THE PROBLEM OF VIGOR

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Several years ago, one of our prominent and progressive farmers asked us to arrange for a meeting with him and his neighbors at the local county agent's office to discuss the matter of seed quality. At the very beginning of the meeting, the farmers stated that "getting a stand" of cotton and soybeans - major crops in the area - was a serious and continuing problem in their operations. Stand failures and poor stands were adding substantially to their costs of production and reducing yield. They recognized that weather conditions at planting time were an important determinant in stand establishment, but were convinced that differences in quality of the seed planted contributed in a major way to their problems. The farmers wanted to purchase high quality seed in the marketplace and were willing to pay a premium for it, but had been frustrated in their efforts because most of the seed lots in the market were labelled 80% germination and, thus, there was no real basis for selection among the lots except by name and reputation of the producer. They had heard of tests for seed vigor and wanted to know more about them, and where they could get such tests made.

I will not relate here the ensuing discussions during the meeting or the decisions made and actions taken because that is not my intent. Rather, I wanted to set the stage from the farmer's perspective for a consideration of the "matter of vigor."

A Look at the Germination Test

The stand and plant producing potential of crop seed are most commonly evaluated by a germination test. Procedures for determining the germination percentage of seed lots have been developed and perfected over the past 100 years. The Rules for Testing Seed prescribe the temperature, substrata, and period for germination testing of seed of agricultural, vegetable, ornamental, and tree seeds, define the term "germination," and establish criteria for interpretation of test results.

In many ways, the standard germination test appears to admirably serve the needs and interests of seed analysts, seed control officials, and a few seedsmen. But, does it also serve the needs of the majority of other seedsmen and, most importantly, the farmer or planter:

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now, in our times, in 1973? This rather basic question has been asked so many times, in so many ways, by so many people in the past 15 years or so that it has become commonplace, and even rather tiresome. Either an affirmative or negative answer, however, is still likely to stir the emotions and rhetoric of both the questioner and answerer and anyone else within hearing distance.

My answer to the question is and has been for many years: NO, the germination test does not now adequately serve the needs of the seedsman who produces, processes, and sells seed, or the farmer who buys and plants it. The facts that the germination test may have adequately served the needs of seedsmen and farmers 40 or even 25 years ago in our country, and may still be adequate for the needs in developing countries are not really germane to the question or answer given. For the question arises within the context of a technologically advanced, mechanized, highly capitalized and economically complex crop agriculture and the answer must be framed within the same perspective.

Germination % is an inadequate measure or index of the stand and crop producing potential of seed lots within a variety and the inadequacy gap widens with each advance in crop production technology, mechanization, input level, and cost of production. Farmers need now some greater assurance that the seed they purchase are capable of producing a rapidly emerging, uniform stand of vigorous plants than is provided by the germination % printed on the label. Although the farmer is a realist - he is too close to nature to be otherwise - and does not expect miracles, he does suspect that something is just not right when he obtains a poor stand, or no stand, from soybean seed labelled 80% germination, when his neighbor across the field road gets a good stand from seed of the same variety and germination but of a different lot. His suspicions are even more aroused when seed with similar germination but from different lots perform completely different in his own field. One of the worst "messes" I've seen was a 200-acre block of cotton planted by loading the planter hoppers more or less indiscriminantly with seed from two different seed lots (of the same variety). Although both lots were tagged 80% germination, they were obviously of different vigor levels. Some rows were up to a perfect stand, while other rows had one of those "head scratching" stands, or were almost complete wipeouts. Because there was not a sufficient pattern in the stand for selective replanting of just the poor and no-stand rows, the farmer had no real alternative but to replant the whole 200 acres.

The deficiencies of the germination test as a means of evaluating the stand and crop producing potential of seed in our times stem from three main sources: the overall philosophy of germination testing, the nature of seed deterioration, and germination labelling requirements.

The philosophy of germination testing has two aspects - an unwritten but well recognized aspect, and an aspect codified in the Rules of Testing Seed. The unwritten aspect relates to establishment of conditions for germination tests. In establishing and "perfecting" conditions for germination testing of each kind of seed, the thrust
has been and still is to optimize test conditions so that the highest possible germination percentage is obtained, although nowhere in the Rules is this "optimization" principle discussed, justified, or even simply stated. Thus, germination tests are made largely on artificial, standardized, essentially sterile media, in humidified, temperature controlled - within close tolerance - germinators for periods of time sufficiently long to permit even the weakest seed to make its debut. It can, of course, be argued that long test periods are required because of the possibility the seed might be dormant. This argument simply doesn't hold because perusal of the Rules will reveal that test periods for non-dormant seed are also overly long and germination test periods remain the same whether the seed are in a dormant condition or not.

To some extent, the principle of optimization of test results is tempered by the definition of "germination" and interpretation criteria which constitute the written aspect of the philosophy of germination testing. The Rules for Testing Seed define germination, "as the emergence and development from the seed embryo of those essential structures, which for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions," and normal seedlings as "Seedlings possessing the essential structures that are indicative of their ability to produce plants under favorable conditions." It is obvious from these basic definitions that there is a decided morphological or structural bias in germination testing. An analyst is largely concerned with the presence or absence of roots, stem, and other seedling parts, but very little with the rate at which they emerged, their size, evident weaknesses, etc., all of which are determinants in stand establishment, plant growth and development. Thus, in practice, the definition of germination and interpretation criteria established thereunder, eliminate only the completely dead, badly diseased and irrecoverably lame from the germination %. The weak, obviously aged, semi-lame, and robust count the same in computing germination percentage.

Perhaps the major deficiency of the present definition of germination is that it is hung on two very subjective, ambiguous phrases: "normal plant" and "favorable conditions." What is a "normal" plant? Favorable conditions where - in the germinator, greenhouse, field? Favorable to what degree - optimal, or just more or less satisfactory? What conditions - temperature, aeration, moisture, well prepared seed bed, in-furrow seed treatment, etc.?

The present philosophy of germination testing severely limits the usefulness of germination % as an index of the physiological quality of seed and, moreover, is misleading since there is the implication that a germinable seed will develop into a "normal" (productive) plant under "favorable" (not adverse) conditions (in the field).
Thru The Glass Obscurely

Somewhere, sometime, I read a poem that began, or ended - "Thru the glass darkly." I cannot recall the name of the author or the poem or even its general theme. I only remember the one line, "Thru the glass darkly." And, this one line was etched into my memory circuits because it seemed to describe a common failing of the human condition in an elegant and highly distilled phrase.

The pull of sentiment, of tradition, is strong indeed. Reluctantly, we cling to concepts and the products of concepts which, although once seemingly clear and unassailable, have been severely obscured by changes in perspective and the rise of other competitive or alternative insights. We continue to look thru the same glass darkly and see less and less.

Fifty years ago, the germination test was a bright, clear glass thru which one could peer knowingly into the realm of seed quality. Twenty-five years ago, the glass began to lose its focus and one looked thru it less and less knowingly. Today, we look thru the glass of the germination test obscurely at best.

One of the three major causes of the present "obscurity" of the germination test as a measure of the physiological quality of seed has been considered above, viz., the prevailing philosophy of the test. The two other "causes" or sources of germination test deficiencies are the nature of seed deterioration, and germination labeling requirements and practices.

It has now been well established that the performance potential of a seed is progressively impaired by deteriorative changes that inevitably occur over time - a few minutes or many years. Although the specific sequence of deteriorative changes - or the manifestations of these changes - which occur in seed as they die has not yet been clearly elucidated, the available evidence suggests that degradation of the seed membranes occurs at an early stage. Energy yielding and biosynthetic mechanisms - vital to the processes of germination - are then impaired with the result that rate of germination and seedling growth slows down. The slowly germinating seed and physiologically weak seedling develop into a slowly developing plant, which flowers and matures later and yields less as compared to those from a seed of better physiological quality (less deteriorated). At about this stage in the progress of deterioration, the seed seems to lose most of its "natural" defense(s) against stresses of any type, and is prone to "kick the bucket" at the slightest discomfort. Since the seed bed is usually less than comfortable as contrasted to the high level of comfort and security in the germinator, the seed is likely to not emerge. Finally, deterioration progresses to the extent that the seed is incapable of initiation and/or completion of the processes of germination and becomes non-germinable.
This highly speculative sequence of the manifestations of progressive deterioration has focused on a seed. Seedsmen, analysts, and farmers, however, are seldom interested in a seed. Rather, they are concerned with the quality and performance of the seed lot or portion thereof. A seed lot is a population of seed that may be "uniform throughout its parts for the factors which appear on the label" but is usually very non-uniform with respect to the physiological quality of the seed. The physiological quality of the individual seeds within a lot ranges from those that are incapable of germination to those whose performance potential is apparently unimpaired with all gradations between these two extremes. This range in physiological quality of seed within a lot accounts for the facts that the germination % of a lot of seed can be anywhere between 100 and 0% and that the germination % decreases progressively and not from 100% to 0% in one big jump. Because the seed within a lot are not uniform in physiological quality and they become more so as deterioration progresses, irregular or non-uniform emergence, plant growth, development, and maturation are other important consequences of seed deterioration that precede the 0% germination stage.

If the discussion above is tenable, then it is obvious that in emphasizing germination % as an index of quality all these years, attention has been riveted on the most disastrous and final consequence of seed deterioration to the neglect of its lesser consequences. Yet, in our modern, high input, highly mechanized agriculture, the lesser consequences of seed deterioration have become of greatest importance. No one knowingly plants non-germinable seed, but all too often, farmers plant seed lots of apparent "good" germination which are deteriorated to the extent that emergence is poor and/or yield is reduced. Use of germination % as an index of quality, therefore, fails to take into account the very substantial loss in performance potential of seed that can and does occur before the capacity to germinate is lost.

Germination % has yet another weakness as an index of seed quality: i.e., the assumption of equivalence. The 0% performance potential of seed that do not germinate "normally" in test is essentially inarguable. It is highly arguable, however, that the performance potential of every "normally" germinating seed is 100%, which is certainly implied in a germination %. In this connection, the statement of Goss - one of the pioneers in seed testing in the U.S. - is revealing. In 1933, he posed this rhetorical question before the Association of Official Seed Analysts, "If one compares two lots of seed, one germinating 96% and the other 62%, then is it not reasonable to expect that the condition of storage or age which proved fatal to over one-third of the seed in the low germinating lot has also left its degenerating influence on those seed still capable of germination?"

Labeling requirements or practices also contribute, albeit indirectly, to the deficiency of germination % as an index of seed quality.
The various seed laws require that seed lots be accurately labeled for germination %. Improved seed production, drying, processing, and storage practices and education of the farmer to "read the seed tag" have all but eliminated "low germination" seed lots from the marketplace save in exceptional seasons. There usually just isn't any market for 80% germinating corn seed, or 60% soybean seed. The requirement for accurate labeling, which in practice means that germination % must not be lower than stated, within allowable tolerances, coupled with present market demands has resulted in the widespread practice of "standard labeling." With few exceptions, all corn seed lots are labeled 95% germination or higher. Cotton and soybean seed lots are traditionally labeled 80 or 85% germination, depending on the season and locality, and so on. The farmer purchasing seed, therefore, is usually confronted with a host of seed lots of the variety he desires which all have the same germination % on the label. The only basis for discrimination among the lots is the "brand." The dilemma to the farmer posed by standard labels is evident from results of some tests we did several years ago. Fifty official inspection samples of soybean seed - all from different lots - were selected at random. Every lot was labeled 80% germination; however, germination percentages obtained from our official tests ranged from 68 to 96%. Only one sample - the 68% - was out of tolerance. Seed from the 50 samples were then planted in field tests in late May in well prepared plots and given favorable moisture with sprinkler irrigation. Emergence % under these "favorable" field conditions ranged from 23% to 97% among the lots. Analyzing the data a bit closer, we compared emergence percentages of only the 30 samples that actually germinated between 80 and 85% in our tests. Emergence ranged from 27% to 86%. Six lots, or 20% of the samples germinating between 80 and 85%, had an emergence % less than 50%, while 20% of the samples emerged above 80%. Our conclusion was that it made a whale of a lot of difference which 80% germinating soybean seed lot the farmer got when he purchased seed. The differences among the seed lots which were not reflected in germination % are related to an attribute of seed quality commonly termed vigor.

A Joseph's Coat

I have often heard or read statements to the effect that, "there is little or no relation between germination % of a seed lot and performance of the lot in the field." Indeed, in my zealous promotion of better quality seed and better means of identifying and evaluating seed quality, I, too, have been guilty of similar mis- or over-statements. The statement is, of course, not true. There is a very close and consistent relationship between the germination % of a seed lot and its performance in the field. Given ten lots of a variety of soybean or sorghum seed, or any kind and variety of seed for that matter, which range in germination % among the lots from, say, 95% down to 60%, the probability is very high that when planted in the field, total performance of the seed lot germination 95% will be high, while performance of the 60% germination seed will be low. I'd be willing to bet on it.
In former times, when agricultural production was not as intensive as it is today, or as technologically advanced, farmers did encounter seed lots in the market with a wide range of germination percentages and a corresponding array of prices. Advancements in agriculture and much improvement in input supply, however, have all but eliminated seed of relatively low germination from the market save in exceptional years, as previously discussed. Corn seed lots in the market labeled 85% or even 90% are a rare sight in the corn belt! The result of these advancements is a rather remarkable uniformity in germination % among lots of the same seed kind in the market place.

In spite of the considerable upgrading in germination % among lots, it is still relatively easy to demonstrate that there are substantial differences in performance potential among lots of the same variety and actual germination %. These differences which are not reflected in germination % arise out of other properties of seed variously termed vigor, degree of deterioration, germination energy, etc.

Many attempts have been made to rigorously define the term vigor as applied to seed. The result is a Joseph's Coat of definitions in which all have some degree of validity and applicability, and which collectively cover the subject rather thoroughly. In our country, the early concepts and definitions of vigor focused on the differences in emergence or stand producing potential among seedlots under sub-optimal conditions in the field. Focusing on these aspects was natural considering the success of the cold test for corn. The cold test assays the emergence potential of corn seed under simulated wet cold seed bed conditions. Since it was established early that soil microorganisms were the principal destructive agents in the cold test (and in cold, wet soils in the corn belt), emphasis on the seed-soil microorganism relationship was a natural consequence.

Isely of Iowa State made one of the first attempts to rigorously define vigor in our country, and his definition reflected the considerations discussed above: vigor is, "the sum of all seed attributes which favor stand establishment under unfavorable conditions." Bill Caldwell (now of Northrup-King) and I pointed out in 1960 that Isely's definition and concept of vigor were valid and applicable, but were restrictive in the sense that they were limited to emergence or stand establishment under unfavorable conditions. Thus, logical assumptions deriving from the definition were that (1) vigor has an influence only on stand establishment, and (2) vigor was not important when field planting conditions were favorable. We then slightly revised Isely's definition of vigor as follows: "vigor is the sum of all seed attributes which favor rapid and uniform stand establishment in the field." This revised definition was also limiting, as we pointed out at the time, since it did not take into account vigor effects beyond stand establishment.

In more recent years, a variety of other definitions and concepts of seed vigor have been proposed: "Vigor is that condition of active
good health and natural robustness in seed, which, upon planting, permits germination to proceed rapidly and to completion under a wide variety of environmental conditions." (Woodstock, USDA). "Seed vigor is a physiological property determined by the genotype and modified by the environment, which governs the ability of a seed to produce a seedling rapidly in soil and the extent to which the seed tolerates a range of environmental factors. The influence of seed vigor may persist through the life of the plant and affect yield," (Perry, Scottish Horticultural Research Institute). Vigor, "is most fittingly described 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 up a 'good' seed are present in the right proportions, promising a satisfactory performance over a maximum range of environmental conditions," (Heydecker, University of Nottingham).

"The concept of vigor can first be considered as a 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," (Pollock and Roos, USDA).

All of these concepts and definitions of seed vigor adequately define certain aspects of this elusive attribute of quality with some being much more limited in scope than others. Heydecker's concept of vigor comes closer to "capturing" it than the others quoted because it's not limited by arbitrary boundaries such as "stand establishment" or "unfavorable field conditions," etc. Let us look more closely at Heydecker's concept. Essentially, it defines vigor as a "potential" of seed related to performance, which varies from a maximum or unimpaired state to some unstated lower potential, and which at a maximum insures a "satisfactory" performance under a variety of conditions. Presumably, the term "performance" as used by Heydecker encompasses the whole array of developmental benchmarks in crop production: emergence, juvenile plant growth, onset of flowering, maturation, quantity and quality of yield, etc. Overall, the least satisfactory term in Heydecker's concept and definition is "satisfactory." One might speculate at length about what is a "satisfactory performance." As a teacher, I rate and grade a satisfactory performance as "C," a very satisfactory performance rates "B," while a superior performance rates "A." Few farmers are satisfied with a "C" grade crop. They desire and strive for "A" performance.

Ultimately, a satisfactory concept and definition of seed vigor must take into account and be fabricated out of the rapidly accumulating information on the influence of planting seed on the emergence, growth, development and productivity of plants, exclusive of genetic or varietal factors.

The "Poop" Index - An Interlude

The biggest problem with seed vigor, of course, is that it has proven to be most difficult to define in either scientifically rigorous terms or in practical, everyday, working terms. The various defini-
tions of vigor cited above were illustrative of the differing concepts among researchers and workers in the field. Lack of some common base for communication has probably impeded progress in seed vigor testing and research more than any other factor.

Until now I have strongly resisted the temptation to introduce "poop" into this discussion of seed vigor. The "poop" I am referring to is an illegitimate, but otherwise acceptable and descriptive word meaning to wear out or to become exhausted. Its illegitimacy arises from the fact that it cannot be traced to any Latin or Greek root. Indeed, its origin is unknown.

Sometimes a lot of seed germinates well in the air-conditioned comfort of the germinator but is just too worn out to fight the battle of the seed bed. Some folk might say that such seed are low in vigor, while others could say with equal veracity that the seed are high in poop, i.e., they are pretty much exhausted. As used in the sense above in reference to seed, it is obvious that poop and vigor are exactly opposite attributes of seed quality; as vigor decreases, poop increases; or poop is minimal when vigor is at a maximum. "Poop" has another connotation that makes it especially descriptive of that elusive and deceptive property of seed which causes them (the seed) to act well in the lab but poorly in the field. "Poop" can also mean information. More specifically, it means straight information, the unvarnished truth, as in, "Level with me, I want the straight poop." Poop, therefore, turns out to be one of those versatile words that pretty well covers the situation. After all, what we really want in the case of seed is some straight inside information on their suitability for planting.

Thus, a "double poop" as related to seed tells us what we want to know. "Double poop," however, is an inelegant phrase, and I prefer to combine the two "poops" into a single expression: the "poop index." The poop index of seed can be defined as "the straight, unvarnished truth regarding the state of exhaustion of seed, or how worn out they are, hence, their suitability for planting."

While one cannot deny that the poop index has relevancy to the subject under discussion, it is, nonetheless, only an intermediate stage in the thrust toward a universally acceptable concept and definition of seed vigor-poop.

These are no idle words, because attainment of some higher stage of truth regarding seed vigor-poop is inevitable. It is inevitable because careful analysis of the whole problem reveals that some process of Hegelian dialectics is at work. First, there was vigor—an interesting concept but deficient in too many ways for complete acceptance. It was the thesis, the first step on the path to the truth. Out of vigor arose poop, or rather, poop index, the exact opposite of vigor or the antithesis, but a step closer to the real thing. Interaction of vigor, the thesis, and poop index, the antithesis, must inevitably
generate a higher stage of truth, or *synthesis*, according to Hegelian principle. This, however, will take time. Meanwhile, the phrase "performance potential" appears to be a pretty good synonym for both vigor and poop index, as Don Grabe of Oregon State has been contending all along.

It was with some reluctance that I decided to discard the "poop index" so soon after it was introduced. Before it is consigned to the round file, however, the effects of "poop index" (or vigor as one prefers) on stand establishment, growth, development, and productivity of plants needs to be considered.

Poop and Consequences

Loss of the capacity to germinate is the last significant consequence of seed deterioration. A non-germinable seed has a performance potential of 0%, regardless of how much tissue might be still alive in the seed. As deterioration proceeds to the final and most disastrous stage, the seed's performance potential is progressively impaired, and, thus, decreases over time from the 100% maximum value to 0%. The decrease in performance potential of a seed or seed lot during deterioration has several consequences of signal importance to farmers and seedsmen.

Stand Failures and Inadequate Stands

Stand failures or inadequate stands can result from any one or a combination of factors: poor seed bed preparation, low temperature, excessive or insufficient moisture, soil microorganisms and other pests, chemical injury, and low quality seed. Although low quality seed is listed last, it is certainly not the least important factor. Rather, low quality of planting seed is probably the major factor in a majority of stand failures, or near failures, for they are very susceptible to adverse conditions and stresses in the seed bed environment and will usually produce a good stand only under very favorable conditions.

A seed lot may germinate well in the laboratory but be so badly deteriorated that it fails to produce a stand in the field where conditions are seldom as favorable. A stand failure is, perhaps, the most obvious of the lesser consequences of seed deterioration or loss in vigor and it is costly to the farmer. His cost of production is directly increased by the expenses involved in replacement of the seed, the replanting operation, and any other operations that might be necessary. Additionally, there are other losses connected with stand failures and replanting which are not so easily determined. In many cases, the planting time frame for maximum productivity is rather short. A stand failure, therefore, might delay replanting to the extent that it falls later than the most favorable time. The need to replant part or all of a farmer's acreage also upsets the timely scheduling of subsequent operations. These direct and indirect effects of a stand failure interact in such ways as to increase both the cost of production and the chances of reduced yields.
A farmer might "keep" an inadequate, skippy stand because the season is too advanced for replanting, replacement seed are not available, or other reasons. Regardless of the reason for keeping an inadequate stand, the results are the same: weed control is less effective, maturity is often non-uniform, harvest losses are greater, and total yield can be substantially reduced.

Growth, Development and Productivity

A good stand is an important benchmark in crop production, but all problems arising from use of low quality seed do not end with stand establishment. Until fairly recently, it was generally assumed that the influence of seed vigor on performance did not extend beyond emergence.

Now, however, it seems quite clear that the vigor of seed can and does influence the growth, development, and productivity of the plants produced.

During the past ten years, we have been comparing the growth, development, and productivity of crops produced from seed differing in physiological quality or vigor. In our comparisons sufficient seed of the various seed vigor levels were planted to insure adequate stands. After emergence, the stands were hand thinned to the same number of plants per area for all vigor levels, thus eliminating any influence of differences in population density on results. Thus far, these studies have involved corn, sorghum, cotton, rice, soybeans, and several vegetable crops.

The effects of seed vigor on performance of the field crops mentioned above are remarkably similar. Low vigor seed emerge more slowly and develop into initially slow growing seedlings and plants which have thinner stems and less leaf area as compared to those from vigorous seed. The plants from low vigor seed appear to "catch-up" to those from vigorous seed at about the time of flowering. However, flowering of plants from low vigor seed is delayed by 4-8 days, fewer flowers are produced, and these set fewer pods, ears, bolls, etc.

After pollination and fertilization, rate of grain or seed development does not appear to be influenced by vigor level of the planting seed. Nevertheless, maturation of grain or seed on plants from low vigor seed is delayed by a period of time equivalent to the delay in flowering. Moisture loss from seed or grain on low seed vigor plants lags 6 - 8% behind that on plants from vigorous seed during the late maturation, field drying period.

Plots planted with low vigor seed yield 5 - 15% less than those planted with vigorous seed even though the number of plants per unit area is the same. This yield loss is the summation of reduced levels of the various components of yield. In corn, for example, lower vigor seed produce a higher % of barren plants, slightly fewer ears per
plant, and slightly smaller ears with slightly reduced shelling percentages as compared to vigorous seed. These "slight" reductions add up to a 10 - 15% loss in yield.

The influence of seed vigor on plant performance is most dramatically manifested in vegetable crops, especially those produced for their fleshy roots such as radish and turnips. Root development in plants from low vigor seed is slow and many of the roots do not reach marketable size by the time the crop is "normally" harvested. In other vegetable crops, low vigor seed contributes substantially to non-uniformity of maturity as well as to lower yields.

Crop production is limited by the vigor of the seed planted just as it is by the quantity and distribution of precipitation, rate and timing of fertilization, effectiveness of weed control, variety planted, and so on. This constraint on productivity will be eliminated or at least minimized only when farmers begin to demand higher quality seed and seedsmen can consistently supply it.

A Bird In Hand

Thus far, we have examined the inadequacies of the germination test as a measure of the plant producing potential of seed, paraded out seed vigor in its Joseph's coat of concepts and definitions, advanced the poop index, then quickly withdrew it, and reviewed consequences of seed deterioration or loss in vigor that are of more than just academic interest. I must readily admit, however, that there is scant substance in these discussions which can or will contribute significantly to a scientifically rigorous and elegant definition or "theory" of seed vigor. But such was not my purpose. Rather, my aim was to define a problem area within the seed quality sphere which causes economic losses in crop production and concerning which something more than continuing rhetoric ought to be expected.

This long - probably overlong - discussion of vigor was introduced by describing a meeting with a group of concerned farmers toward the end of which several asked about more informative "tests" for seed quality and where could they get such tests made. Their approach to the vigor problem was practical and direct: find some way to identify it and then avoid low vigor seed like the plague.

The matter of tests for assessing the vigor of seed is not new. It is at least as old as my graduate student days at Iowa State, which are relegated to ancient history by my children, for I can recall - albeit faintly - that vigor tests were a favorite subject of debate around midnight, after the more immediate concerns of current studies had been put aside for the day.

The debate on vigor tests continues as is evident from the abstract of a paper presented at the American Society of Agronomy meeting in mid-November, 1973, which concludes, "a rapid, reliable
test for seedling vigor remains an elusive goal." And, so it does. But in the interim, shouldn't some of the slower, less reliable tests available for use now be put to use? A couple of quails in hand are surely worth a fat pheasant in the brush!

At the time I quit counting several years ago, more than 15 different tests for vigor had been proposed, advocated, and backed by substantial experimental data. Any one of several of these tests could, in combination with the germination test, provide much more meaningful information regarding the plant producing potential of seed than is presently available. Yet, few of them are routinely used except by the quality control departments of the larger seed companies. Only a few laboratories - most of them commercial - offer vigor test services to seed companies and farmers, except for the cold test for corn seed and the low temperature test for cotton seed.

The apparent failure of any of the vigor tests - other than the cold test - to "catch on" can probably be attributed to several factors. First, the Seed Testing Associations, which have the dominant voice and influence in seed quality evaluation matters are extremely conservative. Real innovations such as the tetrazolium test, enter the inner sanctum of the "Rules" very, very slowly if at all. Conservatism is, of course, very necessary in the Rules for Testing Seed because intemperate acceptance of all new tests proposed would quickly lead to chaos in seed labeling and inspection. The "official" sector of the Rules, however, could remain conservative - while at the same time permitting some scope for "tentative" and/or "supplemental" tests. Incorporation of procedures for a few of the most promising vigor tests in the Rules for Seed Testing in the fashion suggested would do more for advancement of the concept of vigor and vigor testing than all the papers and talks on the subject during the past 10 years - including the present.

The second factor contributing to the relative failure of vigor tests to "catch on" is one not often discussed because it involves some very human traits of researchers who develop and advocate vigor tests. It is quite natural for a researcher to pause only long enough to shoot holes in concepts proposed and advocated by another researcher as he proceeds with his own developmental work. This natural reaction serves the cause of science admirably because it more or less guarantees advancement, but in the case of seed vigor research, it leaves the seedsmen and seed analyst holding (and eventually discarding) some bedraggled, very porous tests, which they may have just begun to try out.

Seed researchers could contribute materially to the "cause of vigor testing by "agreeing" on two or three of the more informative tests already developed, strongly advocating their use, while continuing efforts to develop still better, more rigorous and reliable assay techniques. Even agreeing to seek some agreement would be a giant first step.
In these connections, I am poorly echoing some of the sentiments expressed by Walter Heydecker (Univ. of Nottingham, U.K.) in his preposterous but elegant, rational, and sensitive blank verse plea for some consensus now among seed vigor workers. The few quotes below from Heydecker's "Vigour/Anti-Vigour" reveal both the clarity of his insights into the vigor "problem" and his concern, lest the babble of vigor voices keep us too long from the practical tasks that must be accomplished.

"Friends! Foes!
I sing you vigour
Vanity of vanities . . . .

"Vigour is complex enough
To keep arguments going for centuries.
Trying to define it
Is a futile
Intellectual party game . . . .

"But we should realize (in deciding on vigor tests)
That all we are doing
Is to select an index,
Or a series of indices
Or a tower of Babel of indices
That indicates some of the components of vigour.
Unfortunately
We can get nowhere without simplifying
But if we do not see
That we are simplifying
We shall get nowhere at all
Very fast."

On The Shore Dimly Seen

Germination is defined in the Rules for Testing Seed as, "the emergence and development from the seed embryo of those essential structures, which for the kind of seed in question are indicative of the ability to produce a normal plant under favorable conditions." Despite the lack of precision of the terms "normal plant" and "favorable conditions," which were discussed in a previous column, this is a good, practical, workable, definition for the seed analyst, seed technologist, agronomist, horticulturist, forester, and farmer. The fact that it might be quite unsatisfactory for the purposes of the morphologist, physiologist, and biochemist, neither causes concern nor creates an issue. And, this is as it should be for the scale of observation and special concerns of the various disciplines interested in "germination" are different.

The practical, working definition of germination quoted above and the more detailed criteria for "normal seedlings," which are also
specified in the Rules for Testing Seed, are somewhat arbitrary. Since they are somewhat arbitrary, application of the definition and criteria do vary from one person to the next. Although such variability is often vexing to both the analyst and the seedsman, it does not appreciably diminish their value or usefulness in germination testing.

Other basic definitions routinely used in seed testing, such as the definition of "pure seed," are as limited as the definition of germination, and usually much more arbitrary. They are also practical, workable, and have contributed most significantly to the advancements in seed quality evaluation.

It is not my purpose here to rehash the basic working definitions of seed testing, but rather to establish a background for these questions: Why has it seemingly been so necessary to seek a degree of absolutism, universality, and precision in a definition of seed vigor (or deterioration) that is far beyond any of the practical, workable definitions currently used in seed testing? Should we not be seeking instead one or more practical, workable definitions that are relevant within the context of present seed testing concepts and procedures, even though it (or they) might be limited and arbitrary?

In early years, I defined seed vigor as "the sum of all seed attributes which favor rapid and uniform stand establishment in the field." Later, I referred to vigor as "physiological stamina of seed." These may be acceptable "concepts" of vigor, but as working definitions, they are just so many words. Without exception, the other definitions quoted previously, although they might be more acceptable alternative concepts, are equally poor working definitions. In a sense, therefore, the debate on vigor has been more concerned with clarity of insight and elegance of expression than with the nitty-gritty of vigor testing or evaluation. This is unfortunate because as one seedsman pointed out to me recently, there's not "more'n a gnat's eye" of difference in all the definitions of vigor.

Before attempting to formulate a definition of seed vigor, it is important to establish certain criteria for the definition that will ensure its practicality, workability, and relevancy to other established definitions of seed analysis. Criteria which come to mind include: (1) the definition should be applicable on an individual seed basis; (2) it should be related to some specific response-reaction of seed which is measurable by routine test procedures; (3) application of the definition should produce data that can be expressed as converted to a percentage by number of response-reactions per sample of seed; (4) the definition should be precise enough to minimize variability in its application from analyst to analyst; and (5) it should relate to emergence, growth, and development of plants under field conditions.
Considering these criteria as well as the several other considerations discussed, a "working" definition might be formulated as follows:

Seed Vigor - In seed testing practice, vigor is defined as the emergence and development of a normal seedling under prescribed conditions which, for the kind of seed in question, are indicative of superior ability to produce a healthy, productive plant under a wide range of field conditions,

and

Vigorous Seedlings - Normal seedlings which emerge under prescribed vigor test conditions.

These two very tentative definitions contain many imprecise and ambiguous terms and are quite arbitrary, but not more so in these respects than the present definitions of germination and normal seedling. The key qualification in the seed vigor definition "development and emergence of a normal seedling under prescribed conditions . . . ," may even seem ridiculously imprecise, but it isn't. The term "under prescribed conditions" is also implicit in the definition of germination but is simply not stated. Rather, conditions under which the definition of germination is applied are prescribed in the test methods for each kind of seed. Other terms in the definition such as "normal seedling" are already defined.

The tentative working definition of vigor advanced above would restrict vigor evaluation to those tests which Dr. R. P. Moore has termed "growth tests," viz, rate of germination, cold tests, accelerated aging tests, seedling growth rate, etc. Broadening the definition to encompass the non-growth tests, such as the tetrazolium test, is not, however, very difficult.

Seed Vigor - In seed testing, vigor is defined as the actual emergence of a normal seedling, or specific evidence of a capability for such emergence, under prescribed conditions, which, for the kind of seed in question is indicative of the superior ability to produce a productive plant under a wide variety of field conditions.

Under this definition, it would be possible to establish criteria for interpretation of a tetrazolium test which would estimate results of some specific vigor growth test, the cold test for example, just as the TZ test is now used to estimate germination. Other non-germinative tests could be fitted into the scheme in the same manner.

Nothing I have discussed in this section, or in previous sections for that matter, is original or very imaginative. Most of the matters of substance have been advanced much more lucidly by others. I only attempted to bring these matters together and to examine them in the hope that some avenue could be identified which might lead us off the dead center on which the matter of vigor had settled.
I am convinced that one wide open avenue off dead center leads directly back to the working concepts and definitions of seed analysis. Vigor can be defined as the response (emergence) of a seed under prescribed conditions in the same manner as germination is defined. Indeed, it is already so defined in all the quality control and testing laboratories which make cold tests, accelerated aging tests, tetrazolium tests (for vigor), first count tests, and the many other tests for vigor.

Agreement on a workable, working definition of vigor would permit the concentrated effort needed to establish and prescribe those conditions for vigor testing of the different kinds of seed which are most meaningful in modern crop production. Seed testing would advance, agriculture would benefit, and the problem of vigor could become the problem of vigor testing.

Conclusions

In the previous section, I proposed the following working definition of seed vigor:

Seed Vigor - In seed testing, vigor is defined as the actual emergence of a normal seedling, or specific evidence of a capability for such emergence, under prescribed conditions, which for the kind of seed in question is indicative of the superior ability to produce a productive plant under a wide range of field conditions.

This definition was purposely modeled after the accepted definition of "germination" as set forth in the various Rules for Testing Seed. It focuses on specific, repeatable evidence of vigor rather than on processes and properties involved. Furthermore, the definition proposed becomes applicable (and meaningful) only when "prescribed conditions" for obtaining evidence of vigor of each seed kind are established. In these aspects, the similarity of the proposed definition of seed vigor and the accepted definition of germination are also evident.

The greatest difficulty in applying the proposed definition of seed vigor will be in establishing the "prescribed conditions." This, however, does not have to be accomplished for all kinds of seed before vigor testing can be initiated in a routine manner. Initially, vigor test methodology - the "prescribed conditions" - should be established only for those kinds of seed for which a substantial body of base data on vigor and vigor tests are available, e.g., corn, cotton, sorghum, soybeans, etc. As adequate base data become available for other seed kinds, conditions for vigor testing of them can be added to the prescribed procedures.

It might be good "psychology" in the beginning to limit the definition and concern of seed vigor testing to emergence and stand
establishment. A relative abundance of data are available on the influence of seed vigor on emergence and stand establishment, and more people might be willing to accept vigor testing on this limited basis. As vigor testing progresses and becomes more standardized, and as additional information on the influence of seed vigor on productivity of plants is obtained, the definition can be broadened to encompass assessment of performance potential of seed beyond the stand establishment stage.

Even in the case of those kinds of seed for which an abundance of vigor data are available, viz., corn, cotton, soybean, and sorghum seed, additional work will be necessary before decisions can be reached on specific vigor test conditions and methodology. The pertinent committees of the Seed Testing Associations are best suited to undertake this additional work. They are organized for just such purposes and are experienced in evaluating proposed definitions and methodology from the standpoint of their applicability to routine seed testing operations.

Evaluation of the effectiveness of vigor tests already developed for the various seed kinds and selection of the best from among them would require careful review of available data to identify the most promising vigor tests, re-definition of procedures into seed testing methodology as necessary, and development of suitable criteria for evaluation and "referee testing." Such criteria should include: (1) correlation of vigor test results with emergence and stand establishment under a wide range of field conditions; (2) potential of test methods for standardization; (3) uniformity or repeatability of test results within and among testing laboratories; and (4) suitability of unit of measurement for describing seed quality, i.e., vigor test results should be expressed in terms that are readily understood by seed analysts, seedsmen, and farmers.

The methodology and uses of vigor tests are not difficult to envision – we have only to look around. Many kinds of tests for seed vigor are in use in the quality control programs of seed companies. An increasing number of commercial and official seed testing laboratories also offer vigor testing services to seed companies and farmers. It is time for these efforts and services to be "recognized," standardized, publicized more widely, and extended to all seedsmen and farmers who want and need the additional information they provide.

The information obtained from vigor tests could be expressed in any one of several meaningful ways. As an example, assume that the low temperature germination test (65 F constant) is prescribed as a vigor test for cotton seed. Test results could be expressed as a percentage in the same manner as germination and complementary to germination: Germination - 85%, vigor - 76%. This would mean that 76% of the seed were vigorous enough to complete germination under the prescribed vigor test conditions, i.e., 65 F. Alternatively, vigor test results could be expressed in well defined qualitative terms: vigor -
high (defined, say, as 80% or higher germination in low temperature test); vigor - medium (65 to 79% low temperature germination); vigor - low (less than 65%). I emphasize that these are examples of how vigor test results might be expressed and not recommendations.

I tend to favor use of qualitative terms in reporting vigor test results for several reasons: (1) properly defined terms such as high, medium, and low (or equivalent numbers such as vigor rating 1, 2, 3, etc.) provide the information needed by seedsmen and farmers; and (2) qualitative terminology takes into account the inherent problems in rigorously quantifying biological properties such as vigor, or germination for that matter.

Before bringing this long discussion of the "problem of vigor" to a close, I want to make one final, but most important, point. Seed vigor should not become a labeling requirement. Rather, it should be considered as permissive labeling information subject to verification by test. Seedsmen could then label or not label for vigor at their discretion. In my view, the most beneficial use of vigor tests is in the in-house quality control programs of seed companies.