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COMPARISON OF LABORATORY INDICES OF SEED VIGOR WITH FIELD PERFORMANCE OF NAVY BEAN (*PHASEOLUS VULGARIS* L.)

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GIAT SURYATMANA

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COMPARISON OF LABORATORY INDICES OF SEED VIGOR WITH FIELD PERFORMANCE OF NAVY BEAN (*PHASEOLUS VULGARIS* L.)

By

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ABSTRACT

COMPARISON OF LABORATORY INDICES OF SEED VIGOR WITH FIELD PERFORMANCE OF NAVY BEAN (*PHASEOLUS VULGARIS* L.)

By

Giat Suryatmana

Comparison of laboratory indices of seed vigor with field performance of navy bean was investigated for three years. Seed lots were selected representing different levels of vigor. All seed lots were evaluated by the following laboratory tests: (a) standard germination; (b) first count of germination (4 and 3 days); (c) cold germination; (d) cold vigor; (e) tetrazolium (TZ) viability determined by tetrazolium dye; (f) TZ vigor; (g) accelerating aging; and (h) leachate conductivity. Field trials were conducted at optimal and variable stress conditions in 1977 through 1979.

Standard germination of seed lots averaged 90.5, 83.1 and 93.3%, respectively in 1977, 1978, and 1979. The 3-day cold test exposed to 10 C in 1978 and 1979 averaged 32.7 and 71.5%. The conductivity test results were closely related to standard germination.

Total field emergence in 1977 and 1978 averaged 13 and 20% lower than standard germination. Lowest total emergence was obtained at the first planting date due to low temperature and soil crusting in 1979. As soil temperature

become more favorable, emergence progressively increased at two successive planting dates.

Under optimal field conditions, standard germination provided the best single estimate of field emergence. For less favorable conditions, the best estimate was provided by a combination of standard germination and accelerated aging tests. Under stress conditions, the conductivity test appeared to give the best single estimate of vigor and field emergence potential. A combination of at least two or three variables such as: conductivity, standard germination, TZ test; conductivity, standard germination, accelerated aging test or conductivity and standard germination, showed more promise for predicting field emergence than results of any single test.

Very low correlations were found between seed vigor indices and crop yield under both optimal and stress conditions. It may be concluded, therefore, that high variation in navy bean yield can not necessarily be attributed to variation in seed vigor.

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INTRODUCTION

More than one third of the 18 million cwt of navy beans produced annually in the United States is grown in Michigan. Every year some of the performance potential is lost because of low vigor seed, however, no data are available which indicate the nature or magnitude of the loss.

Seed vigor refers to the potential of a seed lot for germination and field emergence under a wide range of environmental conditions, and is a quality factor of seeds which greatly influences agricultural production. It is especially significant in a crop such as navy beans (*Phaseolus vulgaris* L.), which has seeds that are fragile and easily damaged thus decreasing seed vigor. Mechanical injury at harvest and during processing is believed to be a major cause of decreased seed and seedling vigor. A number of important diseases can be carried in or on the seed, which may also contribute to decreased seed vigor. These and other factors contribute to impairment of seed vigor, loss in stand establishment and perhaps yield potential.

This problem could be avoided by development and use of reliable, accurate vigor tests for identifying high vigor seed lots and for eliminating low vigor seeds. Many vigor tests have been proposed for use in evaluating seed vigor and are used to varying extents for various crops. There is a need to establish vigor tests for navy beans that are based on experimental data indicating reproducibility of results and good correlation with field performance.

The purpose of this research was to establish the possible relationships between various indices of seed vigor and field performance in order to provide the basis for a valid vigor testing program.

LITERATURE REVIEW

Seed and Seedling Vigor

Although a concise definition of vigor satisfactory to most investigators has yet to be realized, the concept of vigor and its importance in crop development are well accepted.

Early reviews of the concept of vigor were made by Isely (68,69) and Delouche and Caldwell (39). According to Isely, vigor is the sum of all attributes which favor stand establishment under unfavorable conditions. He suggested that the primary factor influencing vigor in the field is the degree of susceptibility to attack by microorganisms. Two ideas appeared from this definition, vigor per se in terms of speed of germination and growth, and susceptibility to unfavorable growing conditions. Delouche and Caldwell (39) believed that Isely's definition was too restrictive for stand establishment under unfavorable conditions and they revised Isley's definition as follows: vigor is the sum of all seed attributes which favor rapid and uniform stand establishment in the field. Both the definition of Delouche and Caldwell and of Isely define vigor in terms which have meaning only for the seed lot, and can not be applied to an individual seed (139).

More recently, several other definitions and concepts of seed vigor have been proposed. Woodstock (136,138,139) focuses attention on the individual seed in characterizing seed vigor as that condition of active good health and natural robustness in seeds which, upon planting, permits germination to proceed rapidly and to completion under a wide range of environmental conditions. Perry (91) limited the definition of vigor to the physiological sense. He defined seed vigor as a physiological property determined by genotype and modified by the environment, which governs the ability of a seed to produce a seedling rapidly in soil and the extent to which the seed tolerates a range of environmental factors. The influence of seed vigor may persist through the life of the plant and affect yield. Thus the effect of seedborne diseases, insect and mechanical injury and response to soilborne microorganisms are not included in this definition. Ching (30) stated that seed vigor involved two components, i.e., germination and seedling growth. She defined vigor as the potential for rapid and uniform germination and fast seedling growth under field conditions. Heydecker (62) described vigor as the condition of a seed which is at the height of its potential powers when all factors that may detract from its quality are absent and those that make a 'good' seed are present in the right proportion, promising satisfactory performance over a maximum range of environmental conditions. Pollock and Roos (98) stated that the concept of vigor can first be considered as the maximum potential for seedling establishment, and second as a continuum of potential decrease from that maximum until the seed is dead, i.e., has zero potential for establishment. The maximum is set by the genetic constitution of the plant and is normally attained by part of each population. Burris (21) reserves the term vigor for the positive side of the physiological sense. He defined vigor as the summation of seed and seedling attributes that allow or promote rapid uniform germination over a range of environments, followed by a rapid uniform seedling emergence and development culminating in a sustained high rate of growth throughout the vegetative development. Certain attributes are excluded from this definition. One of the most obvious characteristics of high seed vigor is a high germination capacity. The reasoning behind this omission is that germination and vigor are considered to be controlled by different systems. More recently, two broad vigor definition were recommended by committees of the Association of Official Seed Analysts (AOSA) and The International Seed Testing Association (ISTA) (12). According to AOSA definition, seed vigor is the sum total of all those properties in seeds which, upon planting, result in rapid and uniform production of healthy seedlings under a wide range of environment including both favorable and stress conditions. In the ISTA version, seed vigor is the sum total of these properties of the seed which determine the potential level of performance and activity of a nondormant seed or seedlot during germination and seedling emergence.

Factors Affecting Seed Vigor

The inherent vigor of seeds within a given lot is not usually uniform nor necessarily normally distributed. Moreover individual seedlings may be more or less vigorous according to where they are growing; environmental factors greatly influence their performance (78). Schoorel (106, 107) and Isely (68) have separately listed the following conditions which influence the vigor of seeds: (a) water availability during ripening and harvest; (b) post-harvest treatment of the seeds such as threshing, drying, and cleaning; (c) duration and conditions of storage; (d) the presence and activity of insects and seedborne microorganisms; (e) the wise or unwise use of chemical compounds such as fungicides and herbicides; and (f) genetic properties of the seeds. Genetic aspects of seed vigor have been reviewed extensively by Kneebone (76), however, further information is needed about biochemical or physiological aspects of vigor.

A major feature of post-fertilization seed development is the accumulation of nutrition reserve. There is some evidence that the greater the supply of stored nutrients in the seed, the greater the vigor of the seedling and its potential for survival (98). Fox and Albrecht (49) found that wheat seed with a high crude protein content (14.4%) germinated and emerged more rapidly and produced more vigorous seedlings than seeds with lower crude protein (11%). The application of nitrogen to wheat fields resulted in production of seed with increased seedling vigor potential (110). Ries (104) also showed a positive correlation between protein content and seedling vigor in snap bean. Lang (77) discussed the general subject of seed size and its relationship with seedling vigor and concluded that: (a) any reserve nutrient that can control the rate of seedling development, under any set of conditions is a potential factor in seedling vigor; (b) any environmental condition that influences accumulation of nutrient reserves in seeds has the potential for influencing vigor in the following generation. Several investigators have reported increased seedling vigor with increased seed size in grasses (15,16), soybean (25,115), and groundnut (114). However, the inconsistency of seed size to influence seedling vigor and other aspects of field performance has been reported for soybean (43), snapbean (34) and sorghum (5).

Temperature is also known to influence vigor. Peas planted under constant temperature for several generations have shown decreasing potential for rapid growth in subsequent plants with each succeeding generation, and the original vigor could be restored only if plants were grown under alternating temperature for two or three generations (63). The significance of such temperature changes in affecting vigor of developing seed has not been carefully studied.

Time and method of harvest may also affect seed quality. One problem in harvesting is that seed lots usually consist of seeds removed from the parent plants at different stages of maturity. Within certain limits (e.g., up to physiological maturity), the more mature a seed is when harvested, the greater will be its vigor and its potential for stand establishment (98). Snyder (117) found that sugarbeet seed harvested 5 to 11 days before commercial maturity did not germinate as well as seed harvested at commercial maturity. In navy bean, increases in both germination and seedling growth rate were obtained by harvesting seeds at full maturity (brown pods) rather than at early stages (green pods) (113). Inoue and Suzuki (66) harvested snap bean seeds from 15 to 35 days after anthesis and found that germination rose progressively from nil for seeds harvested at 15 days to 100% for seeds harvested when fully mature. Premature harvesting of immature seed followed by drying at high temperatures may cause reduced vigor (91). Spraying navy bean plants while still in the windrow has been recommended as a means of reducing mechanical damage during threshing (40). Seed deterioration may occur on the plant if harvest is delayed beyond normal maturity. Low vigor in lima bean is known to be caused by bleaching when the seeds are exposed to strong sunlight before harvest (100). A reduction in vigor due to delayed harvest has also been reported for soybean (54). Rainfall has been reported to influence the vigor of seed, not only by causing increased microbial infections, but also by the increased physical stress set up by cycles of swelling and contracting under changing moisture contents (89). Isely (68) classified injuries incurred by bean seeds into two principle categories: (a) external or visible damage; and (b) internal injury that becomes evident only after imbibition and germination of the seed. The first group includes seed injuries ranging from slight cracking of seed coats to actual splitting and breaking of the seed. Internal injury in seeds showing no visual evidence of external damage. Two widely recognized types are 'baldhead' and 'snakehead' seedlings. A very common type of seedling injury is transvere cracking or complete severence of one or both cotyledons (85,130). Judah (72) reported that 2.84% of the navy beans collected from commercial seed lots in Michigan was mechanically damaged. The higher levels of damage were probably due to poor machine adjustment or improper operation. Further investigations by Picket (94) and Hoki and Picket (64) revealed that mechanical damage to navy beans during harvesting depended primarily upon moisture content of the beans and cylinder speed of the thresher. The optimum moisture content of navy bean seed is between 17 and 20%; pod moisture should preferably be less than 12% (94). During cleaning and handling, mechanical damage to seeds may result from even minor impacts. Serious mechanical damage can also occur during planting. Dexter (40) found that if moisture content of beans could be increased from 11 to 16% before planting, emergence of seedlings could be increased from 39 to 78%.

A great deal of work has shown that during storage of seeds, loss of viability is preceded by loss of vigor (14). Temperature and humidity (and its influence on seed moisture content) are the major factors controlling seed longevity in storage. Changes may occur during seed storage which affect germination and result in production of weak and structurally abnormal seedlings. Such abnormalities are usually distinct from those associated with mechanical injury. These stages in the degradation of seed tissues and decline in vigor and in germination potential of seed subjected to unfavorable storage conditions can be demonstrated by the 'Topographical Tetrazolium' method (19).

In the field, the primary environmental factors which influence germination and seedling vigor are soil moisture, oxygen supply (aeration), temperature, soil texture and structure, and microorganisms. Pollock (97) observed the importance of moisture and temperature control during germination tests. Temperatures 15 C or lower during the first hour of seed imbibition immediately inhibited respiration in lima beans with proportional inhibition of subsequent seedling growth (143). Later, Pollock (96) showed that the critical factor was seed moisture at the beginning of imbibition. Imbibition temperature sensitivity occured only if the initial seed moisture was below 12-14%. Similar results have been obtained by Pollock, Roos and Manalo (99) for garden bean and Obendorf and Hobbs (90) for soybean. Sensitivity to oxygen availability changes with stage of germination. Unger and Danielson (125) found that radicle emergence of maize occurred over a wide range of oxygen concentrations.

The effect of adverse soil conditions on the expression of seedling vigor and stand establishment has long been recognized. Subsequent wetting and drying of the surface of certain soils forms crusts which may delay or prevent seedling emergence. Crusting and soil compaction have been shown to be serious retardants to seedling emergence of bean (116).

Reduced seed germination potential resulting from invasion by microorganisms in the field has been observed in pea (47), soybean (75,128,132), and bean (108). The relationship between seed and microflora cannot be considered static. Seeds may lose large amounts of carbohydrates, amino acids and coenzymes to the medium where they germinate. These substrates influence the growth of such organisms as Pythium which cause pre-emergence damping-off of bean (108).

Residual effect of pesticides upon plant growth and development has been extensively documented. For example, applications of Lindane at 40 and 50 ppm were reported to cause significant reductions of bean seed germination (50). Rajanna and de la Cruz (102) pointed out that concentration of higher pesticide residues in soil could be more detrimental to growth of medium or low vigor seeds than on those with high vigor.

Vigor Tests

A laboratory evaluation of seed vigor is needed to assist farmers and seedsmen in identifying high quality seed lots (86). Farmers need such information to make informed decisions about the purchase of seeds, seeding rate and expected uniformity of stand. Seedsmen need such information to aid in monitoring seed quality during harvesting, processing, and storage, and allow them to take preventive or corrective measures by improving production and handling procedures. It also gives them necessary information to help make marketing decision, i.e., which lots to divert from seed channels, which to sell immediately, which lots can be safely stored, and which lots can be labeled and promoted as high vigor seed.

Vigor tests may be direct or indirect. Direct tests are those in which measure some aspect of seed germination or seedling growth under optimum or adverse conditions, e.g., cold test and 3-day germination count. Indirect tests are those which measure other characteristics of the seeds which are correlated with performance under stress conditions, e.g., tetrazolium test, respiration test, and conductivity test.

The physiological quality of seed is commonly evaluated by the standard germination test. Germination percentage, however, is usually not an adequate index of seed vigor because the performance potential of germinable seed varies widely when exposed to varying levels of environmental stress (17,37). Perry (91) stated that the standard germination test may predict field emergence and performance of a seed lot under near optimum field conditions, but additional quality indices (i.e., vigor tests) are needed to supplement the standard germination results to provide growers with a better estimate of how a seed lot may perform under field stress.

Numerous tests have been suggested for measuring vigor including, the cold test, accelerated aging test, and tetrazolium test, which are used extensively for soybean (23,27, 37,41,103,121). Other indices (tests) which have been reported to be promising for soybean are seed size (20, 24,43,48,65,115), speed of germination (23,101), conductivity (4,144), and respiration (3,6,23,127). Several tests which have been reported to measure vigor of bean seed include measurement of seed size (34,104), accelerated aging (105), protein content (104), and conductivity (83). The ISTA Vigor Committee, 1971-1974 (17) reported that the cold test and the conductivity test are able to distinguish between vigor levels of bean (*Phaseolus vulgaris* L.) even though numerical results may not always be comparable from laboratory to laboratory. The AOSA Vigor Subcommittee (13) reported that the major area still requiring study is the standardization of tests between laboratories. However, the cold test for corn, conductivity test of soybean, and cool germination test of corn are considered to be quite reproducible between laboratories.

Cold test. The cold test was originally designed to measure the ability of chemically treated seeds to germinate under adverse cool, moist soil conditions. Today, the cold test used for evaluating vigor for soybean or dry edible bean is usually a modification of the cold test used for corn seed (12,67). Cold test results have been criticized because reproducibility of soil conditions (microorganism content, temperature, moisture, pH, etc.) is difficult to achieve (86). Grabe et al. (53) reported that the cold test was a sensitive index of vigor. Johnson and Wax (71) worked with soybean seed lots differing in quality, and reported that the cold test was consistently highly correlated with field emergence and final stand. On the contrary, Burris and Navratil (26) used various cold test procedures for maize inbred lines and found that the cold test was not a consistently reliable predictor of early emergence. He pointed out that cold test is non-standardizable, as long as soil is a component. He suggested the development of a 'cold test' that incorporates only cold temperature without the added confounding factor of soil. Such a test would be easier to conduct and standardize and would be adaptable for use in seed testing laboratories.

Acelerated aging test. The accelerated aging test was originally developed for predicting the relative storability of seed lots (38), but has also proven useful for evaluating the potential of a seed lot to produce a stand (37). The unimbibed seeds are exposed 24 to 72 hours to adverse conditions of temperature (40-45 C) and relative humidity (99-100%). Then the seeds are removed from the accelerated aging chamber and germinated under optimum conditions. Loss of seed viability and vigor under such conditions have been well documented. Ching (29) classified the effects of aging on seed in six categories: (a) impaired mitochondrial metabolism; (b) damaged cellular membrane; (c) incapacitated anabolism; (d) impaired activity of preexisting enzymes; (e) increased hydrolytic products of biochemicals; and (f) increased chromosomal aberration. Abdul-Baki and Anderson (2) working with barley seeds, found that accelerated aging conditions are not identical to normal aging condition even though the final result, loss of vigor and germination, is the same. Helmer, Delouche, and Lienhard (61) reported that germinative responses of crimson clover seed exposed to several days of stress conditions (35-40 C at 100% R.H.) were closely associated with field emergence. Similar results were reported by Delouche (37) and TeKrony (121) for soybean.

Tetrazolium (TZ) test. The principle of the TZ test is to estimate the viability and germination potential of the seed by determining the presence and location of sound, weak and dead tissue by chemical staining technique. The reduction of the tetrazolium molecules by hydrogen atoms released by dehydrogenase enzymes which are involved in the respiration processes in living tissues, results in the production of formazan, a red dye. Procedures for the use of the TZ test to estimate germination potential under favorable conditions have been developed and published (12,24). The limitations of this test are that it requires special training, is somewhat laborious, and does not reflect effectiveness of fungicide treatment (12). Also, it has been reported that the TZ test is not as reliable as the germination test to estimate viability of such fast growing seeds like lettuce. Many laboratories report that their uncertainty with this vigor test would be alleviated by the availability of detailed photographs for borderline cases (88). Vorst and Mason (126) used the TZ test along with several other tests to estimate field emergence of mechanically damaged soybean seed stored from 1 to 7 months. Although the TZ test overestimated field emergence, as time in storage increased, its prediction accuracy increased. Yacklich and Kulik (145) pointed out that a combination of three variables including the TZ test had a multiple correlation coefficient higher than TZ test alone with field emergence of soybean.

Conductivity test. The conductivity test has been proposed as a vigor test because it measures the loss of vigor in seeds associated with degradation of cell membranes. The leakage and loss of sugars and electrolytes when low vigor seeds are soaked in water, has at least two effects: (a) deterioration of the metabolic and transport efficiency and (b) the encouragement of microorganisms by the leachate exuded (62). In the conductivity test, seeds are steeped in water for a specific period, and then removed. The electrical conductivity of the leachate is measured in micromhos/cm by inserting a cell connected to a conductivity bridge into the solution (12). A more reliable test for predicting field emergence potential has been suggested for pea and French bean, based on the negative correlation between field emergence and exudation of electrolytes into the seed-steep water (82,83,84). However, Halloin (60) showed that the rate of electrolyte loss did not correlate well with cotton seeds which had received accelerated aging treatments. McDonald (86) suggested that seed moisture be standardized prior to conductivity measurement since it has been shown that the amount of leakage from imbibing pea embryos depends upon their initial water content (113). Tao (120) pointed out several factors which might contribute to potential variation in conductivity test results of soybean, including: (a) the ion content in the filter paper, (b) temperature, (c) initial moisture content, and (d) injured seeds. Eliminating the use of filter paper and injured seeds having a moisture content of 13% or higher were suggested.

Respiration. Respiration is a biochemical process that (a) plays a fundamental role in seed germination, (b) coordinates the activity of many enzymes, and (c) is relatively easily measured to permit comparisons between biochemical measurements on the seed and subsequent seedling growth (139). Some workers have shown that respiration expressed either as oxygen uptake or as the respiratory quotient during the first few hours of incubation, is a good index of the seedling growth potential (74,137,141, 142). Measurement of ATP production, which is another parameter of respiration, has been proposed as a good vigor index by Ching (31), and Ching and Danielson (32). Glucose utilization into metabolic intermediates from deteriorating barley and wheat seeds is also related to respiration and has been suggested as an index of vigor (10).

The activity of several enzymes, including glutamic acid decarboxylase (51), peroxidase, catalase, amylase, phenolase (139), protease, isocitritase, and hydrolase (86) has been shown to correlate well with seed vigor.

Glutamic Acid Decarboxylase Activity (GADA). High positive correlation between glutamic acid decarboxylase activity and seedling vigor was reported by Grabe (51) and Woodstock and Grabe (142) for corn. However, James (70) found inconsistencies in correlation coefficients among varieties which limits the use of GADA in estimating the viability of bean seeds. Abdul-Baki and Anderson (3) working with soybean seed, suggested that a search for biochemical indices to measure seed vigor should be focused on embryonic axes rather than on whole seed.

Polyethyleneglycol (PEG) test. A more recent approach to measuring seed vigor is the use of the PEG (Polyethyleneglycol) test (57,58). The basic idea is that the soil water potential greatly affects seed water uptake rates, germination rates, and total germination (35,36,55,56,59). Seeds were germinated in aerated solutions of different PEG concentrations to obtain different osmotic potential. The molecular weights of PEG used were 6,000 and 20,000. The concentration of the solutions changed as the seeds imbibed water, thus causing a change in water potentials. The change in osmotic potential during the seed's water uptake was determined by calculating the changing PEG concentrations and reading off the values in reverse sequences, from PEG - concentration - osmotic potential calibration curve.

Multiple indices of seed vigor. It is still in question, whether one (individual) test is sufficient or if a combination of tests might provide a more meaningful vigor rating (86). There are indications that a combination of two or more tests may be more reliable than one test alone: for example, the combination of standard germination and hot flood tests in Reed canarygrass (80), standard germination and seedling growth in peanut (33), seedling length, artificial aging and standard germination in soybean (44) and standard germination, 4-day warm germination and accelerated aging test in soybean (123).

Relation of Vigor to Yield Potential

Recently, there has been much controversy over the relationship between vigor and yield potential. Thus far, this relationship has not been clearly determined (45) and results available are inconsistent.

There have been reports of positive associations between size, seedling vigor, and yield for bean (9,34, 131), soybean (25,46), barley (73,135), peas and sugar beet (135). Other vigor criteria such as protein content (79, 104), speed of germination (28,95), time of emergence (129), and cold test (71), have also been reported to correlate well with yield.

On the contrary, Abdalla and Robert (1) showed no relationship between seed quality and yield for barley, broad bean, and pea, until the quality reached commercially unacceptable levels (below about 50%). Edje and Burris (42) reported for soybean, that once sufficient stand was established, there were no significant differences in yield between high, medium, and low vigor seed. Egli and TeKrony (45) working with soybean, found that seed vigor had no effect on yield regardless of cultivar or planting rate.

The temptation to expect a positive relationship between seed vigor and crop yield has led many people to do so. Delouche (37) stated that vigor of seed can and does influence the growth, development, and productivity of crops such as corn, sorghum, cotton, rice, some vegetables, and probably soybean as well. Grabe (52) also pointed out that seed vigor may show its effects in speed of stand establishment, density of stand, rate of seedling and plant growth, time and uniformity of flowering and maturity, yield, and storability.

In navy bean (<u>Phaseolus</u> <u>vulgaris</u> L.) as well as many other crops, it hasn't been here-to-fore established whether a correlation does exist between seed vigor, field emergence and yield.

As indicated above, many tests are available that could be used for assessing vigor of navy bean seed. However, more information is needed on the relationships between results of such tests and seed/seedling vigor and how vigor influences field performance. One objective of these studies was to determine the relationship of various vigor tests, in addition to the standard germination test, to field emergence and stand establishment under favorable and adverse field conditions. A well defined relationship of this type could serve as an aid to growers for determining expected stand. This should be helpful in making early decisions about planting when soil environment is not favorable for seedling emergence. A secondary objective was to determine the effect of seed vigor on yield, and if such association exists, to evaluate the vigor level required for maximum yield.

MATERIALS AND METHODS

1977 Studies

Seed Material

Forty one seed lots of navy bean (*Phaseolus vulgaris* L.) representing different levels of vigor were selected from the files of the Michigan Crop Improvement Association (MCIA). All seed lots had been produced in 1976 and represented commercial certified seed. The seed material was stored in plastic containers under conditions of 20 C temperature and 55% relative humidity.

Laboratory Tests

Each seed lot was laboratory tested by the following tests for germination and seedling vigor:

Warm Germination Test-4 and 7 Days

This test was conducted at the Michigan Department of Agriculture Laboratory using standard procedures as described in the 'Rules For Testing Seeds' (11) of the Association of Official Seed Analysts. Two replications of one hundred seeds each were germinated on moist Kimpac media at a temperature of 25 C. First and final counts were made four and seven days after planting respectively. The seedlings were classified into normal seedlings, abnormal seedlings, and dead seeds. Only the percent normal seedlings were recorded for this study.

Classification of normal seedlings was based on the following criteria: (a) strong primary root sufficient to anchor seedling grown in the media; (b) sturdy hypocotyl with no open breaks or lesions extending into the central conducting tissue; (c) having the equivalent of at least one cotyledon attached; (d) the epicotyl having at least one primary leaf and an intact terminal bud. Abnormal seedlings were those with the following criteria: (a) no primary root or no well developed secondary roots; (b) hypocotyls with open cracks extending into the central conducting tissue or exhibiting structural malformations such as markedly shortened, curled or thickened growth; (c) both cotyledons missing; and (d) damaged or missing plumule (baldhead).

Cold Test

A modified standard cold test procedure (12) was conducted at MCIA laboratory by pre-exposing the seeds to 4 C for three and five days, and then germinating for seven days under standard warm germination conditions. The cold test was performed by planting 200 seeds (four 50-seed replications) in a soil medium composed of equal parts of peat and sand. A 2 cm thick layer of soil was placed on the bottom of the plastic box (29.5 cm x 16.0 cm x 8.5 cm) on which 50 seeds were placed. Approximately the same amount of soil was then placed over the seeds after which the soil was leveled. Enough water (238.5 ml) was added to bring the medium to 70% of its water holding capacity. After placing the covers on the plastic boxes, they were stored for three and five days at 4 C, and then transferred to a germinator at 25 C. After the seedlings emerged, the covers were removed. Normal seedlings were evaluated after seven days and separated into vigor categories based on length of hypocotyl. The lengths of hypocotyls were separated into <5 cm, 5-13 cm, and >13 cm, then multiplied by index number 1, 2, and 3 respectively ((<5 cm)x1; (5-13 cm)x2; (>13 cm)x3). The total combined index of four boxes (four replicates) was categorized into high, medium, or low vigor on the basis of the following: <200, low; 200-399, medium; 400-600, high.

Tetrazolium Test

The test was conducted in the MCIA laboratory based on the standard procedures as described in AOSA 'Tetrazolium Testing Handbook for Agricultural Seeds' (124). The TZ test was performed by allowing the seeds (110 seeds) to imbibe water from moderately moist corn paper at 35 C overnight and then placing the fully imbibed seeds in a 0.5% TZ solution to stain in darkness at 35 C for 3-4 hours.

By using a sliding motion of a sharp razor blade each seed was cut longitudinally through the mid-section of the radicle to expose the stele. The surfaces of each embryo structure (radicle, epicotyl, plumules, cotyledons) were observed for presence and location of sound, weak, dead, and fractured tissue as indicated by pattern and intensity of staining. Each viable seed was individually classified as high, medium, low or dead and multiplied by factors 6, 4, 2 and 0 respectively, and added to obtain a cumulative index of vigor. Vigor classifications were assigned by the following classes: <200, low; 200-399, medium, 400-600, high. Two 100-seed replicates for each lot were used for this test. The extra seeds were reserved in case of seed loss or uncertainty due to artifacts of the slicing process.

<u>Accelerated Aging Test</u>

The accelerated aging test was conducted by placing approximately 250 seeds in a 250 ml plastic cup without tops with twenty five 4 mm diameter holes in the bottom to facilitate the free flow of air and moisture. The cup was placed in a 2000 ml jar consisting of a 3-legged wire mesh basket and 350 ml of water. The jar was tightly closed to help maintain near 100% relative humidity and then placed in an incubator maintained at 42 ± 1 C. After 72 hours in the incubator, seeds were removed and permitted to dry at room temperature. The aged seed was then germinated in two

100-seed replicates by standard methods as described in the AOSA "Rules For Testing Seeds" (11).

Hundred Seed Weight

Four 100-seed replicates at about 18% moisture content were weighed for each lot.

All laboratory tests were arranged as independent variables:

X_1: Warm Germination Test - 4 days (WG-4), untreated.

X_2: Warm Germination Test - 7 days (WG-7), untreated.

X_3: Cold Test 4 C - 3 days (CT-3), untreated.

X_4: Cold Test 4 C - 5 days (CT-5), untreated.

X_5: TZ Viability Test (TZ), untreated.

X_6: Accelerated Aging Test (AA), untreated.

X_7: Cold Vigor Test - 3 days (CV-3), untreated.

X_8: TZ Vigor Test (TZV), untreated.

X_9: Hundred Seed Weight (SW), untreated.

Field Studies

Each of forty one seed lots was tested in the field for emergence, length of hypocotyl, length of hypocotyl plus epicotyl, and yield. Tests were conducted at Reese, Michigan in clay loam soil, using untreated seeds of each lot. All lots were planted on June 10, 1977 in 3 rows 6.1 m long at a planting depth of 3.8 cm in three completely randomized 100-seed replications. Plants that emerged in the center row were counted as soon as seedlings began to appear (7 days after planting). The final count was made when the first trifoliolate leaves were extended (14 days after planting), at which time the percent normal and abnormal seedlings was recorded. The length of hypocotyl was measured from the radicle-hypocotyl junction to the cotyledon-hypocotyl junction, and the epicotyl was measured from the cotyledon-hypocotyl junction to the bud. Measurements were made 16 days after planting. The purpose of hypocotyl measurement was to determine the uniformity of stand. The seedlings were sampled from every third row.

Plants were harvested following seed maturity with a stationary plot thresher after the plants were pulled by hand and piled at the end of each row. After short-term storage in paper bags, the seed was hand cleaned to remove dirt, leaves, and stems. After air drying to a uniform moisture level, the seeds were weighed. Yield was expressed in grams per plot.

1978 Studies

Seed Material

Twenty four seed lots of navy bean (*Phaseolus vulgaris* L.) representing different levels of vigor were obtained from the MCIA files. The seed was stored at temperature of 4 C to preserve the quality and tested by a battery of vigor tests in addition to standard germination.

Laboratory Tests

Cold Test

Due to excessively low cold test results (average 24.3%) in 1977, the cold temperature was increased to 10 C to provide less stress on germinating seeds. Otherwise the procedure was the same as in 1977, except that the test was exposed for 3 and 5 days to cold temperatures of 10 C and 7 days in warm temperatures of 25 C.

Conductivity Test

This test was originally developed to aid in evaluating wrinkled pea seed in which lots with high laboratory germination were subject to preemergence failure in the field. In these studies, a modification of the classic test (12) by Agro Sciences, Inc., Ann Arbor, Michigan, called the Seed Analyzer model MS-110 was used. Unlike the classic method, the MS-110 measures the conductivity across fully imbibed seeds by means of sensing electrodes (8).

Samples of the 24 bean seed lots were evaluated by the MS-110 Seed Analyzer. The measurement was taken across the seed tissue after soaking for 15 minutes at temperature 23-26 C. The results were calibrated to vigor (7) at partition values of 110 microamps. The other laboratory tests were performed the same as in 1977.

All laboratory tests were arranged as independent variables:

X_1: Warm Germination Test - 7 days (WG-7), untreated.

X_2: Warm Germination Test - 4 days (WG-4), untreated.

X_3 Cold Test (10 C) - 3 days (CT-3), untreated.

X_4: Cold Test (10 C) - 5 days (CT-5), untreated.

X_5: TZ Viability Test (TZ), untreated.

X_6: Accelerated Aging Test (AA), untreated.

X_7: Conductivity Test (CD), untreated.

X_8: Cold Vigor Test (10 C) - 3 days (CV-3), untreated.

X_9: Cold Vigor Test (10 C) - 5 days (CV-5), untreated.

X_{10}: TZ Vigor Test (TZV), untreated.

X_{11}: Hundred Seed Weight (SW), untreated.

Field Studies

Each of the twenty four seed lots was field tested for emergence and yield at two different locations. One was located at Reese on clay loam soil, and the other was at Mason with loamy soil, however the entire location was compacted using a 300-pound self-propelled turf compressor. Treated (Captan-slurry, 1.04 grams per 1.00 kilogram seeds) and untreated seed of all lots were planted in two rows 6.1 m long at 3.8 cm planting depth in 4 completely randomized 100-seed replications. The plots were planted at Reese on June 6, and at Mason on May 23.

The first emergence count was made 7 days after planting, as soon as seedlings began to appear and 14 days for the final count, when the first trifoliolates leaves were extended. No hypocotyl or hypocotyl plus epicotyl measurements were made. Otherwise, the procedure of reading field emergence, harvesting, and cleaning were the same as in 1977.

Field performances as dependent variables are:

Y_1: Seedling emergence, Reese - First count, untreated.
Y_2: " " , " - Final count, untreated.
Y_3: " " , " - First count, treated.
Y_4: " " , " - Final count, treated.
Y_5: " " , Mason - First count, untreated.
Y_6: " " , " - Final count, untreated.
Y_7: " " , " - First count, treated.
Y_8: " " , " - Final count, treated.
Y_9: Yield, Reese, untreated.
Y_{10}: Yield, Reese, treated.
Y_{11}: Yield, Mason, untreated.
Y_{12}: Yield, Mason, treated.

1979 Studies

Seed Material

Two different seed lots produced in Michigan and two lots produced in Idaho (western-grown) of three different navy bean cultivars (Tuscola, Sanilac and Seafarer - 12 lots total) were used for the 1979 studies. All lots represented commercial certified seed with different levels of vigor. To maintain initial quality, the seed was stored in plastic bags at a temperature of 4 C. Treated (Hopkins bean seed protectant-slurry; 0.35 gram per 1.00 kilogram seeds) and untreated seeds were evaluated by laboratory tests as independent variables. The active ingredients of Hopkins bean seed protectant are: 25.00% Diazinon, 25.00% Captan and 6.26% Strptomycin Sulfate.

Laboratory Tests

Seven-day Warm Germination (WG-7), Cold (CT-3 and 5), TZ, and Accelerated Aging (AA) tests were conducted the same as in 1978 tests. Other tests were modified as discussed below.

Three-day Warm Germination

Since the results of 1977 and 1978 showed that the 4-day warm germination result was almost the same as that after 7 days and thus didn't show adequate sensitivity as a vigor test (88), only hypocotyl lengths longer than 1.0 cm were counted three days after planting. Otherwise, the normal seedlings were evaluated by criteria specified in the AOSA 'Rules For Testing Seeds' (11).

Accelerated Aging Test

Accelerated aging test used in 1979 were made following procedures developed by McDonald and Praneendranath

(87) called the 'Wire-mesh Tray' system. This new method is inexpensive, subjects all seed to uniform aging conditions, and is more rapid than previously recommended processes. It consists of a 11.0 cm x 11.0 cm x 3.5 cm inverted plastic sandwich box containing a 10.0 cm x 10.0 cm x 3.0 cm copper wire mesh tray. The wire-mesh tray was 2.0 cm from the bottom of the plastic box which contained 80 ml of water. About 250 seeds were placed on the wire-mesh tray, then placed in the 'Precision dual program illuminated incubator' maintained at 41.0 ± 2.3 C for 72 hours, then transfered to optimum germination conditions described in previous years' tests.

Conductivity Test

In the 1979 studies, a further modification of the electrical conductivity test was conducted using the ASA-610 conductivity machine developed by Agro Sciences Inc., Ann Arbor, Michigan. This machine provides simultaneous conductivity measurements from 100 individual cells containing one seed each and gives an electronic readout of the percent of the cells with conductivity less than the preselected criterion. The procedure for this test is described in the instruction manual (7).

Based on the preliminary studies, 18 hours soaking time was used in these studies at temperature 23-26 C. Vigor calibrations were made by selecting the optimum select partition. This was accomplished by circling the range of predicted value (±10) of germination percentage points from the best prediction. The vertical column of predictions at a given microamp partition value which intersects the greatest number of these plus and minus ten range circles was chosen as the optimum partition value. We found the 115 microamp partition gave the optimum value of vigor.

All laboratory tests were arranged as independent variables:

1. Warm Germination Test - 7 days (WG-7), untreated and treated.
2. Warm Germination Test - 3 days (WG-3), untreated and treated.
3. Cold Test (10 C) - 3 days (CT-3), untreated and treated.
4. Cold Test (10 C) - 5 days (CT-5), untreated and treated.
5. Cold Vigor Test (10 C) - 3 days (CV-3), untreated and treated.
6. Cold Vigor Test (10 C) - 5 days (CV-5), untreated and treated.
7. TZ Viability Test (TZ), untreated.
8. TZ Vigor Test (TZV), untreated.
9. Accelerated Aging Test (AA), untreated.
10. Conductivity Test (CD), untreated

Field Studies

Each of the twelve seed lots was field tested for emergence and yield at three planting dates, located at

MSU Soils Farm, E. Lansing, MI. Treated (Hopkins bean seed protectant-slurry; 3 oz. per bushel) and untreated seed of all lots were planted in one row 6.1 m long at a depth of 3.8 cm in three completely randomized 100-seed replications. The seeds were planted on May 21, May 31, and June 22, representing early, near optimum and optimum planting dates respectively.

The first emergence count was made when seedlings had one to two unrolled trifoliolate leaves (7 days) and the final count was made when the trifoliolate begin to expand (14 days). Because of low soil temperature (Table 1) and soil crusting, the first count needed 15 days emergence for the first planting date, and 7 days for second and third planting date.

At the second planting date, an extra completely randomized plot was planted to help further clarify the association between vigor and yield. Twenty three days after planting the plots were thinned to equalize the population of plots planted from all seed lots, and thus eliminate plant population as a factor in yield.

Harvesting, threshing and cleaning were performed as in previous studies.

All field tests were arranged as dependent variables:

1. Seedling emergence, 21 May - First count, treated and untreated.
2. Seedling emergence, 21 May - Final count, treated and

Table 1. Means for soil and air temperature during emergence at three planting dates.

	Emergence	*Soil temp.		*Air temp.	
		Min.	Max.	Min.	Max.
21 May	15 days	9.5	17.9	6.7	22.4
	22 days	11.7	20.3	22.6	36.2
31 May	7 days	13.1	23.3	11.4	30.8
	14 days	14.0	24.9	12.3	31.4
22 June	7 days	14.3	27.1	9.4	30.0
	14 days	14.0	24.1	9.8	28.8

*Soil (3.8 cm depth) and air temperature in C.

untreated.

3. Seedling emergence, 31 May - First count, treated and untreated.
4. Seedling emergence, 31 May - Final count, treated and untreated.
5. Seedling emergence, 22 June - First count, treated and untreated.
6. Seedling emergence, 22 June - Final count, treated and untreated.
7. Yield, 21 May, untreated and treated.
8. Yield, 31 May, untreated and treated.
9. Yield, 22 June, untreated and treated.

Simple and multiple correlations were calculated by regression analysis using all laboratory tests and dependent variables. The effects of planting date, cultivar and counting date upon field emergence and yield were determined by analysis of variance and Duncan's new multiple-range test.

RESULTS AND DISCUSSION

Laboratory Tests

The mean standard germination (WG-7) of all seed lots in 1977 was 90.5% (Table 2). Of 41 seed lots, 67.5% had standard germination of 90.0% or above; 20.0% had standard germination of 90.0% or above; 20.0% had standard germination of 80.0-90.0%; and 12.5% had germination of below 80.0%, indicating that seeds used for these studies were of commercially acceptable seed quality. The 4-day warm germination test (WG-4) gave percentages averaging 3.5 point higher than standard 7-day germination test and ranged between 71.0 and 100.0%. Cold test results at 4 C for both 3 and 5 days (CT-3 and CT-5) averaged about 66.0 and 80.0% below standard germination and ranging between 0.5-59.0% and 0.0-56.0% respectively. This indicated that the temperature stress was too severe. TZ test results averaged about 0.3% below standard germination and ranged between 75.0 and 97.5%, indicating its suitability as a seed viability test. Accelerated aging test (AA) results averaged 34.0% below that for standard germination and ranged between 14.5 and 91.5%. Variability of accelerated aging test results was high, with a standard deviation of 20.3.

Table 2. Mean and standard deviation of seed vigor tests (untreated) of all seed lots.* Navy bean, 1977 and 1978.

	1977 (41 seed lots)			1978 (24 seed lots)		
	Mean	Range	Sd	Mean	Range	Sd
WG-7	90.5	67.0-99.5	8.4	83.1	62.7-97.3	10.4
WG-4	94.0	71.0-100.0	8.1	80.6	61.0-93.7	8.9
CT-3**	24.3	0.5-59.0	14.7	32.7	4.5-75.0	20.8
CT-5	11.0	0.0-56.0	10.1	27.2	1.0-85.0	24.0
CV-3	105.7	1.0-274.0	68.2	127.6	20.0-312.0	86.7
CV-5	--	--	--	101.1	4.0-312.0	87.4
TZ	90.2	75.0-97.5	5.1	83.2	58.5-98.0	12.0
TZV	323.4	221.0-408.0	35.9	225.0	152.0-362.0	59.7
AA	56.5	14.5-91.5	20.3	67.9	2.0-99.0	31.4
CD	--	--	--	76.8	26.0-100.0	24.4
SW	19.4	13.5-28.8	2.2	22.2	19.2-27.6	2.1

*Values shown are expressed as percentage of hundred, except for SW, CV and TZV. SW - gram; CV and TZV - total frequencies of vigor classes.

**CT at 4 C for 1977 and 10 C for 1978.

The mean standard germination (WG-7) was 83.1% in the 1978 studies (Table 2). From 24 seed lots, 29.2% had standard germination of 90.0% or above; 41.7% had standard germinations of 80.0-90.0%; and 29.1% had germinations below 80.5%, indicating that 1978 seed quality was also commercially acceptable. The 4-day warm germination test (WG-4) gave a mean germination 2.5% below the 7-day warm germination and ranged between 61.0 and 93.5%. Results of the cold test at 10 C for both 3 and 5 days (CT-3 and CT-5) averaged 50.4 and 55.9 points below that for standard germination and ranged 4.5-75.0 and 1.0-85.0% respectively. The TZ test averaged 0.1% above standard germination and ranged between 58.5 and 98.0%. Accelerated aging test (AA) averaged 15.2% below standard germination and ranged between 2.0 and 99.0%. It also showed high variation, with a standard deviation of 31.4. The conductivity test (CD) averaged 6.3% below standard germination and ranged between 26.0 and 100.0%. The variation in conductivity test results was high, indicated by a standard deviation of 24.4.

In 1979 studies, both treated and untreated seeds were used for all laboratory tests except for the TZ and conductivity tests (CD) for which no treated seeds were used. Table 3 shows the results of laboratory tests for treated and untreated seeds. No significant differences occur between treated and untreated seeds. Table 4 shows

Table 3. Results of laboratory tests of treated and untreated seeds (12 lots)*. Navy bean, 1979.

	WG-3	WG-7	CT-3	CT-5	AA	CV-3	CV-5
Untr.**	60.4a	95.1b	68.5c	60.4d	37.1e	429.5f	280.8g
Tr.	57.2a	91.5b	74.4c	66.2d	46.1e	445.2f	332.0g

Means in columns followed by the same letters are not significantly different at the 0.05 level of probability.

* Values shown are expressed as percentage of hundred.

**Untr. = Untreated seeds; Tr. = Treated seeds.

Table 4. Mean and standard deviation of seed vigor tests (12 seed lots).* Navy bean, 1979.

	Mean	Range	Sd
WG-7	93.3	79.8-97.3	4.9
WG-3	58.8	27.5-75.3	12.5
CT-3	71.5	38.0-94.0	14.2
CT-5	53.3	41.5-85.0	13.7
CV-3**	437.3	251.0-556.0	78.4
CV-5	301.4	170.0-524.0	103.5
TZ	92.3	85.5-98.0	3.7
TZV**	392.3	337.0-449.0	28.5
AA	41.6	18.3-67.8	15.9
CD	93.6	86.5-99.5	4.9

* Values shown are expressed as percentage of hundred.

**CV and TZV - total frequencies of vigor classes.

results of 1979 laboratory germination and vigor tests reflecting the use of both treated and untreated seed as described earlier. The mean of standard germination (WG-7) was 93.3% and ranged between 79.8 and 97.3%. From 12 seed lots, 83.3% had germinations of 90.0% or above and 16.7% between 80.0 and 90.0%, indicating that quality of seed used in these studies was commercially acceptable. The 3-day warm germination (WG-3) resulted in percentages averaging 34.5 point below that for the 7-day standard warm germination test and ranged between 27.5 and 75.3%. Cold test (CT) results for 3 and 5 days were higher than those in 1977 and 1978. The cold germination percentage averaged 21.8, 30.0 points below those for standard germination and ranged from 38.0-94.0% and 41.5-85.0% respectively. The difference in results of the cold test between 1978 and 1979 may be due to difference in composition of microorganisms, temperature, pH, etc. the affect of which has been reported previously (26,86). TZ tests averaged 1.0% below that for standard germination and ranged between 85.5 and 98.0%. Accelerated aging test (AA) results averaged 51.7 point below that for standard germination and ranged between 18.3 and 67.8%. The conductivity test results were similar to those obtained by the 7-day warm germination test, averaging only 0.3% higher and ranging between 86.5 and 99.5%. The variation in results was relatively small, indicated by a standard deviation of 4.0.

Correlation between Laboratory Tests Results

In the 1977 studies, high correlations were obtained between results of the 4-day warm germination and those of the 7-day warm germination (Table 5).

In the 1978 studies significant correlations occurred between WG-4 and WG-7 results (Table 6). TZ and conductivity test results also correlated very well with standard germination.

1979 studies gave poor correlation between conductivity test and standard germination (Table 7). This was expected since seed quality for 1978 was more variable than in 1979.

Field Performance

In 1977 only untreated seed was planted in the field plots. Seedbed conditions were ideal and seedlings began to emerge 7 days after planting. Adequate moisture, warm soil temperature and lack of crusting resulted in no unusual stress to field emergence. Table 8 shows that total field emergence averaged 77.8% (about 12% below standard germination) and ranged between 40.7 and 94.7%. The length of hypocotyl averaged 6.5 cm and ranged between 6.0 and 7.3 cm; length of hypocotyl plus epicotyl averaged 10.4 cm and ranged between 9.1 and 11.4 cm. Variation among the measurements was small, as shown by standard deviations between 0.3 and 0.5, indicating good stand uniformity.

Table 5. Simple correlation coefficients of 9 variables, 41 lots. Navy beans, 1977.

	1	2	3	4	5	6	7	8	9
1. WG-7									
2. WG-4	.949**								
3. CT-3	.503**	.557**							
4. CT-5	.225	.223	.618**						
5. TZ	.526**	.557**	.435**	.206					
6. CV-3	.497**	.536**	.965**	.591**	.493**				
7. TZV	.256	.331*	.289	.101	.791**	.317*			
8. AA	.055	.100	.288	.334*	.222	-.146	.147		
9. SW	.150	.163	-.141	-.100	-.179	-.147	-.111	-.127	

*,**Significance at the 0.05, 0.01 level of probability.

Table 6. Simple correlation coefficients of 11 variables, 24 lots. Navy beans, 1978.

	1	2	3	4	5	6	7	8	9	10	11
1. WG-7											
2. WG-4	.847**										
3. CT-3	.368	.272									
4. CT-5	.350	.214	.859**								
5. TZ	.900**	.837**	.306	.335							
6. CV-3	.309	.209	.979**	.829**	.253						
7. CV-5	.362	.204	.868**	.993**	.349	.843**					
8. TZV	.530**	.602**	-.030	-.036	.686**	-.068	-.021				
9. AA	.500*	.547**	.609**	.504*	.524**	.556**	.512*	.381			
10. CD	.813**	.704**	.386	.447*	.844**	.364	.451*	.592**	.462*		
11. SW	.198	.276	-.158	-.124	-.340	-.176	-.132	.581**	.247	.303	

*,**Significance at the 0.05, 0.01 level of probability.

Table 7. Simple correlation coefficients of 10 variables, 12 lots. Navy bean, 1979.

	1	2	3	4	5	6	7	8	9	10
1. WG-7										
2. WG-3	.883**									
3. CT-3	.817**	.752**								
4. CT-5	-.318	-.289	-.291							
5. TZ	.768**	.714**	.763**	-.337						
6. CV-3	.821**	.838**	.841**	.027	.688*					
7. CV-5	-.386	-.278	-.397	.955**	-.423	-.015				
8. TZV	.762**	.718**	.722**	-.467	.912**	.607*	-.531			
9. AA	.372	.429	.494	.096	.702*	.603*	.062	.604*		
10. CD	.339	.205	.634*	-.193	.656*	.337	-.379	.523	.562	

*,**Significance at the 0.05, 0.01 level of probability.

Table 8. Mean and standard deviation of field emergence and length of hypocotyl, 41 seed lots.* Navy bean, 1977.

	Mean	Range	Sd
First count	47.9	11.0-83.0	15.7
Final count	77.8	40.7-94.7	12.4
Hypo. (cm)*	6.5	6.0-7.3	0.3
Hypo. + Epi. (cm)	10.4	9.1-11.4	0.5

* Values shown are expressed as percentage of hundred.

** First count - 7 days after planting; Final count - 14 days after planting.

***Hypo. = hypocotyl in cm; Epi. = Epicotyl in cm.

In 1978, both treated and untreated seed lots were planted in the field. Temperature and soil moisture conditions were favorable, however, the entire plot had been artificially compacted. Table 9 shows no significance difference between field emergence of treated and untreated seed for either the first or final count at Mason as well as at Reese. Total emergence at Reese averaged 60.8 and 70.3% for untreated and treated seeds and ranged 23.0-82.0% and 22.5-95.5% respectively. At Mason total emergence averaged 58.3 and 61.5% for untreated and treated seeds and ranged 32.8-87.0% and 21.3-86.5% respectively. No significant difference occurred in total emergence between Reese and Mason.

In 1979 both treated and untreated seeds were used for all lots at three planting dates. Table 10 shows that no significant difference in field emergence occurred between treated and untreated seeds for the second and third planting dates. The untreated seeds from Idaho were received after the first planting date. This lack of significance might be due to the high quality of seed used (standard germination of 93.3%); TeKrony et al. (122) have previously shown that fungicide treatment significantly increased field emergence in soybean seed of marginal quality (less than 85% germination). For further comparisons, a combination of field emergence results from treated and untreated seeds is shown in Table 11.

Table 9. Mean and standard deviation of field emergence, 24 lots.* Navy bean, 1978.

	First count			Final count		
Location	Mean	Range	Sd	Mean	Range	Sd
Reese, Untr.**	59.8a	12.5-90.3	17.8	60.8cd	23.0-82.0	17.1
Reese, Tr.	67.1a	16.5-91.0	19.8	70.3d	22.5-95.5	10.3
Mason, Untr.	29.7b	7.8-64.7	17.5	58.3c	32.8-87.0	15.8
Mason, Tr.	31.6b	5.0-65.0	14.9	61.5cd	21.3-86.5	15.8

Means in columns followed by the same letter are not significantly different at 0.05 level using Duncan's new multiple range test.

* Values shown are expressed as percentage of hundred.

**Untr. = Untreated; Tr. = Treated.

Table 10. Field emergence of treated and untreated seeds, 12 lots.* Navy bean, 1979.

	21 May		31 May		22 June	
	1-ct	2-ct**	1-ct	2-ct	1-ct	2-ct
Untr.†	--	--***	61.9a	80.0b	66.4c	72.4d
Tr.	24.1	70.8	65.9a	84.1b	66.3c	70.6d

Means in columns followed by the same letter are not significantly different at the 0.05 level of probability.

*Values shown are expressed as percentage of hundred.

**1-ct = first count - 7 days after planting, except for 21 May (15 days).

2-ct = final count - 14 days after planting, except for 21 May (22 days).

***The untreated seeds from Idaho were received after the first planting date.

†Untr. = Untreated; Tr. = Treated.

Table 11. Mean and standard deviation of field emergence, 12 lots.* Navy bean, 1979.

	First count**			Final count		
Plt. date	Mean	Range	Sd	Mean	Range	Sd
21 May	24.1a	5.0-53.5	13.1	70.8c	51.0-88.6	11.3
31 May	64.0b	54.6-74.9	6.8	82.3d	73.3-88.9	5.2
22 June	66.4b	48.8-78.4	8.3	71.6c	50.6-83.1	9.8

Means in columns followed by the same letter are not significantly different at 0.05 level using Duncan's multiple range test.

*Values shown are expressed as percentage of hundred.

**First count - 7 days after planting, except 21 May (15 days).

Final count - 14 days after planting, except 21 May (22 days).

Because of low temperature and crusted soil, the first field emergence count for the first planting date was low, averaging 24.1% (69.2% below standard germination) and ranging between 5.0 and 53.5%. Total emergence averaged 70.8, 82.3 and 71.6% and ranged from 51.0-88.6, 73.3-88.9 and 50.6-83.1% for first, second and third planting dates respectively.

Analyses of variance were performed on field emergence to determine the planting date x day emergence and planting date x cultivar interactions. These interactions were highly significant, indicating that seedlings at various planting dates performed differently depending on date of abservation and cultivar. But no interaction occurred between cultivar and day of observation, indicating that cultivars performed the same regardless of the observation date.

Table 12 shows the field emergence of various cultivars and seed sources across three planting dates. Michigan grown seed showed relatively higher emergence than Western seed indicating that Michigan-produced seed of all cultivars was of higher quality than that of Western grown seed.

Interrelationship of Field and Laboratory Tests

In the 1977 studies, nearly all independent variables correlated well with total emergence (Table 13), including standard germination (WG-7) and 4-day warm germination

Table 12. Field emergence of cultivars within three planting dates.* Navy bean, 1979.

	21 May		31 May		22 June	
Variety-Seed source	early emg.**	total emg.	early emg.	total emg.	early emg.	total emg.
Seafarer-Michigan	25.5a	78.3a	58.6a	83.9ac	63.9a	69.7a
Sanilac-Michigan	42.3b	77.3a	66.7bc	83.1ac	74.0b	78.9b
Tuscola-Michigan	17.0a	72.3a	71.6cd	88.7ab	72.5bc	82.3b
Seafarer-West	21.8a	57.8bc	60.0ac	77.2c	56.0d	59.7d
Sanilac-West	21.5a	69.3ac	61.1ac	80.2c	64.6a	68.6a
Tuscola-West	16.5a	69.8ac	65.8acd	80.7c	67.4ac	70.1a

Means in columns within each planting date followed by the same letters are not significantly different ($p=0.05$) using Duncan's new multiple range test.

*Values shown are expressed as percentage of hundred.

**Early emergence - 7 days after planting, except 21 May (15 days).

Total emergence - 14 days after planting, except 21 May (22 days).

Table 13. Simple correlation coefficient between various seed vigor tests and field performance. Navybean, 1977.

Field performance	WG-4	WG-7	CT-3	CT-5	CV-3	TZ	TZV	AA	SW
1st Count †	.821**	.844**	.390*	.145	.376*	.540**	.386*	.155	.019
2nd Count	.811**	.812**	.394*	.146	.345*	.382*	.190	-.013	.123
Yield	.235	.195	-.190	-.025	-.185	.231	.372*	.122	.053

*,**Significance at the 0.05, 0.01 level of probability.

† 1st Count - 7 days after planting; 2nd Count - 14 days after planting.

(WG-4). Significant correlations also occurred for the 3-day cold test (CT-3), cold vigor test (CV-3), and tetrazolium (TZ) test. Conversely, accelerated aging test results (AA), and 100 seed weight (SW) correlated poorly with total emergence.

Results of stepwise multiple regression analyses are presented in Table 14. This procedure selects the best test results for use in an equation to predict field performance under the prevailing experimental conditions. Regression equation:

$$Y = -30.373 + 1.196\ X \qquad ; R^2 = .660$$

Y = Total emergence

X = Standard germination

R^2 = Coefficient of determination

R^2 = .660 means that 66% of the variation in total emergence was attributable to linear regression on the standard germination. The high prediction accuracy of the standard warm germination test under favorable field emergence conditions agrees with reports by TeKrony (121, 122), Egli, TeKrony and Hatfield (44), Wolf (134), Vorst and Mason (126), Sullivan (118), and Burris (22).

In 1978, the highest simple correlations (Table 15) with total field emergence (both treated and untreated) were given by WG-7, WG-4, TZ, AA, and CD. Significant correlations were obtained for CT-3, CT-5, and CV-5 for Reese and TZV for Mason. No significant correlation

Table 14. Result of stepwise multiple regression analysis for selecting best regression equation for predicting Field Performance. Navy bean, 1977.

Field performance	Constant	WG-7	WG-4	CV-3	TZV	R^2
Emergence, 1st Count*	-112.158	+1.458			+.079	.744
Emergence, 2nd Count	- 30.373	+1.196				.660
Yield	+332.832		+4.008	-.655	+.990	.388

*1st Count - 7 days after planting; 2nd Count - 14 days after planting.

Table 15. Simple correlation coefficient between various seed vigor tests and field emergence. Navybean, 1978.

Field emergence	WG-7	WG-4	CT-3	CT-5	TZ	CV-3	CV-5	TZV	AA	CD	SW
REESE											
1st Count, Untr.†	.563**	.499*	.414*	.458*	.466*	.417*	.439*	.193	.629**	.451*	-.013
2nd Count, Untr.	.703**	.576**	.502**	.499*	.627**	.452*	.493*	.371	.657**	.596**	.191
1st Count, Tr.	.674**	.528**	.323	.350	.500*	.284	.340	.181	.527**	.632**	.068
2nd Count, Tr.	.820**	.650**	.429*	.447*	.676**	.378	.443*	.310	.593**	.749**	.197
MASON											
1st Count, Untr.	.569**	.516**	.290	.201	.605**	.276	.220	.317	.526**	.471*	.214
2nd Count, Untr.	.569**	.560**	.231	.173	.631**	.187	.185	.428*	.529**	.493*	.203
1st Count, Tr.	.672**	.603**	.326	.236	.604**	.249	.222	.569**	.591**	.578**	.130
2nd Count, Tr.	.848**	.711**	.404	.326	.758**	.324	.333	.429*	.643**	.714**	.091
Across 2 locations	.860**	.699**	.432*	.407*	.736**	.367	.408*	.374	.636**	.758**	.158

*,**Significance at the 0.05, 0.01 level of probability.

†Untr. = Untreated; Tr. = Treated. 1st Count - 7 days after planting; 2nd Count - 14 days after planting.

occurred for CV-3, TZV, and SW at the Reese or Mason locations. In Reese with near optimum field conditions, standard germination had the highest correlation coefficient with field emergence for both treated and untreated seeds. In Mason with less favorable condition imposed by artificially compacted soil, the highest correlation with field emergence was obtained by the TZ test for field emergence of untreated seed. However, the best correlation between the standard warm germination test and field emergence was obtained with treated seed.

Table 16 shows results of stepwise multiple regression analysis for both the Reese and Mason locations. The most significant multiple correlations (above .500) found were the combination of standard germination and accelerated aging as follows,

Reese: $Y = -51.363 + 1.357\ X_1 + .159\ X_2;\ R^2 = .719$

Mason $Y = .36.616 + 1.067\ X_1 + .147\ X_2;\ R^2 = .783$

Across 2 locations: $Y = -44.082 + 1.213\ X_1 + .153\ X_2;\ R^2 = .797$

where;

Y = Total emergence

X_1 = Standard germination

X_2 = Accelerated Aging

R^2 = Coefficient of determination

R^2 showed that 71.9% and 78.3% of the variation in total emergence at Reese and Mason locations respectively were

Table 16. Result of stepwise multiple regression analysis for selecting best regression equation for predicting Field Emergence. Navy bean, 1978.

Field emergence	Const.	WG-7	CV-3	TZ	AA	R^2
REESE						
1st Count, Untr.*	- 3.286	+ .563			+.263	.478
2nd Count, Untr.	-21.237	+ .818			+.222	.619
1st Count, Tr.	-37.323	-1.277				.455
2nd Count, Tr.	-51.363	-1.357			+.159	.719
MASON						
1st Count, Untr.	-40.923			+ .881		.366
2nd Count, Untr.	-10.264			+ .827		.398
1st Count, Tr.	-44.086	+1.480	-.113	-1.000		.749
2nd Count, Tr.	-36.616	-1.067			+.147	.783
Across 2 locations	-44.082	-1.213			+.153	.797

*Untr. = Untreated; Tr. = Treated. 1st Count - 7 days after planting.

2nd Count - 14 days after planting.

attributable to linear regression on the combination of WG-7 and AA. Thus, in 1978, where field conditions were less favorable than 1977, a combination of test variables (WG-7 and AA) provided a more reliable estimate than results of a single test alone. This agrees with results reported elsewhere (33,44,80,86).

During 1979, seed lots were evaluated at three planting dates. The highest correlation with total emergence (Table 17) was obtained with the conductivity test (CD) at the second planting date. The next highest correlation was obtained with CT-3, TZ, and TZV. No significant correlations were found between any vigor test results and total emergence at the first planting date. Only the conductivity test results were significantly correlated with total emergence at the third planting date. Averaged across the three planting dates, only the conductivity test (CD) correlated well will total emergence (Table 17). In this case standard germination (WG-7) results were not significantly correlated with total emergence for all planting dates. Under stress condition, total field emergence was over estimated by standard germination (WG-7) and stress tests became very valuable in predicting field emergence. These results agree with previous reports (71,123). They also demonstrate that for dry bean the standard warm germination test (WG-7) does not provide a reliable estimate of field emergence, especially under stress conditions.

Table 17. Simple correlation coefficient between various seed vigor tests and field emergence at three planting dates. Navy bean, 1979.

Field emergence	WG-7	WG-3	CT-3	CT-5	TZ	CV-3	CV-5	TZV	AA	CD
21 May										
1st Count	-.065	-.129	.246	.229	-.142	.007	.093	-.113	-.227	.344
2nd Count	.026	.022	.297	-.262	.157	.027	-.350	.212	-.048	.530
31 May										
1st Count	.702*	.621*	.733**	-.163	.538	.653*	-.287	.491	.316	.591
2nd Count	.560	.402	.632*	-.191	.697*	.447	-.368	.653*	.557	.805**
22 June										
1st Count	.412	.303	.576	-.422	.266	.297	-.572	.373	.062	.596*
2nd Count	.470	.297	.520	-.397	.370	.285	-.552	.518	.220	.598*
Across 3 p.d.†										
1st Count	.326	.202	.570	-.088	.188	.286	-.260	.214	-.062	.591*
2nd Count	.342	.229	.512	-.340	.395	.238	-.491	.475	.198	.700*

*,**Significance at the 0.05, 0.01 level of probability.

†Across 3 p.d. = Across three planting dates.

Table 18 shows results of stepwise multiple regression analysis of the 1979 results for field emergence at each of the three planting dates. The best regression equation for predicting field emergence for each of the three planting dates or the average emergence across three planting dates utilized the results of the conductivity test (CD) as follows:

First planting date	$Y = -65.558 + 1.499\ X\ ;\ R^2 = .281$
Second planting date	$Y = -16.474 + 1.052\ X\ ;\ R^2 = .648$
Third planting date	$Y = -66.792 + 1.477\ X\ ;\ R^2 = .358$
Across three planting dates	$Y = -51.046 + 1.344\ X\ ;\ R^2 = .489$

where:

Y = Total emergence

X = Conductivity test (CD)

R^2 = Coefficient of determination

The graphical relationship between CD and WG-7 with field emergence is shown in Fig's 1, 2, and 3. The slope associated with the CD is more gradual than WG-7 and the regression has a better fit. The highest prediction accuracy as indicated by R^2 was found for the second planting date. The regression equation for the average emergence across all planting dates had a multiple correlation lower than that for the second planting date but higher than that for the first and third planting dates. On the basis of the results of these tests, the conductivity test (CD) appears

Table 18. Result of stepwise multiple regression analysis for selecting best regression equation for predicting Field Emergence. Navy bean, 1979.

Field Emergence	Const.	CT-3	CD	R^2
<u>21 May</u>				
1st Count*				
2nd Count	-69.558		+1.499	.281
<u>31 May</u>				
1st Count	+38.873	+.351		.538
2nd Count	-16.474		+1.052	.648
<u>22 June</u>				
1st Count	-49.863		+1.242	.356
2nd Count	-66.792		+1.477	.358
Across 3 plt. dts.**	-51.046		+1.344	.489

*1st Count - 7 days after planting, except 21 May (15 days.

2nd Count - 14 days after planting, except 21 May (22 days.

**Across 3 plt. dts. = Across three planting dates.

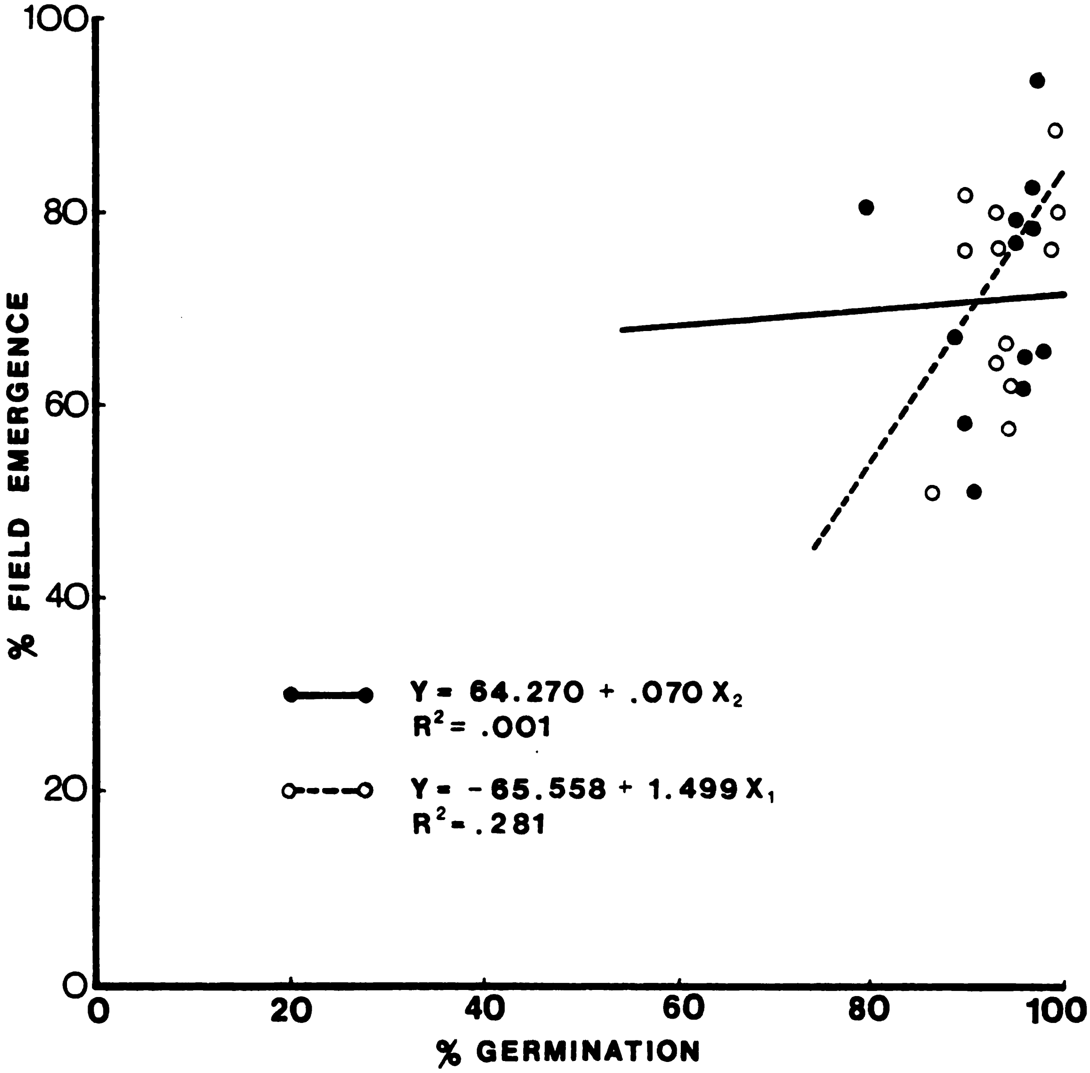

FIG. 1. RELATIONSHIP BETWEEN FIELD EMERGENCE AND CD/WG-7 IN NAVY BEAN SEED LOTS (1979 - FIRST PLANTING DATE): X_1 = CONDUCTIVITY; X_2 = STANDARD WARM GERMINATION.

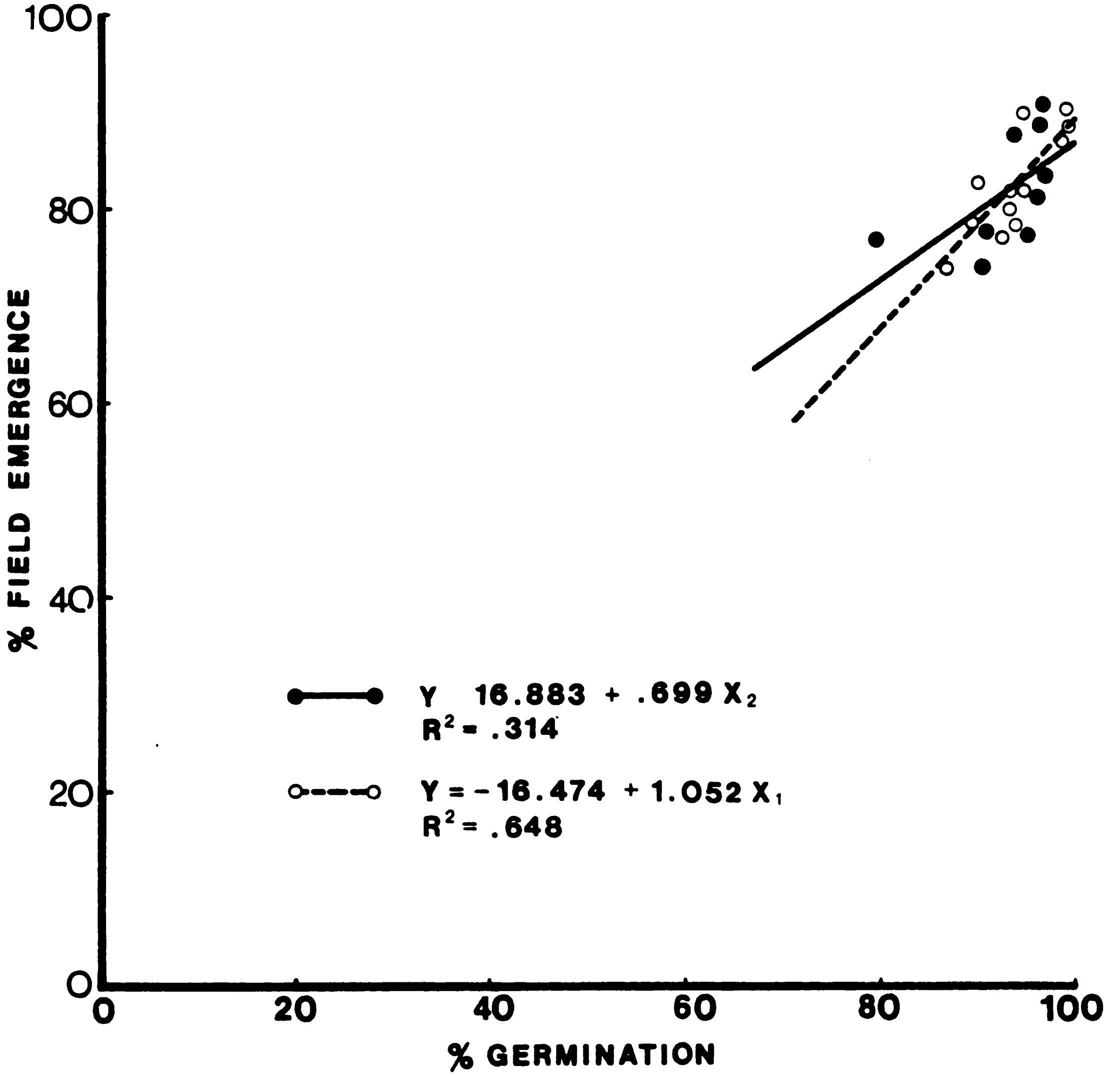

FIG. 2. RELATIONSHIP BETWEEN FIELD EMERGENCE AND CD/WG-7 IN NAVY BEAN SEED LOTS (1979 - SECOND PLANTING DATE): X_1 = CONDUCTIVITY ; X_2 = STANDARD WARM GERMINATION.

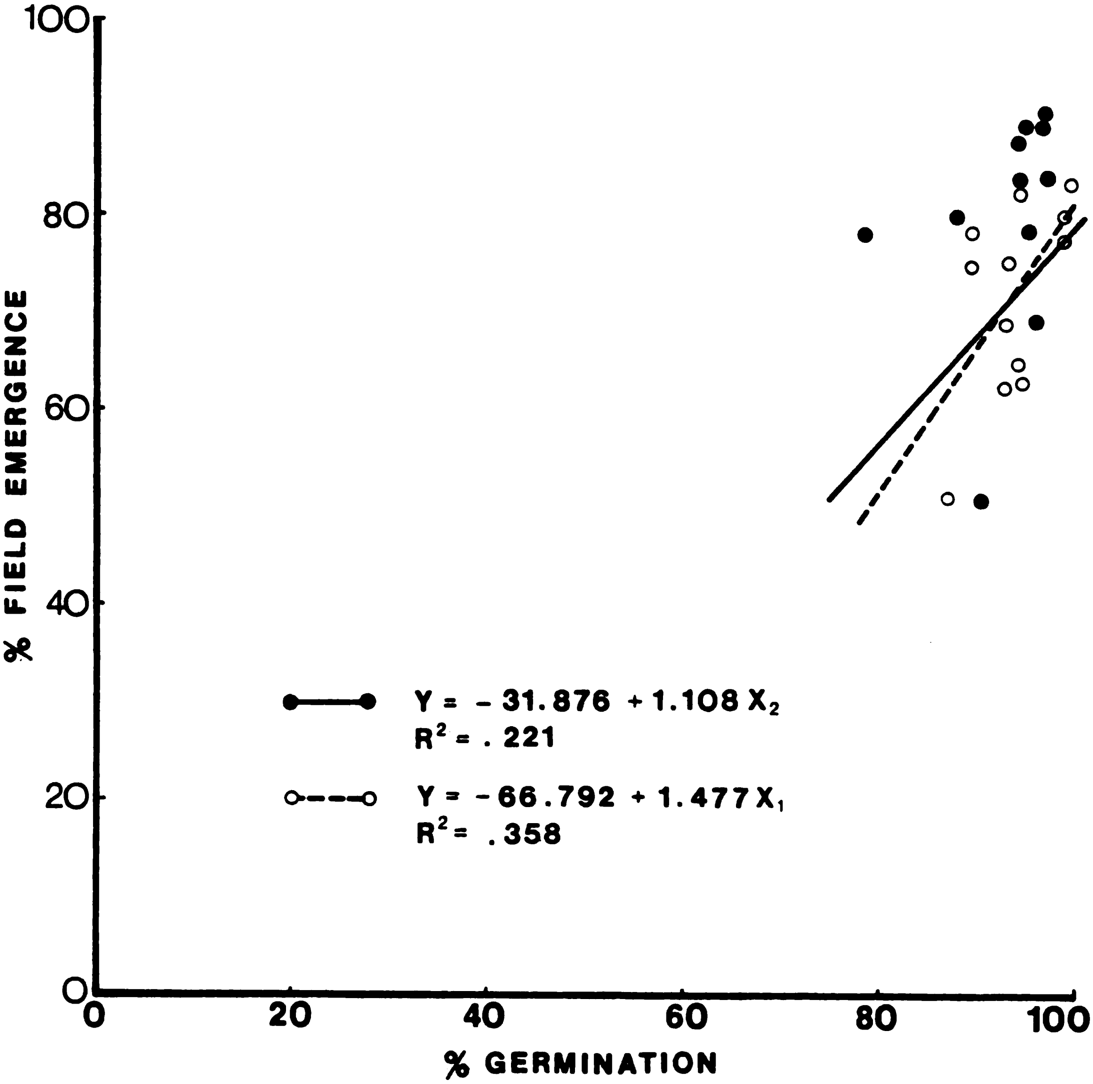

FIG. 3. RELATIONSHIP BETWEEN FIELD EMERGENCE AND CD/WG-7 IN NAVY BEAN SEED LOTS (1979-THIRD PLANTING DATE): X_1 = CONDUCTIVITY ; X_2 = STANDARD WARM GERMINATION.

to provide the single best estimate of vigor and field performance potential. The high relationship between conductivity and field emergence, especially under stress conditions seems to support the evidence that a drop in seed performance potential is associated with cell breakdown and membrane permeability (93,119,143). An insight into this phenomenon has been given by Simon (112) who proposed that membranes of dry seeds are dehydrated and leaky, but upon imbibition, their normal lamellar phospholipid structure reforms and selective permeability is reestablished. When dry seeds imbibe at low temperatures, the phospholipids are unable to change rapidly from the hexagonal (dehydrated) architecture because they are gelled in a rigid molecular shape. Supported by the data of Bramlage et al. (18), this indicates that low temperatures interfere with normal membrane reorganization during imbibition, probably by modifying the physical state of membrane phospholipids and that the consequent abnormal organization of membranes is a basic cause of temperature injury.

Results of these studies show that seeds which have greater potential for loss of electrolytes, and consequent lower performance potential under cold soil conditions can be predicted by use of the conductivity test. The potential performance is probably hindered even more by the high levels of leachates from the tissues which provide a substrate for pathogen activity (92). The actual concentration of exudates available as a substrate for microorganisms should be greater at low than at high temperatures (109). Matthews (81) suggests that cotyledons influence predisposition by either increasing exudation around the seed and stimulating the fungal pathogen or by acting as a food base for the fungal hyphae which infect and kill the seedling axis. Thus, pathological phenomena, in addition to the physiological factors discussed above help explain the relationship between conductivity test results and field performance obtained in these studies.

Multiple Vigor Indices

Several workers have shown that combinations of two or more variables were more accurate than one vigor test for predicting field performance (33,44,80,123). Yacklich and Kulik (145) proposed R^2 method. It is noteworthy that this procedure does not limit the researcher to evaluating seed lots by single test scores and does not give one best formula for estimating predictive capability, but uses combinations of two or more routine vigor tests for developing multiple vigor indices. The following is an attempt to increase the prediction accuracy of laboratory vigor tests in estimating field performance.

In these studies, two or three variables were enough for providing laboratory test measurements. Table 19 shows multiple correlations of 6 laboratory tests with emergence

Table 19. Multiple correlation matrices (R^2), 12 lots of Navy bean, six laboratory tests versus field emergence and yield (Average across 3 planting dates). Navy bean, 1979.

				Multiple correlation				
CD plus	Emg.	Yld.	CD plus	Emg.	Yld.	CD plus	Emg.	Yld
WG-7	.502*	.246	TZ,AA	.547	.273	WG-3TZ	.559	.226
WG-3	.497*	.209	WG-7,AA	.547*	.328	WG-3,CT-3	.498	.346
CT-3	.497*	.434	WG-3,AA	.583*	.281	AA,CT-3	.565*	.494
TZ	.497*	.220	WG-7,WG-3	.502	.248	WG-7,TZ	.572*	.250
AA	.545*	.254	WG-7,CT-3	.502	.474	TZ,CT-3	.527	.435

*Significance at the 0.05 level of probability. Emg = Emergence; Yld = Yield.

and yield. The R^2 of all combinations of 2 variables and four combinations of 3 variables (including CD) were significant at the .05 level. The R^2 of all combinations was higher than for the CD test alone (.489). This is in agreement with reports by Yacklich and Kulik for soybean (145), where a combination of 3 variables including TZ had an R^2 higher than that of the TZ alone for field emergence and stand. Similar results were reported by Clark for peanut (33), and Mark and McKee for Reed canarygrass (80).

Thus the following combinations could predict field emergence at 3 planting dates:

(a) For 2 variables: CD,WG-7; CD,WG-3; CD,CT-3; and CD,AA.

(b) For 3 variables: CD,WG-7,TZ; CD,WG-7,AA; CD,WG-3,AA; and CD,CT-3,AA.

In order to simplify vigor evaluation by the R^2 method only combinations including standard warm germination were chosen, for example, CD,WG-7,TZ; CD,WG-7,AA; or CD,WG-7. These tests are well known for seed quality evaluation and are useful in predicting field emergence. Results from this study are close to those reported by Scott and Close (111) for predicting field emergence in pea (*Pisum sativum* L.) using a combination of conductivity, standard warm germination and hollow heart tests.

Regression equations for predicting field emergence at 3 planting dates, averaged across 3 planting dates are presented at Table 20 and 21.

Table 20. Regression equation of 2 and 3 variables upon field emergence at three planting dates. Navy bean, 1979.

Emg.	CD	WG-7	WG-3	CT-3	TZ	AA	Const.	R^2
21 May	1.665	-.398					-47.990	.308
	1.551		-.082				-69.647	.289
	1.616			-.052			-76.795	.284
	2.116				-1.007		-34.417	.345
	2.203					-.360	-129.826	.457
31 May	.909	.344					-34.136	.742
	.986		.104				-16.361	.742
	.883			.075			- 5.992	.673
	.799				.414		-30.919	.698
	.941					.050	- 8.093	.664
22 June	1.224	.605					-99.575	.439
	1.385		.143				-66.636	.390
	1.109			.163			-43.981	.391
	1.540				-.103		.63.193	.359
	1.711					-.105	.84.388	.378

Table 20 (cont'd.)

	CD	WG-7	WG-3	CT-3	TZ	AA	Const.	R^2
Emg.								
21 May	2.179	.178			-1.231		-36.224	.347
	2.342	-.170				-.346	-118.301	.461
	2.316		.080			-.389	-134.581	.463
	2.223			.043		-.368	-125.123	.458
31 May	.929	.368			- .050		-34.661	.742
	.864	.329				.023	-30.461	.745
	.957		.097			.015	-13.875	.709
	.820			.065		.038	- .957	.682
22 June	2.106	1.592			-2.110		-79.396	.588
	1.544	.713				-.164	-132.836	.484
	1.748		.220			-.185	-97.454	.441
	1.342			.199		-.141	-62.525	.425

Table 21. Regression equation of 2 and 3 variables upon field emergence, average across three planting dates. Navy bean, 1979.

	CD	WG-7	WG-3	CT-3	TZ	AA	Const.	R^2
Emergence			2 variables					
	1.266	.185					-61.091	.502
	1.308		.055				-50.986	.497
	1.203			.062			-42.338	.497
	1.485				-.231	-.138	-42.998	.497
	1.651						-74.083	.545
			3 variables					
	1.739	.715			-1.132		-50.271	.573
	1.583	.292				-.162	-93.926	.574
	1.673		.132			-.185	-81.945	.583
	1.461			.102		-.156	-62.852	.565

The VR method proposed by TeKrony (121) for soybean to develop a Vigor Rating Index is presented at Table 22. By using this information, a single vigor rating can be developed using the mean of each individual vigor test (each laboratory test must be adjusted first to vigor ratings as shown at Table 22). For these studies, only 2 and 3 variables including CD were chosen for VR comparisons. Table 23 shows correlation between VR and field performance. Only one VR using 2 variables and two VR's of 3 variables were well correlated with total emergence (CD,CT-3; CD,TZ, CT-3; and CD,AA,CT-3). Information provided by this method agrees with the R^2 method except for CD,TZ,CT-3.

Relationship between Laboratory Tests and Yield

Plot yields for all years are shown at Table 24. Yields in 1977 were higher than in 1978, however, the range of yields was very wide in both years. No significant differences in yields were obtained in 1978 between Reese and Mason.

Results of 1979 studies showed that the highest yields were achieved from plots at the third planting date, followed by those at the second planting date. The lowest yields were from plots established at the first planting date. Yields across three planting dates (Table 24) varied widely. No interaction was found between planting date and speed of emergence or between planting date and cultivar. Table 25 shows yield of various cultivars at each planting

Table 22. Procedure for determining seed vigor index using the percentage of laboratory tests.*

Stand. Germ.	Vigor rating	Vigor tests
<50	0	<45
51-55	1	46-50
56-60	2	51=55
61-65	3	56-60
66-70	4	61-65
71-75	5	66-70
76-80	6	71-75
81-85	7	76-80
86-90	8	81-86
91-95	9	86-90
96-100	10	91-100

*Adopted from TeKrony and Egli (123).

Table 23. Correlation coefficient between VR and field emergence and yield (average across 3 planting dates). Navy bean, 1979.

	Simple correlation							
CD plus	Emg.	Yld		Emg.	Yld		Emg.	Yld
WG-7	.459	.017	TZ,AA	.419	-.012	WG-3,TZ	.304	.091
WG-3	.329	.137	WG-7,AA	.474	-.159	WG-3,CT-3	.514	-.039
CT-3	.589*	-.067	WG-3,AA	.380	-.043	AA,CT-3	.577*	-.161
TZ	.485	.461	WG-7,WG-3	.370	.004	WG-7,TZ	.385	-.017
ZZ	.539	.082	WG-7,CT-3	.576	-.127	TZ,CT-3	.579*	-.020

*Significance at the 0.05 level of probability.

Emg. + Emergence; Yld = Yield.

Table 24. Mean and standard deviation of yield of all seed lots (grams/plot).

	Mean	Range	Sd
1977-Reese	950.6	782.5-1190.7	86.4
1978-Reese, Untr.*	475.4a	160.4-666.0	114.6
Reese, Tr.	517.7a	291.5-764.1	123.6
Mason, Untr.	624.7a	349.5-996.2	137.1
Mason, Tr.	603.5a	322.6-917.0	135.5
1979 - 21 May	214.1b	152.8-346.7	72.3
31 May	263.5bc	232.8-315.1	25.8
22 June	305.9c	191.0-429.4	69.7

Numbers followed by the same letters in particular column (mean for 1978, 1979) are not significantly different at 0.05 level using Duncan's multiple range test.

*Untr. = Untreated; Tr. = Treated.

Table 25. Yield of various cultivars at each planting date (grams/plot). Navy bean, 1979.

	21 May	31 May	22 June
Tuscola-Mich.	163.8a	296.6a	348.0a
Seafarer-Mich.	234.9a	254.6a	346.2a
Sanilac-Mich.	168.3a	257.5a	254.0a
Tuscola-West	249.8a	279.7a	335.6ac
Seafarer-West	238.5a	251.6a	242.2bc
Sanilac-West	229.2a	241.1a	309.8ac

Mean in columns followed by the same letters are not significantly different at 0.05 level using Duncan's multiple range test.

date. No significant differences between yield of cultivars were obtained at each planting date. At the third planting date, Michigan-grown Tuscola and Seafarer had relatively higher yield than other cultivars. Yield of each cultivar across three planting dates are presented in Table 26. No significant difference occurred between planting date for Western seed of any cultivar and for Michigan grown Sanilac seed. Significant differences in yield were found between first planting date and two other planting dates for Michigan grown Tuscola seed, and between first planting date and third planting date for Michigan grown Seafarer seeds.

Association between vigor tests and yields for 3 years of studies are shown at Tables 13, 27 and 29 for 1977, 1978 and 1979 respectively.

1977 studies show that only TZV (Table 13) correlated well with yield. No significant correlation were found between field emergence and yield. The best regression equation for predicting yield (Table 14) is as follows: Y = 4.008 WG-4 - 0.655 CV-3 + 0.990 TZV + 332.832; R^2 = 0.388 where Y = Yield.

In 1978 at Reese only WG-4 (treated seed), CT-5, CV-5 (untreated seed) correlated well with yield (Table 28). For the Mason location, only WG-7 (untreated seed) correlated well with yield. A significant correlation was found between field emergence and yield both for Mason (.475) and Reese (.476). Stepwise multiple regression (Table 28)

Table 26. Yield of each cultivar across three planting dates (grams/plot). Navy bean, 1979).

	TS-M*	Sf-M	Sn-M	Ts-W	Sf-W	Sn-W
21 May	163.8a	234.9a	168.3a	249.8a	238.5a	229.2a
31 May	296.6b	254.6ac	257.5a	279.7a	251.6a	241.1a
22 June	348.0b	346.2bc	254.0a	335.6a	242.2a	309.8a

Means in columns followed by the same letters are not significantly different at 0.05 level using Duncan's multiple range test. *Ts = Tuscola; SF = Seafarer; Sn = Sanilac; M = Michigan; W = West.

Table 27. Simple correlation coefficient between various seed vigor tests and yield. Navy bean, 1978.

Location	WG-7	WG-4	CT-3	CT-5	TZ	CV-3	CV-5	TZV	AA	CD	SW
Reese, Untr.†	.209	.207	.306	.442*	.085	.318	.413*	.116	.266	.188	.126
Reese, Tr.	.379	.443*	.024	.138	.286	-.054	.106	.032	.231	.209	.011
Mason, Untr.	.404	.264	.083	-.056	.323	-.012	-.049	-.031	.292	.145	.063
Mason, Tr.	.238	.210	.312	.184	.113	.266	.160	-.040	-.098	.193	-.049
Across 2 loc.	.425*	.447*	.243	.225	.272	.157	.187	-.008	.279	.279	-.105

*,**Significance at the 0.05; 0.01 level of probability.

†Untr. = Untreated; Tr. = Treated; loc. = locations.

Table 28. Results of stepwise multiple regression analysis for selecting best regression equation for predicting Yield. Navy bean, 1978.

Location	Const.	WG-4	WG-7	CT-5	TZV	R^2
Reese, Untr.	+417.957			+2.110		.195
Reese, Tr.	+ 23.234	+6.132				.196
Mason, Untr.	-494.038		+8.033			.163
Mason, Tr.	-					-
Across 2 loct.*	+135.190	+7.381			-.678	.320

*loct. = locations.

Table 29. Simple correlation coefficient between various seed vigor tests and yield. Navy bean, 1979.

Planting date	WG-7	WG-3	CT-3	CT-5	TZ	VC-3	VC-5	VTZ	AA	CD
21 May	-.126	-.159	-.224	.092	.035	-.306	.034	-.176	-.159	.100
31 May	.288	.350	.208	-.252	.358	.161	-.328	.303	.403	.479
22 June	-.344	-.338	-.209	-.283	-.169	-.390	-.294	-.335	-.158	.348
Across 3 p.d.	-.207	-.210	-.205	-.158	-.000	-.365	-.214	-.228	-.098	.354

*,**Significance at the 0.05, 0.01 level of probability.

Across 3 p.d. = Across three planting dates.

showed that CT-5, WG-4 for Reese and WG-7 for Mason were the best tests for predicting yield, however, the prediction accuracies as indicated by R^2's are low. Thus, none of the laboratory vigor test results correlated very well with yield either in 1977 or 1978.

In the 1979 studies (Table 29), no significant correlations occurred between any laboratory test and yield at any of the three planting dates or across planting dates. None of the variables were selected by stepwise multiple regression as the best predictor of field. Only the second planting date resulted in significant correlation between laboratory vigor tests and yield (.645). These results agree with those reported by Egli and TeKrony (45), but contrasted with Johnson and Wax (71) who reported that cold test in soybeans showed consistent correlations with crop yield as well as vigor.

At the second planting date, thinning to equalize plant populations was conducted 23 days after planting to determine if there is a relation between vigor per se and yield, or whether increased yields of high vigor seed comes about because of higher stand establishment from high vigor seed. Table 30 shows that no significant correlations were found between results of any laboratory test and yield of either thinned or unthinned plots, except for TZ test. TZ test results correlated well with yield from unthinned plots but not with that from thinned plots. However, there was a

Table 30. Correlation between various vigor tests and yield at second planting date (extra plot). Navy bean, 1979.

	WG-3	WG-7	CT-3	CT-5	TZ	VC-3	VC-5	TZV	AA	CD
Unthin.	.350	.288	.208	-.252	.358	.161	-.328	.303	.403	.479
Thin.	.328	.426	.359	-.410	.579*	.247	-.496	.479	.565	.523

*Significant at the 0.05 level of probability.

tendency toward better correlation coefficients between laboratory test results and yield from unthinned than thinned plots.

It is concluded that high variation in yield is not caused by seedling vigor or population density, and that, as stated by Egli and TeKrony (45), the primary advantage to be gained from high vigor planting seed is improved stands and not necessarily increased yields.

SUMMARY AND CONCLUSIONS

Studies to determine the relationships between laboratory indices of navy bean seed vigor and field performance were conducted in laboratory and field tests in 1977, 1978 and 1979. Laboratory tests used were the standard germination test, the first count (3 and 4 days) germination, cold test, cold vigor test, TZ test, TZ vigor test, accelerated aging and the leachate conductivity test. Seedling emergence and yield were observed in the field.

In 1977 and 1978 soil temperature and moisture conditions were favorable for seed germination and emergence, except in Mason (1978) where the entire plot was artificially compacted. In 1979 three plantings, using both treated and untreated seeds, were made to provide varying amounts of temperature and moisture stress on the emerging seed. Relationships between vigor test results and field performance (including yield) were determined using regression analysis.

Standard germination of seed lots in 1977 and 1979 exceeded 90% and in 1978 average 83.1%. The 4-day germination was closely correlated with standard germination, averaging 94.0 and 80.6%, respectively. The 3-day germination also correlated very well (.883) with the standard germination but averaged 34.5% lower.

Higher correlations were obtained by increasing temperature of exposure in the cold test from 5 C to 10 C. Because of sensitivity of navy bean seed to stress, particularly from soil borne microorganisms, it has been suggested that a cold test might be developed that incorporates only cold temperature without the added confounding factor of soil (26). More studies are needed before this technique can be verified and recommended.

The TZ, accelerated aging and conductivity tests all displayed good promise as vigor tests.

The conductivity test utilizing the Seed Analyzer, ASA 610, shows good, fast, easy operation and simplified record keeping with good promise for measuring seed vigor. In these studies, using a selected criterion, conductivity test results were closely related to standard germination.

Field emergence results showed no significant difference between treated and untreated seeds. Total emergence at Reese in 1977 and Mason in 1978 averaged 13% and 20% points lower than standard germination.

Due to low temperature (9.5-17.9 C) and soil crusting in 1979, lowest total emergence was obtained at the first planting date. As soil temperature become more favorable, emergence progressively increased at successive planting dates.

Michigan-grown seed showed relatively higher emergence than western-grown seed, reflecting a comparatively better physical condition.

Results of these studies indicate that if field conditions are optimum for germination, the standard germination test is the best predictor of field emergence. For less favorable conditions, as in 1978, the best prediction is given by a combination of the standard germination and accelerated aging tests. Under stress conditions, however, field emergence is overestimated by standard germination and seed vigor tests are more sensitive in predicting field performance. For example, in 1979 the conductivity test appeared to provide the single best estimate of vigor and field performance potential. However, it is suggested that it be used in combination with other vigor tests to provide broad evaluation of field bean seed vigor.

A combination of three tests such as conductivity, standard germination, TZ test; conductivity, standard germination, accelerated aging test, and at least conductivity, standard germination are suggested for predicting field emergence in a routine vigor evaluation program.

These studies further confirm the inconsistencies and low correlations existing between seed vigor and crop yield under both optimal and stress field conditions. Thus, the advantage to be gained from high vigor seed is improved growth and uniformity of healthy seedlings under a wide range of environments and not necessary increased yield.

It is suggested that at least two additional years of vigor research should be conducted by adding criteria such as: (a) wider range of seed quality from low to high vigor; (b) use of at least 20 seed lots; and (c) conducted at two different types of soil at three planting dates at two or three locations.

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