor test should be related to field performance. Standardization of vigor tests is being achieved for many crops. Vigor testing of wheat has not been extensively studied. The objective of this study was to evaluate several vigor tests and determine their relationship with field performance of wheat.

A series of vigor tests was conducted on winter wheat and spring wheat for two years. In the first year winter wheat study (1980-81), the following vigor tests were evaluated in the laboratory: speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity on 10 seed lots representing five cultivars. Standard germination was determined as an indicator of present seed quality. Field performance was assessed by emergence rate index, stand establishment (total emergence), and grain yield.

To determine which vigor test was related the best with field performance a multiple regression stepwise procedure, BMDP (Dixon and Jennrich, 1981) was used. Each parameter of field performance was compared with all the vigor tests and those best related with field performance were selected. Emergence rate index was most closely related with the accelerated aging and respiration rate (R = 0.83*). Stand establishment was most closely related with the accelerated aging, electrical conductivity and respiration rate (R = 0.90*). Grain yield was related with the accelerated aging test (R = 0.73*). It was observed that accelerated aging was the most important vigor test in predicting field performance (Table 19). However, this relationship was strengthened by adding respiration rate and electrical conductivity. These results suggest that one vigor test is not enough to measure overall seed quality. A combination of tests, which measure the different aspects of seed vigor should be used. It was concluded that field performance was closely related with accelerated aging (stress test), respiration rate (which measures energy potential of seeds) and electrical conductivity (related to membrane integration/degradation). All of these vigor tests measure different aspects of seed vigor.

Table 19. Summary of Relationship Between Seed Vigor Tests and Field Performance in Winter Wheat.

Laboratory Studies	Field Studies					
	Emerg Rate (index)		Stand Estab (seedling m^{-1})		Grain Yield (kg ha^{-1})	
Seed Vigor Tests	1980-81	1981-82	1980-81	1981-82	1980-81	1981-82
Std Germ (%)	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.
Germ Index	N.I.	–	N.I.	–	N.I.	–
Cold Test (%)	N.I.	–	N.I.	–	N.I.	–
Acc Aging (%)	I	N.I.	I	N.I.	I	N.I.
Resp (μLO_2 $seed^{-1}$ min^{-1})	I	–	I	–	N.I.	–
Cond Index	N.I.	–	I	–	N.I.	–
GADA (μLCO_2 g^{-1} min^{-1})	–	N.I.	–	N.I.	–	N.I.

I (Important) indicates that vigor test had significant relationship with field performance either alone or in combination with other vigor tests.
N.I. (Not Important) indicates that vigor test did not have significant relationship with field performance.
– Blank shows that vigor test was not evaluated.

Seed lots were not significantly different at 0.05 level for emergence rate index ($P = 0.09$) and stand establishment ($P = 0.12$). However, there were significant differences for grain yield among seed lots ($P < 0.01$). Nonsignificance of field performance was attributed to the normal seeding rate. Equal number of seeds were planted for each seed lot and also adjusted to equal number of pure live seeds. Moreover, these seed lots were sized for uniformity which eliminated the effect of seed size on vigor, which is a very important component of seed vigor in wheat.

In the second year study (1981-82) of winter wheat, the objective was to evaluate the sensitivity of accelerated aging on several certified lots of Redwin winter wheat. Inferences concerning the relation between seed vigor tests and field performance are limited because of the narrow range of variability among seed lots for field emergence. Seed lots were not significantly different at the 0.05 level for emergence rate index (P = 0.14), stand establishment (P = 0.08), and grain yield (P = 0.63). The nonsignificance of results was attributed to the lack of variability among seed sources. These lots were all of high quality. Equal numbers of seed based on a pure live seed basis were planted at normal seeding rates. Field conditions were also optimum.

In both years of the winter wheat studies, there were no significant differences among seed lots for emergence rate index and stand establishment. Accelerated aging, respiration rate and electrical conductivity tests are thought to be important in relation to field performance. However, validity of these vigor tests needs to be confirmed on a large number of seed lots from farmers. These studies should be conducted under a wide range of field conditions at several locations and for several years. These existing tests may be modified according to crop condition as has been done by Hampton (1981) for New Zealand cereals or new vigor tests may be developed which would be more closely related with field performance.

In 1981, spring wheat cultivars Lew and Newana were evaluated using standard germination, speed of germination, cold test, accelerated aging, respiration rate, and electrical conductivity. Sized and unsized seed lots of both cultivars were the seed source for this study. It was observed that sizing of seed did not change the evaluation of vigor tests. Size X lots interactions were not significant in general for vigor tests and field performance variables. In the cultivar Lew, emergence rate index was most closely related with respiration rate (R = 0.72*); stand establishment with cold test (R = 0.43 NS); and grain yield with respiration rate (R = 0.66**). In Newana, emergence rate index was most closely related with the cold test and accelerated aging (R = 0.90**); stand establishment with the cold test and respiration rate (R = 0.89**); and grain yield with respiration rate and standard germination (R = 0.84*). We consider respiration rate to be the most important vigor test conducted for spring wheat. Other tests considered important were accelerated aging, cold test, and standard germination (Table 20).

There were no significant differences among seed lots of Lew spring wheat for emergence rate index (P = 0.31), stand establishment (P = 0.68), and grain yield (P = 0.34). Seed lots of Newana were also not different for emergence rate index (P = 0.07), stand establishment (P = 0.10), and grain yield (P = 0.70).

In the 1982 spring wheat studies, two experiments were conducted: one using different lots of Newana and the second using artificially aged seeds. The objective of experiment 1 was to evaluate the sensitivity of certain vigor tests on several lots of Newana spring wheat. Laboratory tests conducted included: the standard germination, speed of germination index, accelerated aging, respiration rate, and glutamic acid decarboxylase activity tests. Emergence rate index was closely related with the standard germination and accelerated aging (R = 0.81**), stand establishment with speed of germination index (R = 0.79**) and grain yield with the standard germination, glutamic acid decarboxylase activity, and respiration rate (R = 0.86**). Seed lots evaluated were different for emergence rate index ($P < 0.05$) and stand establishment ($P < 0.01$). However, there were no significant differences in grain yield among seed lots (P = 0.34).

The objective of experiment 2 was to evaluate several vigor tests on a wide range of seed quality of both Lew and Newana spring wheat. Laboratory tests evaluated included the standard germination, speed of germination index, cold test, accelerated aging, respiration rate, electrical conductivity, and glutamic acid decarboxylase activity tests. Emergence rate index was most closely related to the accelerated aging (R = 0.98**), stand establishment to the cold test (R = 0.93**), and grain yield to respiration rate and standard germination (R = 0.93**). There were significant differences among seed lots for all the vigor tests and emergence rate index ($P < 0.01$), stand establishment ($P < 0.01$), and grain yield ($P < 0.01$). Table 20 summarizes the various vigor tests evaluated in spring wheat for two years.

These results suggest that there is a relationship between seed vigor tests and field performance of wheat. These relationships become stronger as the variability in seed quality increases. One would expect a better relationship of these vigor tests with field emergence rate and stand establishment than with grain yield.

It is concluded that one vigor test is not enough to predict overall seed quality. A combination of tests, which measure the different aspects of seed vigor should be used. Field performance in winter wheat was most closely related with the accelerated aging, respiration rate, and electrical conductivity. In spring wheat, respiration rate was the vigor test most closely related to field performance. However, with the addition of other tests such as cold test, standard germation, and accelerated aging, the magnitude of relationship with field performance increased.

Table 20. Summary of Relationship Between Seed Vigor Tests and Field Performance in Spring Wheat.

Laboratory Studies	Field Studies											
	Emergence Rate (index)				Stand Estab (seedling m^{-1})				Grain Yield (kg ha^{-1})			
	First Year Studies (1981)		Second Year Studies (1982)		First Year Studies (1981)		Second Year Studies (1982)		First Year Studies (1981)		Second Year Studies (1982)	
Seed Vigor Tests	Lew	Newana	Newana	Artificially Aged Lots	Lew	Newana	Newana	Artificially Aged Lots	Lew	Newana	Newana	Artificially Aged Lots
Std Germ (%)	N.I.	N.I.	I	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	I	I	I
Germ Index	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	I	N.I.	N.I.	N.I.	N.I.	N.I.
Cold Test (%)	N.I.	I	–	N.I.	N.I.	I	–	I	N.I.	N.I.	–	N.I.
Acc Aging (%)	N.I.	I	I	I	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.
Resp (μLO_2 $seed^{-1}$ min^{-1})	I	N.I.	N.I.	N.I.	N.I.	I	N.I.	N.I.	I	I	I	I
Cond Index	N.I.	N.I.	–	–	N.I.	N.I.	–	–	N.I.	N.I.	–	–
Cond (μmhos cm^{-1} g^{-1})	–	–	–	N.I.	–	–	–	N.I.	–	–	–	N.I.
GADA (μLCO_2 g^{-1} min^{-1})	–	–	N.I.	N.I.	–	–	N.I.	N.I.	–	–	I	N.I.

I (Important) indicates that vigor test had significant relationship with field performance either alone or in combination with other vigor tests.
N.I. (Not Important) indicates that vigor test did not have important relationship with field performance.
– Blank shows that vigor test was not evaluated.

LITERATURE CITED

LITERATURE CITED

Abdul-Baki, A. A. 1969. Relationship of glucose metabolism to germinability and vigor in barley and wheat seeds. Crop Sci. 9:732-737.

Abdul-Baki, A. A., and J. D. Anderson. 1970. Viability and leaching of sugars from germinating barley. Crop Sci. 10:31-34.

Abdul-Baki, A. A., and J. D. Anderson. 1973a. Vigor determination in soybean seed by multiple criteria. Crop Sci. 13:630-633.

Abdul-Baki, A. A., and J. D. Anderson. 1973b. Relationship between decarboxylation of glutamic acid and vigor in soybean (*Glycine max* L.) seed. Crop Sci. 13:227-232.

Agrawal, P. K. 1977. Germination, fat acidity and leaching of sugars from five cultivars of paddy (*Oryza sativa* L.) seeds during storage. Seed Sci. Technol. 5:489-498.

Allan, R. E., O. A. Vogel, T. S. Russell, and C. J. Peterson, Jr. 1962. Seedling emergence rate of fall-sown wheat and its association with plant height and coleoptile length. Agron. J. 54:347-350.

Anderson, J. D. 1970. Metabolic changes in partially dormant wheat seeds during storage. Plant Physiol. 46:605-608.

Anderson, J. D., and A. A. Abdul-Baki. 1971. Glucose metabolism of embryos and endosperms from deteriorating barley and wheat seeds. Plant Physiol. 48:270-272.

Anderson, K., and S. Anderson. 1979. Germinability and vigor in cereal seed. (In Danish). Tolvmandsbladet 1979(51):35-39.

Association of Official Seed Analysts. 1976. Progress report on the seed vigor testing handbook. Newsl. Assoc. Off. Seed Anal. 50:1-78.

Association of Official Seed Analysts. 1978. Rules for testing seeds. J. Seed Technol. 3:1-126.

Association of Official Seed Analysts. 1983. Seed vigor testing handbook. Assoc. Off. Seed Anal. Publ. AOSA Hand. 32.

Austenson, H. M., and P. D. Walton 1970. Relationship between initial seed weight and mature characteristics in spring wheat. Can. J. Plant Sci. 50:53-58.

Ayre, L. 1980. Seed vigour affects cereal throughout the season. Arable Farming. 7:42-43, 45.

Azizul-Islam, A. J. M., J. C. Delouche, and C. C. Baskin. 1973. Comparison of methods for evaluating deterioration in rice seed. Proc. Assoc. Off. Seed Anal. 63:155-160.

Bakumenko, N. I., O. P. Rodchenko, V. A. Vorobév, A. E. Yudin. 1975. Effect of spring and autumn frosts on yield and sowing qualities of seeds of spring wheat. (In Russian). Cited in: Referativnyi Zhurnal 1975 (12):423.

Bailey, C. H. 1918. Respiration of stored wheat. J. Agric. Res. 12:685-713.

Baskin, C. C. 1971. Relation of certain physiological properties of peanut seed to field performance and storability. Ph.D. Diss., Miss. State Univ. State College. Diss. Abstr. Int. 31 B:3804.

Baskin, C. C. 1977. Vigor test methods: Accelerated aging. Newsl. Assoc. Off. Seed Anal. 51:42-52.

Bautisa, G. M., and P. Linko. 1962. Glutamic acid decarbozylase activity as a measure of damage in artificially dried and stored corn. Cereal Chem. 39:455-459.

Bautisa, G. M., J. C. Lugay, L. J. Cruz, and B. O. Juliano. 1964. Glutamic acid decarboxylase activity as a viability index of artificially dried and stored rice. Cereal Chem. 41: 188-191.

Belcher, E. W., and L. Miller. 1974. Influence of substrate moisture level on the germination of sweet gum and sand pine seed. Proc. Assoc. Off. Seed Anal. 65:88-89.

Berezkin, A. N., N. A. Klochko, V. V. Bakeev, V. N. Bakeev, and V. N. Guida. 1978. Dependence of yielding quality of cereal grains on the locations in which they are grown. (In Russian). Izvestiya Timiryazevskoi Sel'skokhozyaistvennoi Akademii 1978 (4):63-70.

Bishnoi, U. R., and J. C. Delouche. 1980. Relationship of vigour tests and seed lots to cotton seedling establishment. Seed Sci. Technol. 8:341-346.

Bobkova, Z. N., and A. V. Pashkevich. 1980. A cassette method of determining growth vigour of seeds. (In Russian). Selektsiya i Semenovodstvo 1980 (10):35-37.

Boyd, W. J. R., A. G. Gordon, and L. T. Lacroin. 1971. Seed size, germination resistance and seedling vigor in barley. Can. J. Plant Sci. 51:93-99.

Bradnock, W. T., and S. Matthews. 1970. Assessing field emergence potential of wrinkled-seeded peas. Hort. Res. 10:50-58.

Bremner, P. M., R. N. Eckersall, and R. K. Scott, 1963. The relative importance of embryo size and endosperm size in causing the effects associated with seed size in wheat. J. Agric. Sci. 61:139-145.

Briggs, K. G., and A. Horak. 1980. Relationships between wheat seed ATP content, germination and seedling vigor of different spring wheat genotypes. Can. J. Plant Sci. 60: 1455-1457.

Burris, J. S., O. T. Edje, and A. H. Waheb. 1969. Evaluation of various indices of seed and seedling vigor in soybeans (*Glycine max* L. Merr.). Proc. Assoc. Off. Seed Anal. 59: 73-81.

Byrd, H. W., and J. C. Delouche. 1971. Deterioration of soybean seed in storage. Proc. Assoc. Off. Seed Anal. 61:41-48.

Caldwell, W. P. 1960. Laboratory evaluation of vigor of garden peas. Proc. Assoc. Off. Seed Anal. 50:130-136.

Carver, M. F. F., and S. Matthews. 1975. Respiratory measurements as indicators of field emergence ability in peas. Seed Sci. Technol. 3:871-879.

Chang, L. Y., and J. A. Robertson. 1968. Growth and yield of progeny of nitrogen and phosphorus fertilized barley plants. Can. J. Plant Sci. 48:57-66.

Cheng, Y. Y., P. Linko, and M. Milner. 1958. Glutamic acid decarboxylase in winter grains. Suomen Kemistilehti B 31:333-335. Cited in: Linko, P., and L. Sogn. 1960. Relation of viability and storage deterioration of glutamic acid decarboxylase in wheat. Proc. Assoc. Off. Seed Anal. 63:106-116.

Ching, T. M., S. Hedtke, M. C. Boulger, and W. E. Kronstad. 1977. Correlation of field emergence rate and seed vigor criteria in barley cultivars. Crop Sci. 17:312-214.

Clark, B. E. 1953. Relationship between certain laboratory tests and the field germination of sweet corn. Proc. Assoc. Off. Seed Anal. 43:42-44.

Clark, B. E. 1954. Factors affecting the germination of sweet corn in low temperature laboratory tests. N. Y. State Agric. Exp. Stn. Bull. 769:1-24.

Cobb, R. D., and L. G. Jones. 1966. Development of a sensitive laboratory growth tests to measure seed deterioration. Proc. Assoc. Off. Seed Anal. 56:52-60.

Crosier, W. F. 1957. Fungi involved and methods of conducting cold tests. Proc. Assoc. Off. Seed Anal. 47:185-190.

Czabator, F. J. 1962. Germination value: An index combining speed and completeness of pine seed germination. For. Sci. 8:386-396.

Darwinkel, A. 1978. Patterns of tillering and grain production of winter wheat at a wide range of plant densities. Neth. J. Agric. Sci. 26:383-398.

DasGupta, P. R., and H. M. Austenson. 1973a. Relations between estimates of seed vigor and field performance in wheat. Can. J. Plant Sci. 53:43-46.

DasGupta, P. R., and H. M. Austenson. 1973b. Analysis of interrelationships among seedling vigor, field emergence, and yield in wheat. Agron. J. 63:417-422.

Delaney, D. J. 1980. Seed lot differences within two varieties of hard-red spring wheat—Era and Olaf. M. S. Thesis. Univ. of Minn., St. Paul.

Delouche, J. C. 1965. An accelerated aging technique for predicting relative storability of crimson clover and tall fescue seed lots. Agron. Abstr. 57:40.

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

Demirlicakmak, A., M. L. Kaufmann, and L. P. Y. Johnson. 1963. The influence of seed size and seedling rate on yield and yield components in barley. Can. J. Plant Sci. 43:330-337.

Denney, F. E. 1948. The role of the surface microflora in measurements of respiration rate of germinating seeds. Contribution Boyce Thompson Inst. 15:211-227.

Dixon, W. J., and R. Jennrich. 1981. Stepwise regression (P 2 R). p. 251-263. In: W. J. Dixon (Ed.) BMDP Statistical Software. Univ. of Cal. Press. Berkeley.

Djavanshir, K., and H. Pourbeik. 1976. Germination value—a new formula. Silvae Genetica. 25:79-83. Cited in: A. O. S. A. 1983. Seed vigor testing handbook. Assoc. Off. Seed Anal. Publ. AOSA. Hand. 32.

Don, R., W. J. Rennie, and M. M. Tomlin. 1971. A comparison of laboratory vigor test procedures for winter wheat seed samples. Seed Sci. Technol. 9:641-653.

Ellis, J. R. S., and A. D. Hanson. 1974. Tests for cereal yield heterosis based on germinating seeds: a warning. Euphytica. 23:71-77.

Evans, L. E., and G. M. Bhatt. 1977. Influence of seed size, protein content and cultivar on early seedling vigor in wheat. Can. J. Plant Sci. 57:929-935.

Food and Agricultural Organization, Rome. 1970. Amino acid content of foods and biological data on proteins. Nutritional Studies. No. 24, p 285.

Geiszler, G. N., and B. K. Hoag. 1967. Wheat seed size influences yield. N. Dak. Farm. Res. 24:12-14.

Germ, H. 1960. Methodology of the vigour test for wheat, maize, and barley in rolled filter paper. Proc. Int. Seed Test. Assoc. 25:515-518.

Gill, N. S., and J. C. Delouche. 1973. Deterioration of seed corn during storage. Proc. Assoc. Off. Seed Anal. 63:33-50.

Grabe, D. F. 1964. Glutamic acid decarboxylase activity as a measure of seedling vigor Proc. Assoc. Off. Seed Anal. 54:100-105.

Grabe, D. F. 1965. Prediction of the relative storability of corn seed lots. Proc. Assoc. Off. Seed Anal. 55:92-96.

Grabe, D. F., and A. E. Garay. 1975. Effect of seed source and size on wheat yields. Agron. Abstr. 67:93.

Gul, A., and R. E. Allan. 1976. Stand establishment of wheat lines under different levels of water potential. Crop Sci. 16:611-615.

Hampton, J. G. 1981. The relationship between field emergence, laboratory germination, and vigour testing of New Zealand seed wheat lines. N. Z. J. Exp. Agric. 9:191-197.

Hampton, J. G., B. L. McCloy, and R. McMillan. 1981. Ear populations and wheat production. N. Z. J. Exp. Agric. 9:183-189.

Harman, G. E., and A. L. Granett. 1972. Deterioration of stored pea seed: Changes in germination, membrane permeability and ultrastructure resulting from infection by *Aspergillus ruber* and from aging. Physiol. Plant Pathol. 2:271-278.

Helmer, J. D., J. C. Delouche, and M. Lienhard. 1962. Some indices of vigor and deterioration in seed of crimson clover. Proc. Assoc. Off. Seed Anal. 52:154-161.

Herrera, C. V. 1969. Response of wheat to accelerated aging and other tests for vigor and deterioration. M. S. Thesis. Mississippi State Univ., State College.

Heydecker, W. 1965. Report of the vigour test committee 1962-63. Proc. Int. Seed Test. Assoc. 30:369-380.

Heydecker, W. 1972. Vigour, pp. 209-252. In: E. H. Roberts (Ed). Viability of seeds. Chapman and Hall, London.

Hibbard, R. P., and E. V. Miller. 1928. Biochemical studies on seed viability. I. Measurement of conductance and reduction. Plant Physiol. 3:335-352.

Hutchings, R. J., and J. S. Hicks. 1972. Establishment and yield of wheat sown on conventional and minimal tillage seed beds. pp. 159-160. Annual report 1971 CSRIO Div. of Plant Industry, Canberra.

James, E. 1968. Limitation of glutamic acid decarboxylase activity for estimating viability in beans. Crop Sci. 9:403-404.

Kaufmann, M. L., and A. A. Guitard. 1967. The effect of seed size on early plant development in barley. Can. J. Plant Sci. 47:73-78.

Kaufman, M. L., and A. D. McFadden. 1963. The influence of seed size on results of barley yield trials. Can J. Plant Sci. 43:51-58.

Keydel, F., K. Fischer, and H. Fuchs. 1979. Quality and its relationship to yield in seed production of hybrid wheat. (In Danish). Zeitschrift fur Acker-und Pflanzenbau 1979 (148):337-347.

Kidd, F., and C. West. 1918. The effects of soaking seeds in water. Ann. Appl. Biol. 5:1-10.

Kittock, D. L., and A. G. Law. 1968. Relationship of seedling vigor to respiration and tetrazolium chloride reduction by germinating wheat seeds. Agron. J. 60:286-288.

Knott, D. R., and B. Takuldar. 1971. Increasing seed weight in wheat and its effect on yield, yield components, and quality. Crop Sci. 11:280-283.

Koostra, P. 1973. Changes in seed ultra-structure during senescence. Seed Sci. Technol. 1:417-425.

Lawrence, T. 1963. A comparison of methods of evaluating Russian wild ryegrass for seedling vigor. Can. J. Plant Sci. 43:307-312.

Likhachev, B. S. 1973. Some problems of laboratory seed germination and field emergence of cereals. (In Russian). Byulleten' Vsesoyuznogo Ordena Lenina Instituta Rastenievodstva imeni N. I. Vavilova 1973 (33):24-33.

Lindstrom, M. J. 1974. A model to predict emergence of winter wheat (*Triticum aestivum* L.) based on soil temperature, water potential and depth of coverage. Ph.D. Diss. Washington State Univ., Pullman. Diss. Abstr. Int. 34 B:3585-3586.

Linko, P. 1961. Simple and rapid manometric method for determining glutamic acid decarboxylase activity as quality index of wheat. J. Agric Food Chem. 9:310-313.

Linko, P., and M. Milner. 1959. Enzyme activation in wheat grains in relation to water content. Glutamic acid-alanine transaminase, and glutamic acid decarboxylase. Plant Physiol. 34:392-396.

Linko, P., and L. Sogn. 1960. Relation of viability and storage deterioration of glutamic acid decarboxylase in wheat. Cereal Chem. 37:489-499.

Lopez, A., and D. F. Grabe. 1973. Effect of protein content on seed performance in wheat (*Triticum aestivum* L.) Proc. Assoc. Off. Seed Anal. 63:106-116.

Lund, R. E. 1979. A user's guide to MSUSTAT–An interactive statistical analysis package. p. 74. Montana State Univ., Bozeman.

Maguire, J. D. 1962. Speed of germination-aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2:176-177.

Mahdi, M. T., A. A. Lofti, E. Shiltawy, and F. F. Farag. 1971. Cold test of cotton seed. Proc. Int. Seed Test. Assoc. 36:279-287.

Matthews, S., and W. T. Bradnock. 1967. The detection of seed samples of wrinkle-seeded peas (*Pisum sativum* L.) of potentially low planting value. Proc. Int. Seed Test. Assoc. 32:553-563.

Matthews, S., and W. T. Bradnock. 1968. Relationship between seed exudation and field emergence in peas and french beans. Hort. Res. 8:89-93.

Matthews, S., and M. T. Collins. 1975. Laboratory measurements of field emergence potential in barley. Seed Sci. Technol. 3:863-870.

McDaniel, R. G. 1969. Relationship of seed weight, seedling vigor and mitochondrial metabolism in barley. Crop Sci. 9:823-827.

McDonald, M. B., Jr. 1975. A review and evaluation of seed vigor tests. Proc. Assoc. Off. Seed Anal. 65:109-139.

McDonald, M. B., Jr. 1977. The influence of seed moisture on the accelerated aging seed vigor test. J. Seed Technol. 2:18-28.

McDonald, M. B., Jr. 1980. Vigor test sub-committee report. Newsl. Assoc. Off. Seed Anal. 54:37-40.

McDonald, M. B., Jr., and B. R. Phaneendranath. 1978. A modified accelerated aging seed vigor test for soybean. J. Seed Technol. 3:27-37.

McNeal, F. H., and M. A. Berg. 1960. The evaluation of spring wheat seed from different sources. Agron J. 52:303-304.

Mian, A. L., and L. C. Coffey. 1971a. Eighty hour count germination test—a new test method for measuring seed vigour in corn. Proc. Int. Seed Test. Assoc. 36:265-271.

Mian, A. L., and L. C. Coffey. 1971b. Testing seed vigour in rice. Proc. Int. Seed Test. Assoc. 36:273-278.

Munn, M. T. 1935. Further work with soil for testing the vitality of seeds. Proc. Assoc. Off. Seed Anal. 27:78-79.

Nichols, M. A., and W. Heydeker. 1968. Two approaches to the study of germination data. Proc. Int. Seed Test. Assoc. 33:531-540.

Omar, M. R. 1980. Evaluation of seed quality in wheat. M. S. Thesis. Mississippi State Univ. State College.

Oseley, T. A., and J. D. Jones. 1944. Apparant respiration of wheat grains and its relation to a fungal mycelium beneath the epidermis. Nature. 154:826-827.

Perry, D. A. 1973. Interacting effects of seed vigor and environment on seedling establishment. pp. 311-324. In: W. Heydecker (Ed.) Seed Ecology. Penn. State Univ. Press, University Park, PA.

Perry, D. A. 1976. Why cereal seed may need vigor testing. Arable Farming. 3:26,27,29.

Perry, D. A. 1977. Effect of seed vigor on barley emergence. p. 4-5. In: R. A. Fox (Ed.). Proc. Symp. on problems of pest and diseases control in northern Britain. 23-24 March 1977, Univ. of Dundee.

Perry, D. A. 1978. Report of the vigour test committee 1974-1977. Seed Sci. Technol. 6:159-182.

Pili, E. C. 1967. An accelerated aging technique for evaluating the storability of alfalfa, wheat, corn, and cotton seed lots. M. S. Thesis. Mississippi State Univ., State College.

Pinthus, M. J., and R. Osher. 1966. The effect of seed size on plant growth and grain yield components in various wheat and barley varieties. Isr. J. Agric. Res. 16:53-58.

Pinthus, M. J., and J. Rosenblum. 1961. Germination and seedling emergence of sorghum at low temperatures. Crop Sci. 1:293-296.

Presley, J. T. 1958. Relation of protoplast permeability to cottonseed viability and predisposition to seedling disease. Plant Dis. Rept. 42:852.

Ragai, H., and W. E. Loomis. 1954. Respiration of maize grain. Plant Physiol. 29:49-55.

Rajanna, B., and A. A. de La Cruz. 1975. Growth analysis—an aid in determining seedling vigor of field crops. Agron. Abstr. 67:195.

Rennie, W. J. 1979. Vigor tests no better than germination test as field emergence indicator. Arable Farming. 6:56,61,65.

Rice, W. N. 1960. Development of the cold test for seed evaluation. Proc. Assoc. Off. Seed Anal. 50:118-123.

Robertson, D. W., and A. M. Lute. 1939. Effect of relative humidity on viability, moisture content, and respiration of wheat, oats, and barley seed in storage. J. Agric. Res. 59: 281-291.

Roos, E. E., and J. N. Manalo. 1971. Testing vigor of beans following unfavorable storage conditions. Hort. Sci. 6:347-348.

Scott, R. K. 1961. The significance of seed size and associated factors in the early growth of winter wheat. B. Sc. Dissertation. Univ. of Nottingham. U.K. Cited in: Wood et al. 1977. Seed size variation: Its extent, source and significance in field crops. Seed Sci. Technol. 5:337-352.

Scott. D. J., and R. C. Close. 1976. An assessment of seed factors affecting emergence of garden pea seed lots. Seed Sci. Technol. 4:287-300.

Stormonth, D. A., and D. A. Doling. 1977. Laboratory tests predict cereal emergence. Arable Farming. 4:50-51.

Stormonth, D. A., and D. A. Doling. 1979. The significance of seed vigour in cereals. Arable Farming. 6:42,43,46.

Svien, T. A., and D. Isely. 1955. Factors affecting the germination of corn in the cold test. Proc. Assoc. Off. Seed Anal. 45:80-86.

Tao, K. J. 1979. An evaluation of alternative methods of accelerated aging seed vigor test for soybeans. J. Seed Technol. 3:30-40.

Tao, K. J. 1980a. Vigor "referee" test for soybean and corn. Newsl. Assoc. Off. Seed Anal. 54:40-58.

Tao, K. J. 1980b. The 1980 vigor "referee" test for soybean and corn seed. Newsl. Assoc. Off. Seed Anal. 54:53-68.

Tekrony, D. M., and D. B. Egli. 1977. Relationship between laboratory indices of soybean seed vigor and field emergence. Crop Sci. 17:573-577.

Timson, J. 1965. New method of recording germination data. Nature. 207:216-217.

Tucker, H., and L. Wright. 1965. Estimating rapidity of germination. Crop Sci. 5:398-399.

Whitcomb, W. O. 1936. Weight per bushel of wheat in relation to its seed value. Proc. Assoc. Off. Seed Anal. 28:59-61.

Wood, D. W., P. C. Longden, and R. K. Scott. 1977. Seed size variation: Its extent, source and significance in field crops. Seed Sci. Technol. 5:337-352.

Woodstock, L. W. 1966. A respiration test for corn seed vigor. Proc. Assoc. Off. Seed Anal. 56:95-98.

Woodstock, L. W. 1968. Relationship between respiration during imbibition and subsequent growth rates in germinating seeds. pp. 136-146. In: E. A. Locker (Ed). Third International Symposium on Qualitative Biology of Metabolism. Springer-Verlag, New York.

Woodstock, L. W. 1969. Biochemical tests for seed vigour. Proc. Int. Seed Test. Assoc. 34:253-263.

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

Woodstock, L. W., and M. F. Combs. 1964. A comparison of some possible indices of seedling vigor in corn. Proc. Assoc. Off. Seed Anal. 54:50-60.

Woodstock, L. W., and M. F. Combs. 1965. Effects of gamma-irradiation of corn seed on the respiration and growth of the seedling. Am. J. Bot. 52:563-569.

Woodstock, L. W., and M. F. Combs. 1967. Application of the respiration test for seed vigor of pea seed. Proc. Assoc. Off. Seed Anal. 57:144-147.

Woodstock, L. W., and D. F. Grabe. 1967. Relationships between seed respiration during imbibition and subsequent seedling growth in *Zea mays* L. Plant Physiol. 42:1071-1076.

Woodstock, L. W., and O. L. Justice. 1967. Radiation-induced changes in respiration of corn, wheat, sorghum, and radish seeds during initial stages of germination in relationship to subsequent seedling growth. Rad. Bot. 7:129-136.

Voronin, N., A. Kirieuko, A. Zavarzin, A. Ishin, and P. Sedlov. 1970. Seed size and crop yields. Field Crop Abstr. 23:1229.

Yaklich, R. W., M. M. Kulik, and J. D. Anderson. 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.

APPENDIX

APPENDIX

TABLES

Table 21. Abbreviations Used in Tables and Figures.

Variables	Abbreviation	Units
Standard germination percent	Std Germ	%
Speed of germination index	Germ Index	no.
Cold test	Cold Test	%
Accelerated aging	Acc Aging	%
Respiration rate per gram per min	Resp	μLO_2 g^{-1} min^{-1}
Respiration rate per seed per min	Resp	μLO_2 $seed^{-1}$ min^{-1}
Electrical conductivity index	Cond Index	no.
Electrical conductivity	Cond	$\mu mhos$ cm^{-1} g^{-1}
Glutamic acid decarboxylase activity	GADA	μLCO_2 g^{-1} min^{-1}
Emergence rate index	Emerg Rate	no.
Seedling stand establishment	Stand Estab	seedling m^{-1}
Seedling height	Seedling Ht	cm
Plant height	Plant Ht	cm
Heading date	Heading Date	days
Number of plants per meter of row at maturity	Plants m^{-1}	no.
Number of heads per plant	Heads $Plant^{-1}$	no.
Number of seeds head	Seeds $Head^{-1}$	no.
1000 seed weight	1000sd wt	g
Grain yield	Yield	kg ha^{-1}

Table 22. Seed Source–Winter Wheat (First Year Studies, 1980-81).

Assigned Lot No.	Cultivar	Year	Source	Std Germ (%)
1	Crest	1975	Breeder	96
2	Crest	1979	Breeder	91
3	Redwin	1979	Foundation	97
4	Redwin	1979	Breeder	93
5	Yogo regular	1973	Breeder	95
6	Yogo regular	1976	Breeder	89
7	Nugaines	1975	Breeder	91
8	Nugaines	1979	Breeder	93
9	Winalta	1976	Breeder	93
10	Winalta	1977	Breeder	94

Table 23. Seed Source–Redwin Winter Wheat (Second Year Studies, 1981-82).

Assigned Lot No.	Seed Testing Lab No.	Place	Montana County	Std Germ (%)
1	253	Denton	Fergus	98
2	259	Billings	Yellowstone	95
3	302	Fallon	Prairie	97
4	308	Rapelje	Stillwater	98
5	329	Star Route	Roberts, Carbon	92
6	332	Ryegate	Golden Valley	97
7	344	Roberts	Carbon	94
8	357	Moccasin	Judith Basin	96
9	368	Townsend	Broadwater	87
10	427	Chester	Liberty	94
11	447	Havre	Hill	92
12	496	Bozeman	Gallatin	94

Table 24. Seed Source—Spring Wheat (First Year Studies, 1981).

Assigned Lot No.	Seed Testing Lab No.	Remarks	Std Germ (%)
Cultivar Lew			
1	484	Sized	86
2	484	Unsized	77
3	1296	Sized	86
4	1296	Unsized	86
5	1696	Sized	92
6	1969	Unsized	92
7	1740	Sized	92
8	1740	Unsized	87
9	2137	Sized	86
10	2137	Unsized	88
Cultivar Newana			
1	823	Sized	91
2	823	Unsized	92
3	1231	Sized	94
4	1231	Unsized	90
5	1356	Sized	95
6	1356	Unsized	83
7	1697	Sized	91
8	1697	Unsized	91
9	2052	Sized	91
10	2052	Unsized	83

Table 25. Seed Source–Newana Spring Wheat (Second Year Studies, 1982) Experiment 1.

Assigned Lot No.	Source	Remarks	Std Germ (%)
1	Seed Lab	Common Seed	91
2	Spring Wheat Breeder	1978	88
3	Spring Wheat Breeder	1979	98
4	Spring Wheat Breeder	1980	57
5	Seed Lab No. 1045	1981-1982 Certified	87
6	" 1417	" Certified	96
7	" 1588	" Certified	97
8	" 1760	" Certified	93
9	" 1852	" Certified	90
10	" 1853	" Certified	49
11	" 1872	" Common	96
12	" 2563	1980-1981 Certified	97

Table 26. Seed Source–Spring Wheat (Second Year Studies, 1982) Experiment 2.

Assigned Lot No.	Cultivar	Seed Testing Lab No.	Aging Time (hrs)	Std Germ (%)
1	Lew	2665	0	97
2	Lew	2665	12	95
3	Lew	2665	24	88
4	Lew	2665	36	62
5	Newana	1445	0	96
6	Newana	1445	12	98
7	Newana	1445	24	91
8	Newana	1445	36	89
9	Lew	2654	0	96
10	Newana	1803	24	90
11	Newana	1803	0	98
12	Lew	2654	24	70

Table 27. Mean Squares–Laboratory Studies, Winter Wheat (First Year Studies, 1980-81).

Source of Variation	df	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index
Blocks	3	5.89 ns	61.40**	37.47 ns	877.4**	.0316**	.00004**	742.6**
Lots	9	23.51 ns	20.24**	199.10**	357.3*	.0377**	.00003**	174.2*
Error	27	17.52	4.28	42.65	142.2	.0024	.000003	64.4

*P ⩽ 0.05; **P ⩽ 0.01.

Table 28. Mean Comparisons–Laboratory Studies, Winter Wheat (First Year Studies, 1980-81).

Lot No.	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index
1	96	15.1 a†	89 c	58 ab	0.81 d	0.0261 f	33.1 e
2	91	19.2 bcd	92 c	62 ab	0.79 d	0.0240 def	30.2 de
3	97	17.6 abc	93 c	66 b	0.63 bc	0.0207 bc	16.6 ab
4	93	16.4 ab	89 c	67 b	0.54 a	0.0180 a	22.8 abcde
5	95	15.3 a	69 a	58 ab	0.79 a	0.0250 ef	21.3 abcd
6	89	20.9 d	86 bc	48 a	0.76 d	0.0248 ef	27.5 bcde
7	91	15.2 a	79 b	68 bc	0.56 ab	0.0185 ab	17.6 abc
8	93	19.5 cd	90 c	85 c	0.68 c	0.0223 cd	12.3 a
9	93	17.7 abc	88 bc	68 bc	0.66 c	0.0225 cde	22.0 abcde
10	94	20.8 d	86 bc	62 ab	0.63 bc	0.0209 bc	28.5 cde
Mean	93	17.8	86	64	0.68	0.0223	23.2
LSD (.05)	ns	3.0	9	17	0.07	0.0026	11.64
CV (%)	4	11.6	8	19	7.31	8.01	34.6

†Means within a column not followed by the same letter are different (LSD, P ⩽ 0.05).

Table 29. Mean Squares–Field Studies, Winter Wheat (First Year Studies, 1980-81).

Source of Variation	df	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Seedling Ht (cm)	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
Blocks	3	36.09*	512.9**	3.34 ns	19.54 ns	00.57 ns	60.10 ns	22.60**	7.44ns	2.56ns	803800.0*
Lots	9	15.40 ns	119.5 ns	38.37**	2039.0**	29.40**	21.73 ns	11.84*	59.10**	3.92*	3625000.0**
Error	27	7.95	67.6	1.21	26.18	00.92	22.41	4.57	5.35	1.40	178600.0

*P ≤ 0.05; **P ≤ 0.01.

Table 30. Mean Comparisons–Field Studies, Winter Wheat (First Year Studies, 1980-81).

Lot No.	Emerg Rate (index)	Stand Estb (seedlings m^{-1})	Seedling Ht (cm)	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
1	8.9	37	31.9 c†	130.9 b	168 a	20	12 bcde	30 b	32.68 bcd	5316 bc
2	12.5	45	33.6 d	126.1 b	169 a	21	13 e	27 ab	31.40 ab	5482 c
3	9.3	33	26.2 a	129.6 b	173 b	22	10 abc	28 ab	31.99 abc	5431 c
4	8.6	34	24.9 a	127.6 b	173 b	21	8 a	29 ab	32.76 bcd	5206 bc
5	10.0	34	29.1 b	145.3 c	176 d	21	9 ab	28 ab	31.65 ab	3568 a
6	8.0	28	28.7 b	154.3 d	175 d	16	11 abcde	30 b	30.89 a	3794 a
7	7.1	29	25.1 a	90.7 a	175 cd	20	11 bcde	37 c	33.63 cd	6673 d
8	13.1	43	25.7 a	93.4 a	175 cd	23	13 de	36 c	32.38 abcd	6199 d
9	10.3	38	30.9 b	150.9 cd	175 cd	25	10 abcd	26 a	32.72 d	5223 bc
10	7.9	35	30.8 b	150.7 cd	174 bc	21	12 cde	27 ab	33.57 cd	4737 b
Mean	9.6	36	28.7	130.0	173	21	11	30	32.47	5163
LSD (.05)	ns	ns	1.6	7.4	1.4	ns	5	5	1.44	613
CV (%)	29.5	23	3.8	3.9	0.5	23	20	8	3.64	8.18

†Means within a column not followed by the same letter are different (LSD, P ≤ 0.05).

Table 31. Mean Squares—Laboratory and Field Studies, Redwin Winter Wheat (Second Year Studies, 1981-82).

Source of Variation	df	Std Germ (%)	df	Acc Aging (%)	df	GADA (μLCO_2 g^{-1} min^{-1})	df	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
Blocks	3	17.42ns	(4)	168.2ns	(6)	1.09ns	(3)	237.8ns	111.7ns	13.46ns	133.6**	2.52	12.80ns	5.52**	94.63**
Lots	11	40.45**	(11)	1192.0**	(11)	1.04ns	(11)	182.1ns	255.8ns	3.93ns	46.3ns	1.06	4.74ns	1.34ns	16.19ns
Error	33	13.54	(44)	152.1	(66)	0.76	(33)	113.3	136.8	8.26	29.5	0.98	5.69	0.91	19.93

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

Table 32. Mean Comparisons—Laboratory and Field Studies, Redwin Winter Wheat (Second Year Studies, 1981-82).

Lot No.	Std Germ (%)	Acc Aging (%)	GADA (μLCO_2 g^{-1} min^{-1})	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
1	98 c†	85 e	8.45	53.56	78	93.9	32	4	38	37.38	5297
2	95 bc	75 de	8.56	45.27	62	92.9	28	5	38	37.27	5313
3	97 bc	69 cd	8.99	32.64	59	92.8	29	5	39	38.26	5185
4	98 c	80 de	8.11	34.00	50	93.9	27	6	39	38.08	5454
5	92 b	68 cd	8.55	48.40	69	94.8	28	5	39	38.26	5260
6	97 bc	79 de	7.86	41.44	63	93.9	29	5	36	37.53	5615
7	94 bc	38 a	8.02	38.64	55	96.3	26	6	36	38.46	5603
8	96 bc	74 de	8.05	43.93	67	93.3	31	5	38	37.63	5537
9	87 a	46 ab	8.02	34.24	60	93.3	30	5	38	39.02	5540
10	94 bc	87 e	8.48	49.56	70	93.7	36	5	36	38.28	5599
11	92 b	54 bc	8.55	40.37	61	93.5	28	6	38	38.38	5912
12	94 bc	66 cd	9.06	47.59	75	94.8	37	5	36	37.10	5398
Mean	94	69	8.39	42.47	64	93.9	30	5	38	37.97	5476
LSD (.05)	5	16	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	4	18	10.4	25.06	18	3.1	18	19	6	2.51	8.15

†Means within a column not followed by the same letter are different (LSD, $P \leqslant 0.05$).

Table 33. Mean Squares–Laboratory Studies, Lew Spring Wheat (First Year Studies, 1981).

Source of Variation	df	Std Germ (%)	Germ Index	Cold Test (%)	df	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	df	Cond Index
Blocks	3	47.60 ns	510.30**	39.57 ns	(5)	906.1**	.04337**	.000045**	(3)	795.50**
Size	1	67.60 ns	25.39 ns	8.10 ns	(1)	.1602 ns	.01737 ns	.000011 ns	(1)	15.14 ns
Lots	4	128.60**	76.47**	77.65*	(4)	1992.0**	.08214**	.000014*	(1)	103.60 ns
Size x Lots	4	41.85 ns	22.41 ns	10.35 ns	(4)	55.73 ns	.00760 ns	.000024*	(4)	561.10**
Error	27	30.04	8.80	26.97	(45)	97.86	.00535	.000005	(27)	165.50

Table 34. Mean Comparisons–Laboratory Studies, Lew Spring Wheat (First Year Studies, 1981).

Lot No.	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index
484	81 a	22.53 b	85 a	54 a	0.98 c	0.0313 b	82.61
1296	86 ab	22.04 b	90 ab	84 cd	0.93 c	.0290 a	79.31
1696	92 c	24.09 b	94 b	77 bc	0.78 a	.0292 a	78.55
1740	89 bc	17.49 a	91 b	74 b	0.84 b	.0285 a	80.40
2137	87 abc	17.34 a	89 ab	86 d	0.82 ab	.0291 a	72.93
Mean	87	20.70	90	75	0.87	.0294	78.76
LSD (.05)	6	3.04	5	8	0.06	.0019	NS
Sized	88	21.50	90	75	0.85	.0298	78.15
Unsized	86	19.90	89	75	0.89	.0290	79.38
Mean	87	20.70	90	75	0.87	.0294	78.76
LSD (.05)	NS	NS	NS	NS	NS	NS	NS
C·V (%)	6.31	14.33	6	13.21	8.4	7.84	16.33

Table 35. Mean Squares–Field Studies, Lew Spring Wheat (First Year Studies, 1981).

Source of Variation	df	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads Plant^{-1}	Seeds Head^{-1}	1000 sd wt (g)	Yield (kg ha^{-1})
Blocks	3	6.97 ns	28.03 ns	9.86*	1.27*	4.97 ns	0.01 ns	0.0028 ns	0.4490 ns	68600.0 ns
Size	1	13.10 ns	115.60 ns	2.26 ns	0.40 ns	6.40 ns	0.36 ns	0.1638 ns	0.2310 ns	85410.0 ns
Lots	4	25.62 ns	52.47 ns	1.67 ns	0.46 ns	20.19 ns	0.11 ns	2.0670 ns	1.4300 ns	39080.0 ns
Size x Lots	4	32.05 ns	45.97 ns	9.67**	0.21 ns	16.96 ns	0.09 ns	2.0410 ns	0.1763 ns	37380.0 ns
Error	27	21.69	78.09 ns	2.28	0.32	27.17	0.13	2.0870 ns	0.5818	36330.0 ns

*P ⩽ 0.05; **P ⩽ 0.01.

Table 36. Mean Comparisons–Field Studies, Lew Spring Wheat (First Year Studies, 1981).

Lot No.	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads Plant^{-1}	Seeds Head^{-1}	1000 sd wt (g)	Yield (kg ha^{-1})
484	23.81	74	99.0	191	48	4	25	39.48	4828
1296	20.37	75	98.3	191	48	4	26	40.02	4677
1696	23.05	71	98.0	190	49	3	26	40.43	4750
1740	19.58	69	98.3	191	45	4	27	40.56	4650
2137	21.12	72	97.8	190	48	3	27	40.06	4703
Mean	21.59	72	98.0	190	47	4	26	40.11	4722
LSD (.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sized	21.01	71	98.5	191	47	4	26	40.19	4768
Unsized	22.16	74	98.1	190	48	3	26	40.04	4675
Mean	21.59	72	98.0	190	47	4	26	40.11	4722
LSD (.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	21.57	12.20	1.54	0.30	11.03	10.25	5.48	1.90	4.04

Table 37. Mean Squares–Laboratory Studies, Newana Spring Wheat (First Year Studies, 1981).

Source of Variation	df	Std Germ (%)	Germ Index	Cold Test (%)	df	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	df	Cond Index
Blocks	3	24.90 ns	705.10**	12.37 ns	(5)	104.9 ns	.0137**	0.0000009*	(3)	734.2 ns
Size	1	202.50**	16.21 ns	8.10 ns	(1)	5.766 ns	.0653**	0.00000003 ns	(1)	245.4 ns
Lots	4	35.75 ns	61.13**	7.85 ns	(4)	421.7**	.0585**	.0000055 ns	(4)	1092.0*
Size x Lots	4	56.75**	21.60 ns	5.85 ns	(4)	90.67 ns	.0171**	.0000102*	(4)	71.6 ns
Error	27	15.79	8.88	9.92	(45)	109.0	.0027	.0000030	(27)	346.2

*P ⩽ 0.05; **P ⩽ 0.01.

Table 38. Mean Comparisons–Laboratory Studies, Newana Spring Wheat (First Year Studies, 1981).

Lot No.	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index
823	91	22.46 b†	95	93 b	0.73 b	0.0236	79.81 b
1231	92	23.46 b	96	86 ab	0.69 ab	0.0228	72.12 ab
1356	89	17.23 a	96	78 a	0.66 a	0.0238	88.56 b
1697	91	18.41 a	96	90 b	0.66 a	0.0228	57.15 a
2052	87	18.50 a	94	91 b	0.83 c	0.0244	78.50 b
Mean	90	20.01	95	88	0.71	0.0235	75.23
LSD (.05)	ns	3.06	ns	9	0.043	ns	19.09
Sized	92 a	20.65	96	87	0.68 a	0.0235	77.71
Unsized	88 b	19.38	95	88	0.74 b	0.0234	72.75
Mean	90	20.01	95	88	0.71	0.0235	75.23
LSD (.05)	3	ns	ns	ns	0.027	ns	ns
CV(%)	4.43	14.88	330	15.74	7.36	7.38	24.73

†Means within a column not followed by the same letter are different (LSD, P ⩽ 0.05).

Table 39. Mean Squares–Field Studies, Newana Spring Wheat (First Year Studies, 1981).

Source of Variation	df	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
Blocks	3	41.99 ns	67.13 ns	12.32**	1.00	5.60 ns	0.14 ns	28.57*	0.397	121200.0 ns
Size	1	59.76 ns	25.60 ns	1.89 ns	1.60	0.40 ns	0.29 ns	0.73 ns	0.003	10410.0 ns
Lots	4	51.22*	69.29 ns	4.65*	1.52	25.84 ns	.08 ns	22.44*	0.302	70030.0 ns
Size x Lots	4	16.86 ns	129.30 ns	4.29*	0.48	21.59 ns	.16 ns	13.74 ns	.132	124500.0 ns
Error	27	17.87	48.78	1.55	0.41	37.58	.17	8.04	.279	93040.0

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

Table 40. Mean Comparisons–Field Studies, Newana Spring Wheat (First Year Studies, 1981).

Lot No.	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
823	18.04 abc†	69	79.9 ab	191	47	3	39 bc	35.88	5703
1231	22.23 c	77	78.9 a	191	47	4	38 bc	35.46	5525
1356	16.00 a	75	80.6 b	192	52	3	37 ab	35.80	5615
1697	20.92 bc	75	79.4 ab	191	48	3	36 a	35.89	5463
2052	17.74 ab	73	78.8 a	192	48	3	40 c	35.95	5528
Mean	18.99	74	79.5	191	48	3	38	35.80	5567
LSD (.05)	4.34	ns	1.3	ns	ns	ns	3	ns	ns
Sized	20.21	75	79.8	191	48	3	38	35.81	5583
Unsized	17.76	73	79.3	192	49	3	38	35.79	5550
Mean	18.99	74	79.5	191	48	3	38	35.80	5567
LSD (.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	22.26	9.48	1.56	0.33	12.66	12.85	7.48	1.48	5.48

†Means within a column not followed by the same letter are different (LSD, $P \leq 0.05$).

Table 41. Mean Squares–Laboratory Studies, Newana Spring Wheat (Second Year Studies, 1982) Experiment 1.

Source of Variation	df	Std Germ (%)	Germ Index	df	Acc Aging (%)	df	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	df	GADA (μLCO_2 g^{-1} min^{-1})
Blocks	3	13.11	309.9**	4	224.3	(6)	.0192**	.00002**	(4)	0.40 ns
Lots	11	1049.00**	311.6**	11	1746.0**	(11)	.0487**	.00002**	(11)	2.00**
Error	33	15.84	17.9	44	118.1	(66)	.0029	.000003	(44)	0.05

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

Table 42. Mean Comparisons–Laboratory Studies, Newana Spring Wheat (Second Year Studies, 1982) Experiment 1.

Lot No.	Std Germ (%)	Germ Index	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	GADA (μLCO_2 g^{-1} min^{-1})
1	91 bc†	30.05 bc	56 cde	.54 ab	.0204 bc	4.60 b
2	88 b	27.45 bc	39 ab	.64 def	.0212 cde	5.22 d
3	98 d	42.50 d	43 abc	.66 ef	.0206 bcd	5.23 d
4	57 a	18.47 a	41 ab	.58 bc	.0191 b	3.78 a
5	87 b	28.27 bc	64 ef	.72 g	.0231 e	4.92 c
6	96 cd	29.55 bc	58 def	.60 cde	.0224 de	4.81 bc
7	97 d	32.37 c	95 h	.55 ab	.0216 cde	4.95 c
8	93 bcd	43.17 d	67 efg	.79 h	.0215 cde	4.60 b
9	90 b	24.75 b	72 fg	.59 bcd	.0198 bc	4.95 c
10	49 a	17.25 a	31 a	.50 a	.0162 a	3.07 a
11	96 cd	40.08 d	79 g	.69 fg	.216 cde	4.61 b
12	97 cd	40.25 d	47 bcd	.58 bc	.0198 bc	4.12 a
Mean	86	31.17	57	.63	.0206	4.57
LSD (.05)	6	18.22	14	.06	.0019	0.04
CV (%)	5	13.58	19	8.80	8.91	4.69

†Means within a column not followed by the same letter are different (LSD, $P \leqslant 0.05$).

Table 43. Mean Squares—Field Studies, Newana Spring Wheat (Second Year Studies, 1982) Experiment 1.

Source of Variation	df	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
Blocks	3	225.3**	87.86 ns	6.72*	.69 ns	0.79 ns	3.39**	9.51**	1.48**	28.72 ns
Lots	11	115.0*	316.80**	5.69**	.40 ns	30.51*	.99 ns	18.33**	.42 ns	11.86 ns
Error	33	46.1	59.92	1.71	.28	12.48	.59	2.02	.23	10.09

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

Table 44. Mean Comparisons—Field Studies, Newana Spring Wheat (Second Year Studies, 1982) Experiment 1.

Lot No.	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
1	31.73 bcd†	48 bcde	83.7 c	197	27 bcd	6	35 b	38.07	6256
2	34.88 d	47 bcd	81.5 b	197	24 abc	7	34 ab	38.08	5846
3	33.41 cd	55 de	80.9 ab	197	27 bcd	6	33 a	37.41	6041
4	22.32 ab	31 a	81.1 ab	198	20 a	8	40 c	37.57	5977
5	32.86 cd	55 de	82.0 bc	197	28 cd	6	35 ab	37.74	6255
6	25.03 abc	39 ab	81.2 ab	197	23 abc	6	35 b	37.69	6358
7	27.60 bcd	43 bc	82.1 bc	197	24 abc	7	33 a	38.09	6077
8	29.49 bcd	59 e	82.7 bc	197	27 bcd	6	34 ab	37.34	6208
9	24.00 abc	53 cde	81.4 ab	197	27 bcd	7	35 ab	37.13	6128
10	17.48 a	38 ab	79.5 a	197	22 ab	7	39 c	37.99	5838
11	31.23 bcd	57 de	83.7 c	197	27 bcd	6	35 ab	37.72	6199
12	33.08 cd	56 de	82.5 bc	197	30 a	6	34 ab	38.01	6310
Mean	28.59	48	81.09	197	25	7	35	37.74	6124
LSD (.05)	9.77	11	1.9	ns	5	ns	2	ns	ns
CV (%)	23.75	16	1.6	0.3	14	12	4	1.28	5.19

†Means within a column not followed by the same letter are different (LSD, $P \leqslant 0.05$).

Table 45. Mean Squares–Laboratory Studies, Spring Wheat (Second Year Studies, 1982) Experiment 2.

Source of Variation	df	Std Germ (index)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	GADA (μLCO_2 g^{-1} min^{-1})	Cond (μmhos cm^{-1} g^{-1})
Blocks	3	64.3*	12.4 ns	906.0*	535.2**	.012**	.000014**	.9576**	9.66**
Lots	11	539.1**	488.7**	3746.0**	8427.0**	.042**	.000052**	.9416**	15.30**
Error	33	21.7	17.8	302.7	70.2	.002	.000003	.0276	0.37

*P ⩽ 0.05; **P ⩽ 0.01.

Table 46. Mean Comparisons–Laboratory Studies, Spring Wheat (Second Year Studies, 1982) Experiment 2.

Lot No.	Std Germ (index)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond (μmhos cm^{-1} g^{-1})	GADA (μLCO_2 g^{-1} min^{-1})
1	97 fg†	30.69 de	83 ef	97 f	0.77 h	.0273 d	9.98 fg	5.07 g
2	95 defg	29.67 d	66 de	93 f	.73 gh	.0226 d	10.46 g	4.56 de
3	88 c	13.68 bc	35 bc	44 d	.76h	.0277 d	11.92 h	4.15 bc
4	62 a	4.82 a	00 a	2 a	.73 gh	.0263 d	12.72 h	3.61 a
5	96 efg	32.33 de	76 ef	97 f	.66 ef	.0218 c	8.59 cd	5.18 g
6	98 g	18.04 c	92 f	97 f	.56 bcd	.0189 ab	8.98 de	4.78 ef
7	91 cdef	13.00 bc	75 ef	79 e	.62 def	.0209 bc	9.49 ef	4.36 cd
8	89 cd	7.74 ab	45 cd	16 b	.61 cde	.0211 bc	9.43 de	4.32 bc
9	96 efg	27.77 d	79 ef	95 f	.68 fg	.0254 d	8.07 bc	4.69 ef
10	90 cde	10.53 ab	18 ab	24 bc	.46 a	.0178 a	7.52 b	3.79 a
11	98 fg	35.89 e	94 f	96 f	.51 ab	.0188 ab	5.27 a	4.81 b
12	70 b	9.46 ab	37 bc	32 c	.55 bc	.0205 bc	8.95 de	4.12 b
Mean	89	19.47	58	64	.64	.0227	9.28	4.45
LSD (.05)	7	6.07	25	10	.068	.0025	0.87	0.24
CV (%)	5	21.66	30	13	7.74	7.60	0.07	3.73

†Means within a column not followed by the same letter are different (LSD, P ⩽ 0.05).

Table 47. Mean Squares–Field Studies, Spring Wheat (Second Year Studies, 1982) Experiment 2.

Source of Variation	df	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
Blocks	3	15.81 ns	233.3 ns	11.5 ns	0.79 ns	21.0 ns	11.64 ns	10.9*	1.03 ns	4.24
Lots	11	600.20**	950.8**	389.6**	14.34**	147.7**	18.54*	176.9**	28.03**	498.70**
Error	33	31.00	25.7	9.0	1.67	9.5	8.83	2.7	1.47	9.17

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

Table 48. Mean Comparisons–Field Studies, Spring Wheat (Second Year Studies, 1982) Experiment 2.

Lot No.	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
1	31.79 d†	47 d	102.9 d	197 a	24 cde	7 a	27 a	43.43 cd	4433 b
2	29.99 d	53 de	102.7 d	197 a	28 e	6 a	25 a	42.80 bcd	4362 b
3	9.10 ab	36 c	99.7 d	201 cd	24 cde	9 a	29 b	41.46 b	4473 b
4	1.15 a	7 a	91.4 c	202 d	7 a	14 b	34 c	44.15 a	2679 a
5	28.25 d	52 de	82.8 ab	197 a	28 e	6 a	35 cd	37.79 a	6104 d
6	29.01 d	54 de	83.8 b	197 a	27 de	6 a	36 cd	38.14 a	6341 d
7	18.33 c	58 e	82.8 ab	199 ab	27 de	7 a	37 d	37.72 a	6264 d
8	5.96 ab	33 c	79.0 a	200 bc	20 bc	6 a	43 e	37.67 a	5440 c
9	31.37 d	51 de	102.8 d	197 a	26 de	7 a	24 a	41.77 bc	4393 b
10	4.62 ab	22 b	82.3 ab	200 bc	17 b	7 a	45 e	38.95 a	5476 c
11	31.44 d	51 de	81.7 ab	197 a	27 de	7 a	35 cd	38.31 a	6122 d
12	10.08 b	35 c	100.2 d	200 bc	23 cd	6 a	29 b	43.89 d	4182 b
Mean	19.06	41	91.0	199	23	7	33	40.51	5022
LSD (.05)	8.01	7	4.3	2	4	4	2	1.74	436
CV (%)	28.91	12	3.3	0.7	13	40	5	2.99	6.03

†Means within a column not followed by the same letter are different (LSD, $P \leq 0.05$).

Table 49. Simple Correlations Among Various Seed Vigor Tests and Field Performance Variables in Winter Wheat (First Year Studies, 1980-81).

	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index	Emerg Rate (index)	Std Estab (seedlings m^{-1})	Seedling Ht (cm)	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.00																
2	-.39	1.00															
3	.06	.43	1.00														
4	.19	-.04	.25	1.00													
5	-.01	.07	-.13	-.46	1.00												
6	.02	.09	-.13	.46	.98**	1.00											
7	.15	.11	.12	-.72*	.52	.50	1.00										
8	.06	.22	.29	.52	.39	.33	-.22	1.00									
9	.13	.19	.43	.48	.33	.27	.10	.87**	1.00								
10	-.04	.21	.11	-.44	.71*	.69*	.79**	.24	.48	1.00							
11	.08	.29	-.08	-.71*	.35	.42	.57	-.23	-.16	.54	1.00						
12	-.28	.19	-.51	.13	-.37	-.29	-.62	-.20	-.50	-.50	.03	1.00					
13	.46	-.18	.18	.79**	-.34	-.32	-.52	.51	.54	-.11	-.26	.04	1.00				
14	-.32	.46	.35	.21	.31	.26	.25	.38	.53	.46	-.31	-.36	-.05	1.00			
15	-.28	-.22	-.16	.49	-.30	-.30	-.53	-.05	-.19	-.63*	-.86**	.26	-.05	.23	1.00		
16	.17	-.26	-.01	.43	-.62	-.54	-.15	-.31	-.02	-.13	-.20	.08	.52	.03	.18	1.00	
17	-.01	-.20	.41	.73*	-.49	-.52	-.41	.17	.27	-.33	-.85**	-.22	.46	.42	.61	51	1.00

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

Table 50. Simple Correlations Among Various Seed Vigor Tests and Field Performance Variables in Redwin Winter Wheat (Second Year Studies, 1981-82).

	Std Germ (%)	Acc Aging (%)	GADA (μLCO_2 g^{-1} min^{-1})	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
	1	2	3	4	5	6	7	8	9	10	11
1	1.00										
2	.68*	1.00									
3	.06	.14	1.00								
4	.20	.48	.24	1.00							
5	.09	.40	.41	.87**	1.00						
6	−.05	−.43	−.15	.17	.02	1.00					
7	00	.38	.41	.54	.75**	−.09	1.00				
8	−.25	−.62*	−.62*	−.59	−.76**	.31	−.71**	1.00			
9	.02	.12	.16	−.19	−.20	.04	−.43	.04	1.00		
10	−.65*	−.58*	−.27	−.56	−.51	.04	−.33	.65*	.16	1.00	
11	−.29	−.34	−.44	−.15	−.23	.12	−.06	.54	−.48	.31	1.00

*P ⩽ .05; **P ⩽ 0.01.

Table 51. Simple Correlations Among Various Seed Vigor Tests and Field Performance Variables in Lew Spring Wheat (First Year Studies, 1981).

	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00															
2	.19	1.00														
3	.71*	.16	1.00													
4	.42	−.26	.61	1.00												
5	−.85**	.03	−.67*	−.53	1.00											
6	−.08	.34	−.64*	−.56	.17	1.00										
7	−.03	.25	−.33	−.32	.03	.65*	1.00									
8	.09	.45	−.41	−.49	.06	.72*	.47	1.00								
9	−.24	.30	−.42	−.11	.46	.31	.08	.58	1.00							
10	−.01	.35	−.41	−.34	−.01	.79**	.89**	.42	.08	1.00						
11	−.34	−.31	−.28	−.07	.30	−.04	−.13	−.61	−.22	.13	1.00					
12	.03	.49	−.14	−.09	.07	.27	−.22	.57	.75*	−.04	−.33	1.00				
13	.01	.36	−.12	−.19	.13	.40	.55	−.13	−.14	.72*	.55	−.31	1.00			
14	.14	−.62	.41	.61	−.24	−.49	−.26	−.48	−.37	−.49	−.14	−.45	−.39	1.00		
15	.87**	−.20	.72*	.46	−.76**	−.28	−.06	−.19	−.44	−.16	−.18	−.32	−.05	.49	1.00	
16	−.24	.37	−.35	−.48	.06	.66*	.46	.25	−.25	.64*	.06	−.01	.41	−.35	−.38	1.00

*P ≤ 0.05; **P ≤ 0.01.

Table 52. Simple Correlations Among Various Seed Vigor Tests and Field Performance Variables in Newana Spring Wheat (First Year Studies, 1981).

	Std Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00															
2	.55	1.00														
3	.48	–.12	1.00													
4	.07	.35	–.67*	1.00												
5	–.54	.08	–.72*	.41	1.00											
6	–.39	–.52	–.20	–.01	.00	1.00										
7	.08	.01	–.03	–.40	.03	.39	1.00									
8	.56	.32	.56	.14	–.43	–.20	–.48	1.00								
9	.32	–.30	.85**	–.47	–.52	.08	–.06	.62	1.00							
10	–.11	–.34	.04	–.27	–.56	.52	.32	–.27	–.11	1.00						
11	–.48	–.49	–.16	–.43	.26	–.06	.21	–.71*	–.15	–.02	1.00					
12	–.31	–.80**	.48	–.70*	–.40	.54	.26	–.13	.54	.58	.26	1.00				
13	.30	.15	.56	–.22	–.46	.24	–.05	.65*	.49	.09	–.61	.16	1.00			
14	–.02	.10	–.31	.27	.41	.50	.39	–.14	–.12	–.22	–.19	–.21	.30	1.00		
15	00	–.31	–.30	.26	.26	.13	.13	–.47	–.29	–.06	.28	–.12	–.31	.46	1.00	
16	–.04	–.17	–.05	.00	–.34	.79**	.41	–.06	.04	.72*	–.40	.45	.35	.33	–.08	1.00

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

Table 53. Simple Correlations Among Various Seed Vigor Tests and Field Performance Variables in Newman Spring Wheat (Second Year Studies, 1982) Experiment 1.

	Std Germ (%)	Germ Index	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	GADA (μLCO_2 g^{-1} min^{-1})	Emerg Rate (index)	Stand Estab (seed-lings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.00														
2	.79**	1.00													
3	.57*	.34	1.00												
4	.42	.59*	.23	1.00											
5	.75**	.49	.57*	.64*	1.00										
6	.81**	.48	.45	.47	.79**	1.00									
7	.73**	.69*	.13	.51	.64*	.69*	1.00								
8	.67*	.78**	.33	.65*	.40	.46	.67*	1.00							
9	.61*	.57*	.55	.34	.53	.34	.60*	.53	1.00						
10	−.82**	−.54	−.49	−.25	−.65*	−.56	−.46	−.50	−.36	1.00					
11	.68*	.70**	.29	.37	.32	.35	.63*	.90**	.54	−.55	1.00				
12	−.68*	−.79**	−.12	−.41	−.37	−.29	−.58*	−.77**	−.49	.69*	−.82**	1.00			
13	−.93**	−.77**	−.52	−.43	−.66*	−.82**	−.75**	−.72**	−.45	.75**	−.68*	.59*	1.00		
14	−.08	−.15	−.12	−.12	−.08	−.21	.17	−.28	.15	−.14	−.12	.05	.02	1.00	
15	.63*	.50	.45	.28	.58*	.27	.32	.43	.60*	−.64*	.61*	−.70*	−.39	−.14	1.00

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$.

Table 54. Simple Correlations Among Various Seed Vigor Tests and Field Performance Variables in Spring Wheat (Second Year Studies, 1982) Experiment 2.

	Std. Germ (%)	Germ Index	Cold Test (%)	Acc Aging (%)	Resp (μLO_2 g^{-1} min^{-1})	Resp (μLO_2 $seed^{-1}$ min^{-1})	Cond Index	GADA (μLCO_2 g^{-1} min^{-1})	Emerg Rate (index)	Stand Estab (seedlings m^{-1})	Plant Ht (cm)	Heading Date (days)	Plants m^{-1}	Heads $Plant^{-1}$	Seeds $Head^{-1}$	1000 sd wt (g)	Yield (kg ha^{-1})
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.00																
2	.71**	1.00															
3	.81**	.78**	1.00														
4	.79**	.87**	.93**	1.00													
5	-.09	.15	-.04	.10	1.00												
6	-.15	.13	-.14	.02	.97**	1.00											
7	-.53	-.49	-.52	-.42	.76**	.71**	1.00										
8	.76**	.86**	.90**	.88**	.13	.02	-.41	1.00									
9	.75**	.91**	.92**	.98**	.13	.08	-.43	.90**	1.00								
10	.78**	.70*	.93**	.92**	.02	-.09	-.42	.83**	.86**	1.00							
11	-.14	.18	-.04	.14	.65*	.77**	.40	.03	.21	.05	1.00						
12	-.81**	-.87**	-.93**	-.95**	.04	.10	.55	.89**	.97**	-.87**	-.06	1.00					
13	.78**	.67**	.85**	.83**	-.05	-.12	-.45	.78**	.77**	.95**	.86**	-.78**	1.00				
14	-.73**	-.48	-.69*	-.58*	.34	.38	.62*	-.64*	-.56	.76**	.07	.69*	-.85**	1.00			
15	-.04	-.46	-.29	-.45	-.68*	-.73**	-.27	-.34	-.51	-.35	-.90**	.34	-.34	.04	1.00		
16	-.55	-.10	-.38	-.23	.56	.69*	.53	-.28	-.12	-.37	.86**	.27	-.36	.44	-.69*	1.00	
17	.70*	.30	.62*	.49	-.58*	-.71**	-.65*	.50	.37	.62*	-.07	-.51	.63*	-.67*	.49	-.92**	1.00

*P ⩽ 0.05; **P ⩽ 0.01.