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SEED TECHNOLOGY LABORATORY

MISSISSIPPI STATE MISSISSIPPI

Sponsored By The Mississippi Seedmen's Association

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TWENTY-SECOND SHORT COURSE FOR SEEDSMEN

APRIL 9-11, 1973

SEED TECHNOLOGY LABORATORY

MISSISSIPPI STATE UNIVERSITY

MISSISSIPPI STATE, MISSISSIPPI 39762

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THE PROBLEM OF VIGOR[1]

James C. Delouche[2]

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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[1]Reprinted from articles published in the *Seedsmen's Digest* - Nos. 6, 7, 8, 9, 10, 11, and 12, 1973, and No. 1, 1974.

[2]Dr. Delouche is Agronomist, In Charge, Seed Technology Laboratory, Mississippi State University.

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 ever 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 irrevocably 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 definitions 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, conditons 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.

PRINCIPLES AND PRACTICES OF SEED DRYING

Ray Philpott[1]

The title of this year's Short Course is "End of an Era." This means, of course, the era covering the Seed Technology Lab in the "Twin Towers." My talk today also comes at the end of an era, the era of drying seed by heat only. While it may be the end of one era, it is the beginning of another that hopefully will be much better.

As you all are aware, artificial drying of seed is a requirement in many cases and highly advisable or desirable in others. In drying seed, we are reducing moisture content as a percent of the dry weight of the seed.

Moisture is retained in the fibrous structure of the seed in a condensed or liquid state. It may be between fibers or within the pore structure of the fibers. In either case, it must be evaporated so that it can flow out of the fiber structure. In order to vaporize water, heat must be supplied in addition to that amount which simply raises it to the boiling temperature. At atmospheric pressure, water boils at 212 degrees F, but 1040 BTU (British Thermal Units) of heat are required to vaporize one pound from the liquid state. Water held or condensed within seed takes somewhat more heat to "boil off" or vaporize. The exact amount of heat required is determined by the seed structure, or type of seed, and initial moisture content. In all cases, it takes at least 1040 BTU to vaporize one pound of water, with an additional amount of heat needed to overcome the molecular forces that hold water within the seed.

Functions of Air and Heat in Drying

The air in a heated air dryer has two functions: to supply the minimum 1040 BTU of heat for evaporating the moisture; and to serve as a vehicle for transporting the moisture away from the seed and into the atmosphere. Even in natural air drying, this 1040 BTU per pound of moisture evaporated is supplied by the air with the aid of solar radiation. By picking up moisture from the seed, the air is cooled in dry bulb temperature down near the dew point and is exhausted from the drying bin a few degrees cooler than the entering air temperature.

For each kind of seed there is an equilibrium between moisture content and the relative humidity of the surrounding air (Table 1). For instance, shelled yellow dent corn at 12% moisture is in equilib-

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TABLE # 1

ADSORBED MOISTURE IN EQUILIBRIUM WITH AIR OF VARIOUS HUMIDITIES AT ROOM TEMPERATURE (APPROXIMATELY 77F)

	Moisture content (wet basis), in percent							Authority
Relative humidity (percent)	15	30	45	60	75	90	100	
Barley	6.0	8.4	10.0	12.1	14.4	19.5	26.8	C&F
Buckwheat	6.7	9.1	10.8	12.7	15.0	19.1	24.5	C&F
Corn, shelled, YD	6.4	8.4	10.5	12.9	14.8	19.1	23.8	C&F
Corn, shelled, WD	6.6	8.4	10.4	12.9	14.7	18.9	24.6	C&F
Corn, shelled, Pop	6.8	8.5	9.8	12.2	13.6	18.3	23.0	C&F
Flaxseed	4.4	5.6	6.3	7.9	10.0	15.2	21.4	C&F
Oats	5.7	8.0	9.6	11.8	13.8	18.5	24.1	C&F
Rice, rough	5.6	7.9	9.8	11.8	14.0	17.6	-	K&A
Rice, undermilled	5.9	8.6	10.7	12.8	14.6	18.4	-	K&A
Rice, polished	6.6	9.2	11.3	13.4	15.6	18.8	-	K&A
Rye	7.0	8.7	10.5	12.2	14.8	20.6	26.7	C&F
Sorghum	6.4	8.6	10.5	12.0	15.2	18.8	21.9	C,R&F
Soybeans	-	6.2	7.4	9.7	13.2	-	-	R&G
Wheat, white	6.7	8.6	9.9	11.8	15.0	19.7	26.3	C&F
Wheat, Durum	6.6	8.5	10.0	11.5	14.1	19.3	26.6	C&F
Wheat, soft red winter	6.3	8.6	10.6	11.9	14.6	19.7	25.6	C&F
Wheat, hard red winter	6.4	8.5	10.5	12.5	14.6	20.1	25.3	C&F
Wheat, hard red spring	6.8	8.5	10.1	11.8	14.8	19.7	25.0	C&F

(C&F) Coleman & Fellows. Hygroscopic moisture in cereal grains. Cereal Chem., vol.II, pp.275-287, Sept. 1925. (Moisture content determined by water-oven method.)

(C,R&F) Coleman, Rothgeb & Fellows. Respiration of sorghum grains. USDA Tech. Bul. 100, Nov.,1928. (Moisture determined by vacuum-oven method.)

(R&G) Ramstad & Geddes. The respiration and storage behavior of soybeans. Univ. Minn. Tech. Bul. 156, June, 1942. (Moisture determined by vacuum-oven method.)

(K&A) Karen & Adams. Hygroscopic equilibrium of rice and rice fractions. Cereal Chem., vol. XXVI, pp. 1-12, Jan., 1949. (Moisture determined by forced-draft air-oven method.)

rium with about 55% relative humidity. By the use of such information, proper conditions can be established to dry seed to the desired end point moisture content.

As heat is added from any source, the vapor pressure of moisture in seed rises to a point where it is higher than the vapor pressure of water vapor in the atmosphere. When this point is reached, an out-flow of moisture vapor takes place from the seed to the atmosphere or airstream. Seed moisture content is reduced, while the air moisture content is increased. This type of net moisture exchange takes place as long as there is a difference in vapor pressure of moisture in the seed and the air. If the air is too wet, as on some warm fall days, little or no drying takes place. All of you who have seed dryers have experienced this. The low temperatures at which we have to dry make the drying air humidity very close to the equilibrium point of seed. In fact, we have instances in field drying where there is an actual "re-wetting" of the seed under high humidity conditions.

Just as seeds attain a certain moisture percentage at a given temperature and relative humidity, they also attain a certain moisture content at a fixed temperature and pressure. Unlike the case in seeds, moisture in the air is already in the vapor state, so we simply increase the total amount as more moisture is added. The total amount of water by weight is what controls the moisture vapor pressure of air so that dry air has less moisture vapor pressure than "wetter" air.

We noted previously that the moisture vapor pressure in seed is increased by heating the seed. In contrast, however, the moisture vapor pressure of air cannot be increased by heating unless the air is in a confined space. If such were not the case, heating of air in a heat dryer would defeat the purpose by raising air vapor pressure at the very time when we want it reduced so that moisture vapor will flow from seed to air. Rather, we can only reduce the air moisture vapor pressure by removing some of the vapor, or we can increase the vapor pressure by adding moisture to it.

From these considerations, we see that the usual drying cycle is established by raising seed moisture vapor pressure above the air moisture vapor pressure. Heating air does not so much make it more able to dry, but rather, provides heat to the seed so that its moisture vapor pressure is increased above that of the drying air.

We use the term "relative humidity" very often in the seed industry. In fact, the usual equilibrium curves for seed express seed moisture content as a function of both temperature and relative humidity. Although it is a measure of the ability of air to dry wet products, relative humidity is not the total picture by any means. For example, air at 40 degrees F and 100% relative humidity has an actual weight of 37 grains of moisture in each pound of dry air. Air at 70 degrees F and 50% relative humidity, on the other hand, has an actual weight of 55 grains of moisture per pound of dry air. While the lower relative humidity would appear to be better for drying, we see that it actually has more moisture per pound of air than the other. It would not, therefore, be as efficient in drying when heated to, say, 100 degrees F, as the higher relative humidity air since the latter is really at a lower vapor pressure. The more moisture in the air, the higher will be its vapor pressure. The opposite, of course, is just as true, so that we must dehumidify air or remove moisture vapor if we wish to lower its vapor pressure.

Dehumidified Drying Systems

The seed industry has reached temperature limits to which drying air can be heated, although there is some minor disagreement as to actual maximums. We have also learned that excessive air rates can be as damaging as excessive temperature. To reduce drying time or increase yield of "dry" seed per drying cycle, we seemingly have no place to turn. Further, since most specialists agree that lower temperatures would be more desirable for drying if they were not accompanied by an increase in drying time, there seems no avenue open to achieve more economic and desirable drying systems.

We have built single pass, single pass reversing, double pass, and double pass suction systems for batch drying of seeds over the years. There is little that can be changed to increase efficiency unless we take advantage of the fact pointed out above that reducing the moisture vapor pressure of air increases its drying potential. Thus, lowering air vapor pressure is not only a logical approach to increase drying efficiency, it also offers many practical advantages.

With heat dryers, we know that damage to seed viability and vigor is a function of drying air temperature and excessive air flow over the seed. If we now look at this problem in the light of the seed moisture vapor pressure behavior, we can easily see why there is a problem.

When heated air is forced over the seed, heat is exchanged into the seed at the surface. Moisture is also released at the surface. As moisture leaves the surface, two actions result. There is an out-flow of moisture from the seed center to the surface, and there is local shrink where the surface has dried. As "shrink" comes on the seed, moisture flow is reduced and seed temperature builds up from contact with the continuous heated air stream. Vapor pressure then builds up in the seed until flow is once more established, but seed temperature rise has taken place. Stress resulting from non-uniform shrink and high vapor pressure can damage cell structure. Loss in viability and vigor is certain to follow if temperature limits are not carefully imposed.

On the other hand, if the seed temperature is not raised by the air in contact with it, then seed moisture vapor pressure would never be higher than that established by pre-harvest field conditions.

Yet, surface moisture loss would still occur, and out-flow from the seed interior to the surface would follow. The seed would actually cool as it dried because of the fact that heat of vaporization was not being supplied to it. As a result, seed moisture vapor pressure would fall. Drying rate would naturally be slower, but shrink on the surface would not take place since moisture would flow out from the seed interior at a rate sufficient to keep the surface wet.

The foregoing describes a perfect non-stress, "natural air" drying cycle - perfect for everything but rate of drying. The rate would be slow. However, if we replace the lost drying potential by *lowering air vapor pressure,* then we have all of the safety features of the cool cycle above, and good drying rates as well.

Through dehumidification of air, we can lower its vapor pressure to a desired level. We may elect to apply some heat to the air during drying or run as a cool cycle. During drying, moisture exchange takes place at the seed surface as before, but without the heat input, the shrink is limited. Out-flow of moisture is maintained, and high drying rates result. As the moisture flows out, the seed cools by evaporative cooling effects, further lowering seed vapor pressure.

Because of low air moisture vapor pressure, moisture leaves the seed surface without high temperatures, keeping the seed cooler than if a heated air cycle of the same drying potential were used. Thus, for any drying potential, the seed is always cooler, and "warm" air may safely be used if desired.

We have dried seeds experimentally with air at such high drying potentials that seed actually froze by the evaporative cooling effect. By proper heat addition, it is possible to achieve high drying rates and at moderate temperatures, and decrease drying time 25 to 50%. As drying time decreases, fuel savings per bushel are obtained, and higher quality seed is the result.

Results have shown that seeds dried in as little as four hours show little loss in viability and vigor. While four hours may not be an economical and desirable goal at this point in time, surely the industry will look at a 25 to 50% reduction in drying time with interest. Lack of particle stress assures seed quality, though we freely admit we do not at this point know how short we can run drying cycles and maintain seed quality standards. We have not run the experimental data for seed short drying times, although we have run samples in as little as 30 minutes at very high drying potentials. At least we know that the cycle is effective.

We are sure that time and additional work will lead us to faster cycles. We also feel that a closed cycle will shortly be demanded, especially in the face of fuel costs and shortages. A closed continuous or batch drying cycle has the promise of field-to-bag drying times in a matter of a few hours rather than a few days.

Dehumidification is not a new concept. Industrial products have been dried by such techniques for several decades. Seed has been stored for many years under controlled conditions by use of dehumidification. Commercial dehumidifiers, however, were simply too expensive until recently for agricultural drying applications. For several reasons, however, we began to install dehumidification units in existing dryers and have designed such installations for entire new plants. Aside from mechanical problems in the machine systems newly adapted to the short drying cycle, performance results were astounding. Drying time savings of 25% resulted in actual savings of over 50% in some cases. All of the approaches have been conservative to date, but we feel that even higher savings may be safely expected this season. With a higher seed quality at lower process cost, benefits are available to nearly any class or size of seed producer.

Conventional Drying Systems

I would now like to discuss some of the practices and methods presently being used in the drying of seed. One thing to understand is that the following does not take into consideration the incorporation of a dehumidifier in the system. This means that all of these systems could be enhanced 25 to 50% by adding a dehumidifier.

In discussing drying, I will discuss hybrid seed corn drying, as this is the area that we are the most experienced in, but these same principles can be applied to other kinds of seed and grain drying.

For the most part, seed corn is dryed on the ear. However, a few growers are picker-shelling their seed from the field and then drying. This is usually done in areas that have the time to field dry the seed to 20% moisture or below.

The design of hybrid seed corn plants is not an exact science from an engineering point of view. Certainly there are many known facts and formulas to be applied, but there remains a considerable quantity of practical design information that is constantly changing. Dryer design can be said to be more of an art than a science. In over 30 years of working with the seed industry, we have been in the fortunate position to grow up with and observe the evolutionary changes. As a result, drying plants and equipment design today are very different from the early plants and very much better. Some of you remember the drying equipment used 25 or 30 years ago when gas, as a fuel, was not often available, and practically every drying plant used fuel oil. The burners were very crude and hard to adjust, the temperature was regulated manually by turning the fire a little higher or a little lower, there were practically no safety controls except a high temperature limit, and the burners were manually lighted with a torch. Today, most dryers burn gas with electric ignition, automatic temperature, and safety controls that may go to the other extreme of being a little too complicated, causing nuisance shut downs. But this is better by far than no safety controls at all.

The fans have evolved from the original squirrel cage blowers that considerably overloaded the motors under some conditions of low static pressure and lacked the capacity to build up the static pressures that we use today, to the excellent types available today.

Bin construction has certainly improved to permanent type, fireproof, air tight construction with self cleaning bottoms and more or less self leveling and filling. The materials handling equipment for filling and emptying the bins works almost to perfection. I know of a couple of plants with a capacity of about 10,000 bushels per 24 hours in which two women handled the filling and emptying of the drying bins.

There continues to be a wide variation in the moisture content of the corn put into the drying bins; some as high as 40% early in the season, down to 25% or lower toward the finish.

There is also a wide variation in the number of bins that are filled at any one time. This is influenced by the weather and the ability of management to make the best use of drying bins available. It is quite customary that as soon as the decision is made to pick seed corn, all of the bins in the building are soon filled with very high moisture corn. And, the equipment has to be capable of drying it before mold and bacteria can grow and cause damage. This requires high capacity equipment and the design has to be a compromise which provides for operating efficiency during normal operation of the drying plant. On the other side of the operation, we have seen instances during the drying season when the bins become completely empty due to inclement weather which prevents picking of the seed corn.

The resistance to air flow in a bin of corn varies considerably with the type of corn. The high percentage of single cross hybrid seed corn being produced today packs into the bin rather tightly, making it necessary to provide for a higher static pressure than was the case a few years ago. Furthermore, the single crosses are usually picked at high moisture content to prevent field losses because of high value of single cross seed, and this adds to the drying problem.

The tendency, therefore, in drying plant design is to go to large motors and higher static pressures to produce the air volumes desired. There are also lesser variables, such as the fact that some hybrids have larger cobs that hold moisture, and several others that must be considered.

A seed drying plant can be designed with any number of bins, depending upon the number of different varieties to be handled, the ease of filling and emptying, etc., but it should have enough bins so that an orderly rotation of the bins can be accomplished. Drying plants are usually designed so that each bin will dry in about 72 hours. Using the data shown in Table 2, a chart should be prepared indicating how deep to put the seed corn in the bins for the various

TABLE # 2

Approximate amount of water in ear corn, when harvested at different percentages of moisture content of the kernels

Kernel moisture content (percent)	Amount of water in a bushel of ear corn		
	In kernels (pounds)	In cobs (pounds)	Total (pounds)
35	25.5	12.4	37.9
30	20.3	9.9	30.2
28	18.4	8.8	27.2
26	16.6	7.8	24.4
24	14.9	6.7	21.6
22	13.3	5.5	18.8
20	11.8	4.4	16.2
18	10.4	3.2	13.6
16	9.0	2.1	11.1
14	7.7	1.4	9.1
12	6.5	0.9	7.4
10	5.3	0.5	5.8

*A bushel of ear corn is defined here as the quantity that will yield 56 pounds of shelled corn at 15.5 percent moisture.

original moisture contents, so that there will be about the same amount of moisture to evaporate from that bin, whether it goes in originally at 35% or higher, or later in the season at 25% or lower. The manager of the drying operation can expect that the bin will dry in 72 hours and rotate the use of them accordingly. The 72-hour drying time for a bin is accepted by the industry as it is well within the time seed corn must be dried to prevent mold and bacterial action which causes damage to the germination. This drying time also works out to be the most economical for use of the drying bin and drying equipment. The addition of a dehumidifier would, of course, speed up drying time considerably.

The efficiency of the drying plant design always has to be compromise, taking into consideration the original investment in the drying bin building itself and the relation of air handling and heating equipment to the operational costs for fuel and power. It is a pretty complex problem to arrive at the best solution in view of the wide range of different building costs, power and fuel costs, etc.

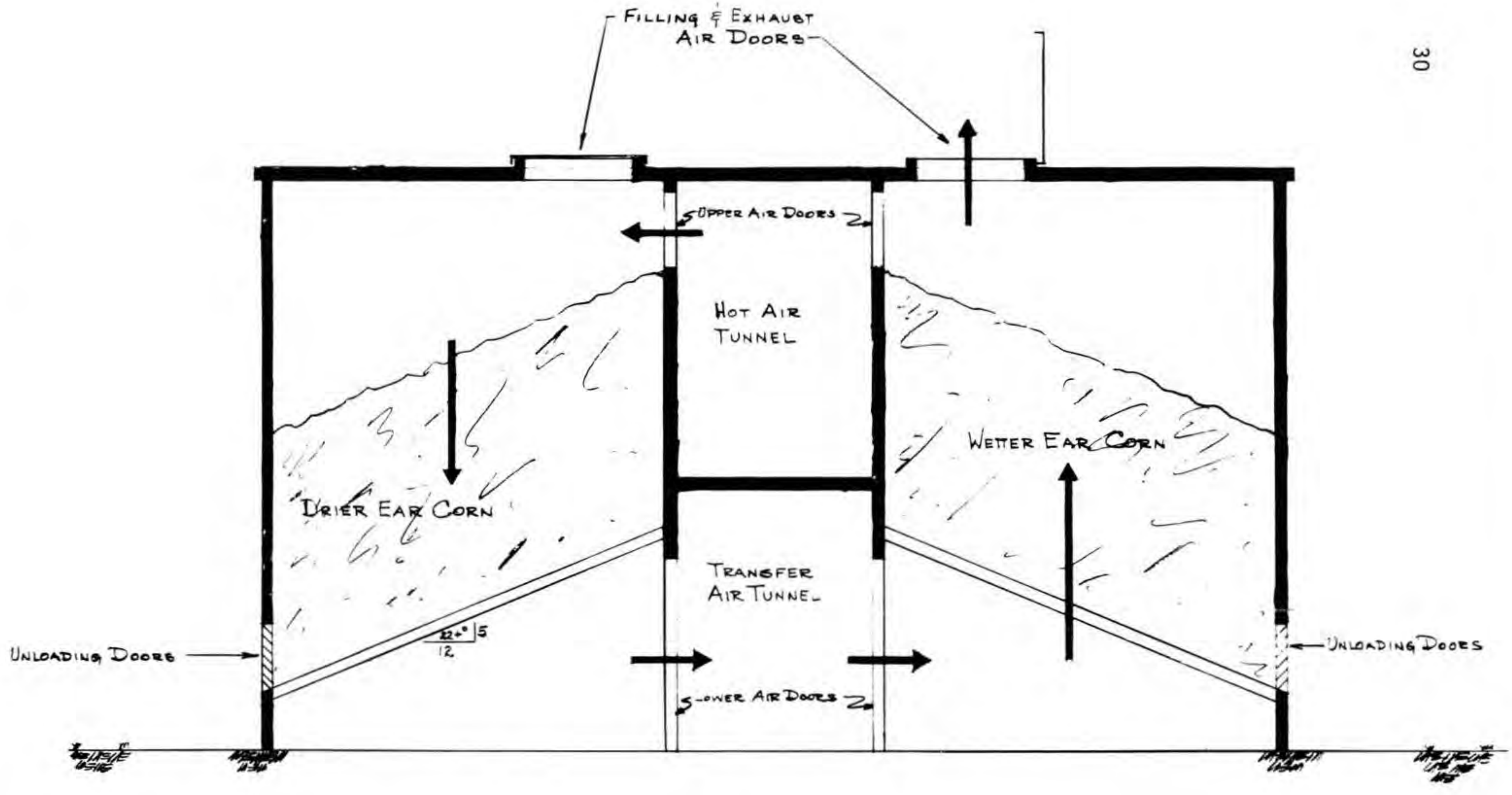
Seed corn is being dried in crib type structures, round steel bins with perforated floors, multiple round bins, concrete stave silo types, or drying bin structures of frame construction, pole construction, prefabricated steel, masonary construction, poured concrete structures, and tilt up concrete structures.

The cheaper structures might not be economical because of higher depreciation rates, higher fire insurance rates, and less operating efficiency. However, less capital investment is sometimes a necessity, and any of the above types of construction can be used in the design of an effective seed drying plant. The best type of construction and design of your plant should be worked out with your consulting engineer and contractor.

There are two basic designs of drying plants: continuous flow dryers and batch dryers. Seed drying has not, in general, worked out well for continuous flow dryers due to the necessity of keeping individual varieties or batches separate. At one time, it seemed the sorghum seed industry could use the continuous flow dryer to good advantage, but the trend is now to batch type dryers very similar to that of hybrid seed corn drying plants. The drying bins are built with the same type of sloping or flat floors, filling and emptying conveyors and heated air drying equipment.

There are several methods of batch drying: double pass or two pass; single pass reversing; single pass; and suction systems.

<u>Double or Two Pass Drying System</u> (Figure 1): The double pass system is one in which the high temperature drying air is first directed through the bins containing the drier seed. The drying air picks up only a small amount of moisture it is capable of holding and loses only a small portion of its heat. It is then transferred and exhausted



DOUBLE OR TWO PASS SYSTEM

FIGURE 1

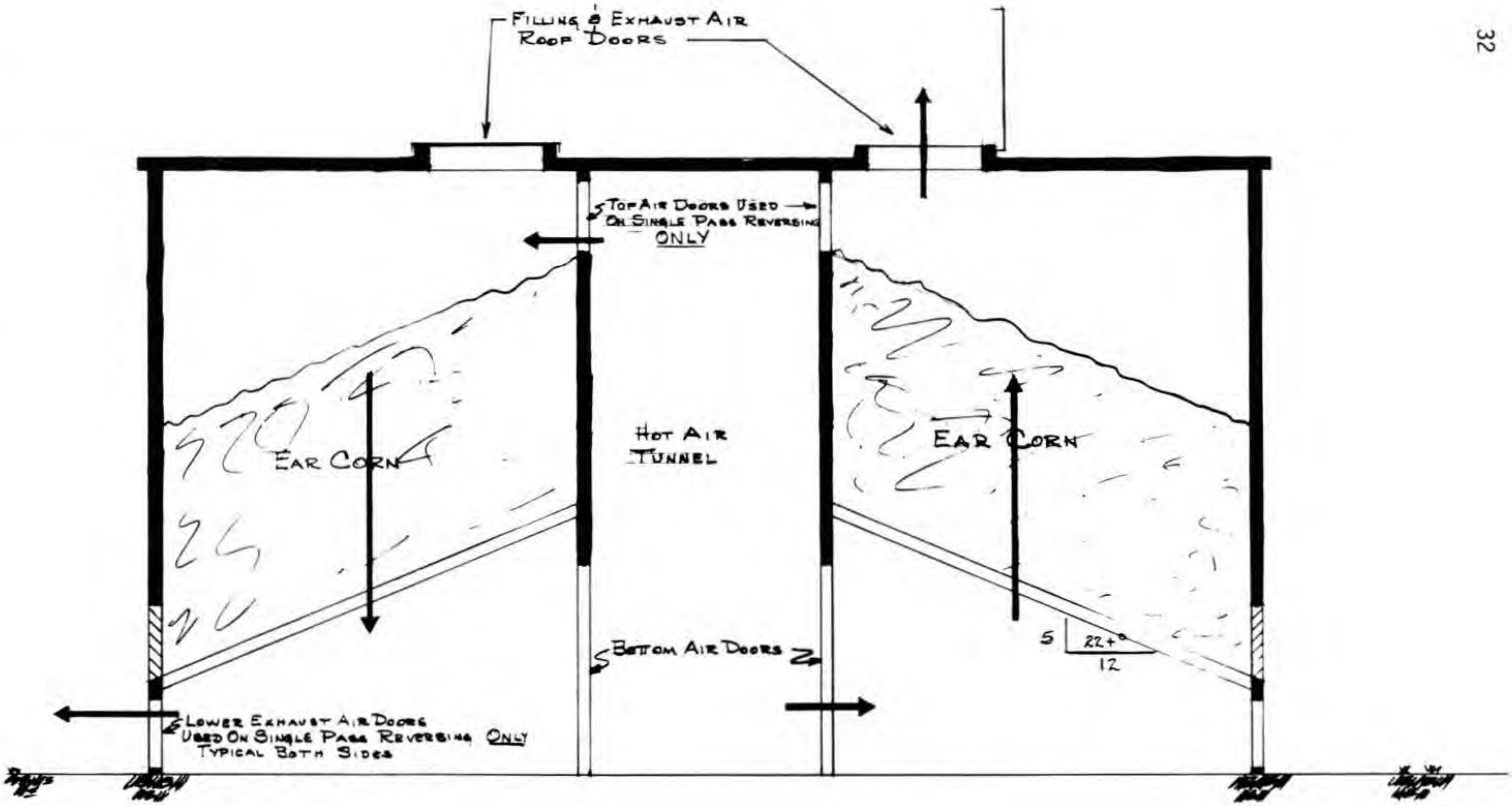
through bins with higher moisture seed which need to be warmed up and has "surface" moisture that is readily evaporated. This makes for a somewhat complicated drying procedure, but it is worthwhile, as it is said to add about 25% to the drying capacity of a given sized drying plant and reduces the fuel costs considerably, although it does add to the power costs.

The two pass design also has an advantage in that there is some added protection to the germination of the seed. Seed are most susceptible to damage from high drying air temperatures when the moisture content is high, and less susceptible to this damage when the moisture content is low. Therefore, only the nearly dried seed are subjected to a possible 100 degrees F drying air temperature, while high moisture seed are exposed to drying air at 80 to 90 degrees F or less.

Single Pass Reversing Drying System (Figure 2): Another common design of seed drying plants is a single pass arrangement with the capability of reversing the air direction through the various bins occasionally to obtain uniform drying. In the single pass system, you can realize that when the bin is filled, the drying air first comes through the bin and is exhausted, nearly saturated, but toward the end of the drying cycle the air is being exhausted before it has picked up very much moisture and given up much of its heat. Thus, considerable drying potential is wasted. This method of drying has only about 80% of the efficiency and capacity of the two pass system.

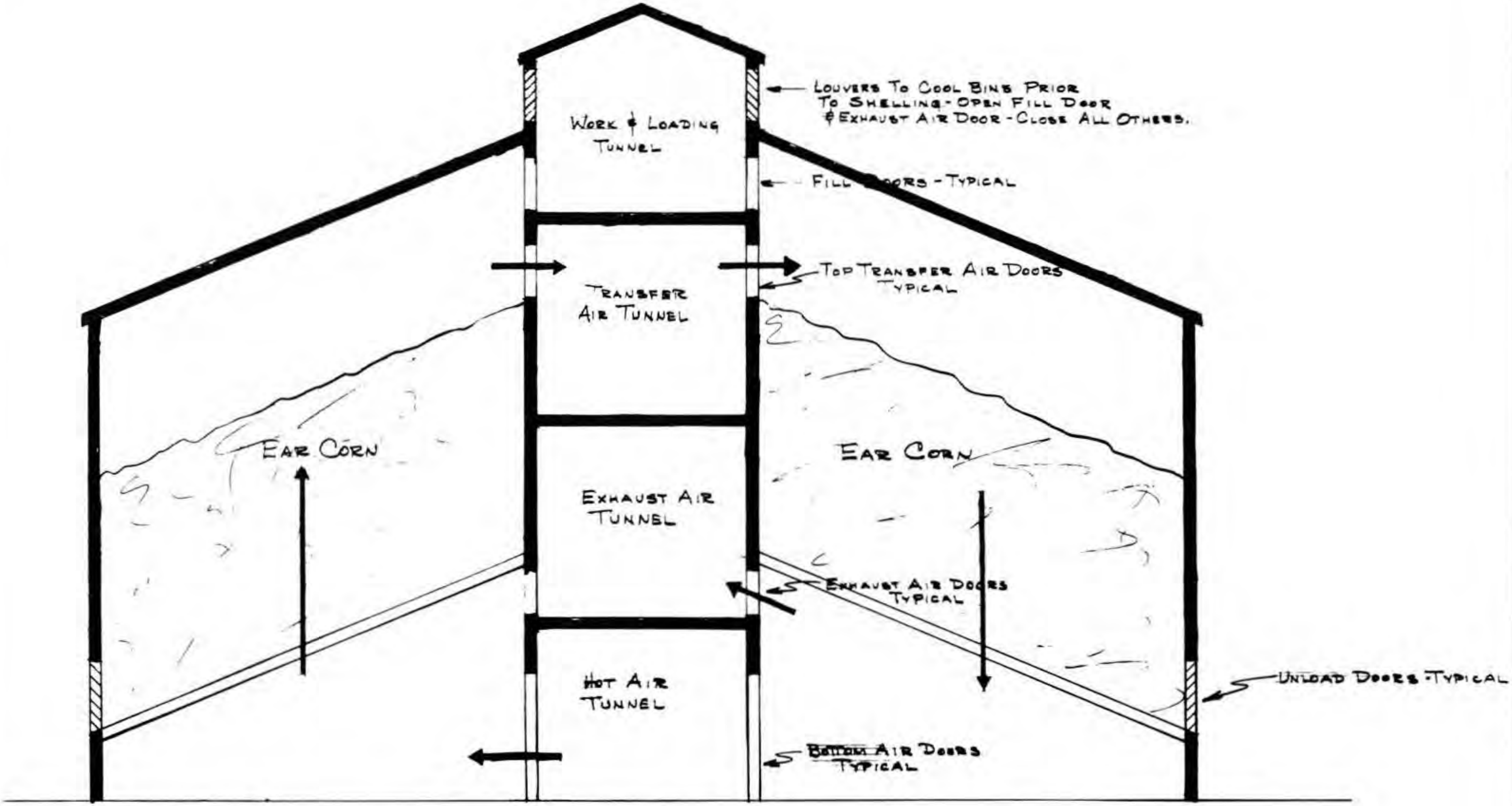
Single Pass Drying System: A third type of drying plant design is a single pass system with no provision for reversing air direction. The result is that the seed are probably several percentage points too low where the air enters the bin, usually the bottom of the bin, and several percentage points too high where the air leaves the bin. The operator then depends upon the blending of the seed to equalize the moisture content. There probably is some damage to the rough ears in shelling, and we estimate that such a plant has about 75% of the capacity and efficiency of the two pass system.

Suction System Drying System (Figure 3): A fourth type of drying plant design is the so-called suction system in which the blower is placed at the exhaust side of the drying bins, and the heated air is drawn through these bins. There are certainly economy factors that should be considered in this drying principle, such as the fact that no heated air can be lost. However, this also cuts down on drying time by bringing in some outside temperature air and cooling the 110 degree air down, therefore increasing drying time per bin. This system also allows cooling of bins after drying, just before shelling, for better shelling percentage. This type of drying should also be considered by any prospective buyer of drying equipment but should be as airtight as possible.



SINGLE PASS & SINGLE PASS REVERSING SYSTEMS

FIGURE 2



SUCTION TWO PASS SYSTEM

FIGURE 3

Fuels and Controls

We might discuss briefly the various fuels. Natural gas is, ordinarily, the cheapest and best fuel. LP gas may require vaporizing of the fuel from the tank and is probably the most expensive fuel. Fuel oil is in between, and with the proper fuel oil burning equipment, causes very little difficulty. To get a rough check on the comparative fuel cost, simply figure the cost of a therm, which is 100,000 BTU.

The burner controls that you need for seed drying equipment consist of the following in the order of their importance.

1. An air flow, air pressure switch that will assure that the blower is delivering somewhere near full air volume before the burner can be operated, or if the volume should fail during operation, the burner will automatically shut off. This is the most important safety control on the burner. Even with the gas supply valve wide open and unlighted, there is so much dilution of the gas with the air being handled that it does not form an explosive mixture. Those of you who have drying equipment know that with the blower running, you can open the gas valve and some minutes later ignite the gas burner with a nice smooth ignition without trouble.

2. The burner should be wired in electrically so that it cannot possibly operate unless the blower motor is energized.

3. An operating high temperature limit control set a few degrees higher than the normal operating temperature will shut the burner down when the set limit is exceeded. The burner, in all cases, should shut down and remain off until manually relighted.

4. The automatic temperature regulation should modulate the burner with a good steady size to maintain the drying temperature without the fluctuation and surging that is sometimes observed with what is supposed to be a modulating temperature controller.

5. A flame sensing device that will shut down the burner in case of flame failure. This does not need to be a quick acting, complicated, or expensive electronic control such as is so essential on burners in boilers and in confined combustion spaces. A shut-down of the burner in a matter of 20 or 30 seconds even after the flame has gone out presents no hazard.

6. Any alarm system using multiple 165-degree thermostats to detect overheating from any cause, and especially from external sources of fire. This control should not only shut down the burner, but shut off the blower and sound an alarm. It is intended to detect fires from sources other than the burner. It should shut off the blower to keep from fanning the fire to greater intensity. These alarm thermostats are relatively inexpensive and can be located at many points throughout the drying plant.

AIR POLLUTION CONTROL SYSTEMS

P. E. Sherman[1]

Although air pollution has been a problem in the industrial areas since the dawn of the industrial revolution, only within the past decade have scientists, legislatures, and the public come to recognize it as a serious hazard to health and a costly economic burden which merits national attention.

It is estimated that 150,000,000 tons of pollutants are discharged into the atmosphere in this country every year. This amounts to 3/4 of a ton per every man, woman, and child in America.

Industry accounts for 25% of this amount, with the automobile being the biggest polluter accounting for 60%.

Only 10% of the pollution is in the form of particulate matter, commonly called dust. While 10% may seem small, it is estimated that by 1977, industry will be spending 500 to 700 million dollars each year in control equipment.

Attitudes of industries, the public, and government are changing and will continue to change. I am sure each of you has heard in the past of a large company saying "If we must install air pollution control equipment, we'll move to another city or state." This situation was occurring with a great deal of regularity. The main cause was that some of our larger industrial states, because of extreme public pressure, began enacting stricter regulations requiring the installation of sophisticated air pollution control equipment. There was a great discrepancy between regulations from state to state. In fact, many states attempting to attract industry had no regulations.

This became a very unhealthy situation, and the federal government became involved. Congress passed the Clean Air Act of 1970. In brief, this law defined and established ambient air standards. Each state is required to meet or exceed these air standards by 1975. The first step in meeting these standards is for each state agency to monitor and determine the quality of the air within its jurisdiction. Once having determined this, it must submit a plan to the federal government giving an outline of how it plans to bring the air quality within the federal standards. All of you have probably come in contact with local or state environmental control agents. Their task, at present, is to determine major sources of air pollution and eliminate these sources. The main concern of the state agencies is that if they do not do their job as laid out by the federal guidelines, the federal government

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will step in. Most people are trying to avoid this situation.

Even with the enactment of stricter air pollution regulations, the situation remained that you could create all the dust you wanted as long as it did not leave your plant or property. Now, with the new OSHA requirements, the air quality within any plant must also meet a certain standard.

Each of you in the past has had to become knowledgeable about various pieces of process equipment used in your plants. Now you will find it not only important but necessary to become familiar with air pollution codes, dust dynamics, and the limitations of various types of dust collectors. Some terms I will be using and which are commonly used in air pollution control work should be defined.

1. Dust is particulate matter that can become airborne and varies in size from 1 to 100 microns.

2. The micron is a unit of length or diameter equal to 1 over 25-thousandths four-hundreths of an inch. For example, a 25-micron particle is about one-thousandth of an inch in diameter.

The dust concentration in air streams is expressed in terms of grains per cubic foot of air. A grain is a unit of weight with 7,000 grains equalling one pound. In ordinary dust collection systems, you may encounter dust concentrations of 5 to 10 grains per cu. ft. of air. However, some state codes may restrict emissions from dust collectors to less than .1 grain per CFM; thus, more than 98% of the dust must be collected.

Any dust sample is a mixture of particle sizes. Figure 1 is a graph that shows how a hypothetical dust sample can be distributed.

Particle diameter in microns is plotted along the horizontal axis of this graph (Figure 1), and the percent by weight for each fraction of particle sizes is plotted vertically. According to the graph, there is a small percentage of one-micron particles, a small percentage of 100-micron particles, and a very large percentage of 10-micron particles. This dust would be very difficult to collect in an ordinary cyclone, which would be about 80% efficient at the 30-micron level. In fact, most of this dust would go out the top.

The dust concentration in an air stream expressed in grains per cu. ft. of air can be obtained by simply weighing the dust that is in the air stream. The problem comes in collecting a representative sample. Most samples are taken using an Iso-Kinetic Sampler. If you were to insert a sampling tube into a dusty air stream and provide the same velocity of air flowing into the tube that is immediately adjacent, a representative sample of dust should pass into the tube. If this air is then passed through a suitable filter, the dust can be

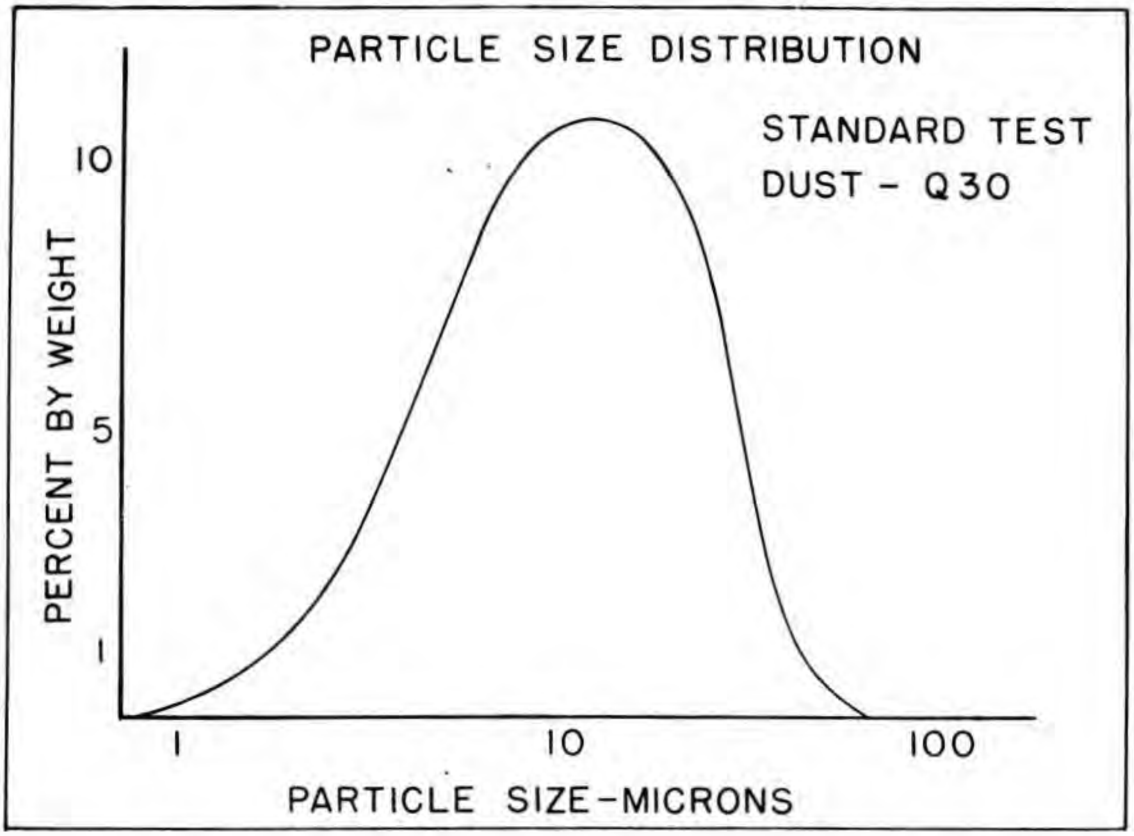

Figure 1. Hypothetical size distribution of particles in dust sample.

EXAMPLES OF ALLOWABLE RATE OF EMISSION
BASED ON PROCESS WEIGHT RATE

PROCESS WEIGHT RATE LBS./HR.	ALLOWABLE EMISSION LBS./HR.
100	0.55
1,000	2.58
5,000	7.58
10,000	12.0
50,000	35.4
100,000	44.6
500,000	63.0
1,000,000	69.0

Figure 2. Typical dust emission allowances.

caught, weighed, and saved for particle size analysis. This is a procedure used by most state agencies and independent testing firms to determine the amount of dust being emitted to the air from a dust control system or collector.

Dust particles are subjected to a variety of forces, such as gravity or centrifugal forces. They react to these forces with certain motions that can be described as "Stokes Law." One form of "Stokes Law" simply states that the settling rate of a small particle is proportional to the product of the square of the particle diameter and its specific gravity. The specific gravity of water is 1, the specific gravity of most dust is between 1 and 3. An example will illustrate what happens to a small particle suspended in an air stream. Consider a 2-micron particle with a specific gravity of 2. It can be shown that the settling rate of this particle will be 3 ft. per hour in still air. If this particle is emitted 3 ft. off the ground in a light wind of 5 miles per hour, it will take 1 hour for it to settle, and the wind will have carried it 5 miles, probably far beyond your property line. This principle is used in the design of dust control systems to obtain a minimum conveying velocity, so that the dust does not settle out in the duct work. We will look at this in more detail later.

Most state regulations specify the maximum allowable dust emissions from a process in terms of a process weight rate. Figure 2 is an example of the table used in most states. Assume you have an unloading facility that handles 50,000 lbs. per hour of grain (the process weight rate). There is a maximum dust emission that can be discharged from your process that is found in the process weight rate table. At 50,000 lbs. per hour, we see that the maximum allowable emission would be 35.4 lbs. per hour; calculating this out would show that you would have to collect 99.93% of the dust to meet the regulation, far beyond the capability of cyclones.

All dust control systems are made of four major components: the hoods, duct work, fan, and collector. We will discuss the collector first because it is the heart of a good dust control system.

<u>Cyclones</u> - Im am certain most of you are familiar with cyclones (Figure 3). They have been used by the grain and feed industry for years. Their design varies from those fabricated by a local sheet metal man to those with a great deal of scientific design.

The graph in Figure 4 shows the collection efficiency (in percentage) of two types of cyclones versus particle size which is plotted on the horizontal axis of the graph from zero to 100 microns. Consider the curve labeled "Ordinary Cyclone." The graph shows that approximately 80% of the 30-micron particles will be captured by the cyclone. If you recall, Figure 1 showed the particle analysis of a typical dust sample, the major portion of which was about 10 microns. It is not hard to understand, then, why many states have arbitrarily said that cyclones will not be approved as collectors in dust control sys-

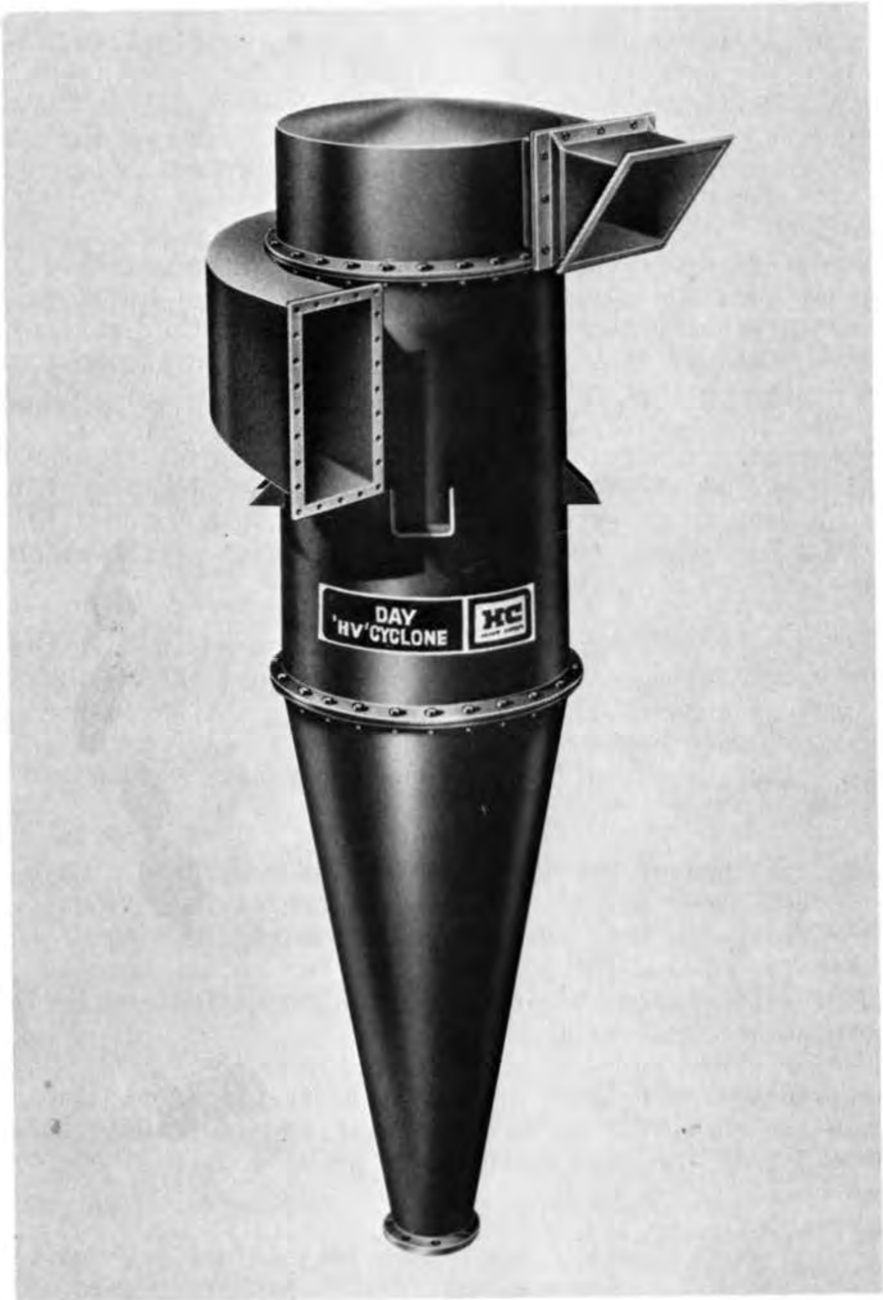

Figure 3. High efficiency cyclone (Day 'HV').

tems. Yet, high efficiency cyclones will do a more effective job than ordinary cyclones in capturing small particles. The curve marked "HV" represents a high efficiency cyclone. In this cyclone, a particle 30 microns in diameter will be collected with 96% efficiency, and a particle 10 microns in diameter will be collected with approximately 85% efficiency.

The reason for this higher efficiency is that the unit is long and slender in order to allow more turns or settling out of small particles. It is smaller in diameter than ordinary cyclones, so the settling forces are very large. This unit is good, but still not good enough to meet the codes when used on very fine dust.

Fabric filters are not in wide use as a replacement for the less efficient cyclones. Most of these filters have a collection efficiency in the range of 99.9+%. They are constructed by suspending a felted or woven cloth in a dusty air stream to filter out dust particles and allow the clean air to pass through.

The problem resides in keeping the media cleaned so that the filter can operate continuously. If cleaning is not accomplished, the cake of collected dust will build up to the point where the resistance to air flow would be so great that it would cease or be drastically reduced. Thus, your hoods would no longer have enough air flow to capture airborne dust.

Years ago, bag houses, as they were called, operated at air to cloth ratios of 1 or 2 CFM per sq. ft. of cloth in the filter. Today, normal air to cloth ratios are 10 or 15 to 1 and improved cleaning of the media is necessary. Thus, the modern filter has become more and more compact; and, in order to maintain continuous operation, better and more frequent cleaning is required.

Shaking, vibrating, reverse jet, and reverse flow collapse are used to remove the bulk of the dust cake from the individual filter tube. Reverse jet is the most common, and we will concentrate on this method.

Fabrics used vary widely depending on temperature, corrosivenss of the air, and the dust. The two most common materials used on grain dust are Dacron and wool felt. The RJ filter shown in Figure 5 consists of a cylindrical body which spins out heavy particles. The filter is divided into two parts by a tube sheet which separates the clean air section from the dust laden air section. Attached to the bottom of the tube sheet are filter media envelopes made from felt or woven material. Cleaned air passes through the openings in the tube sheet, after having first passed through the filter media. The filter media is in the shape of envelopes that are opened at one end and are prevented from collapsing by rigid wire frames mounted inside the bag.

To clean the RJ media, a reverse air manifold is provided that

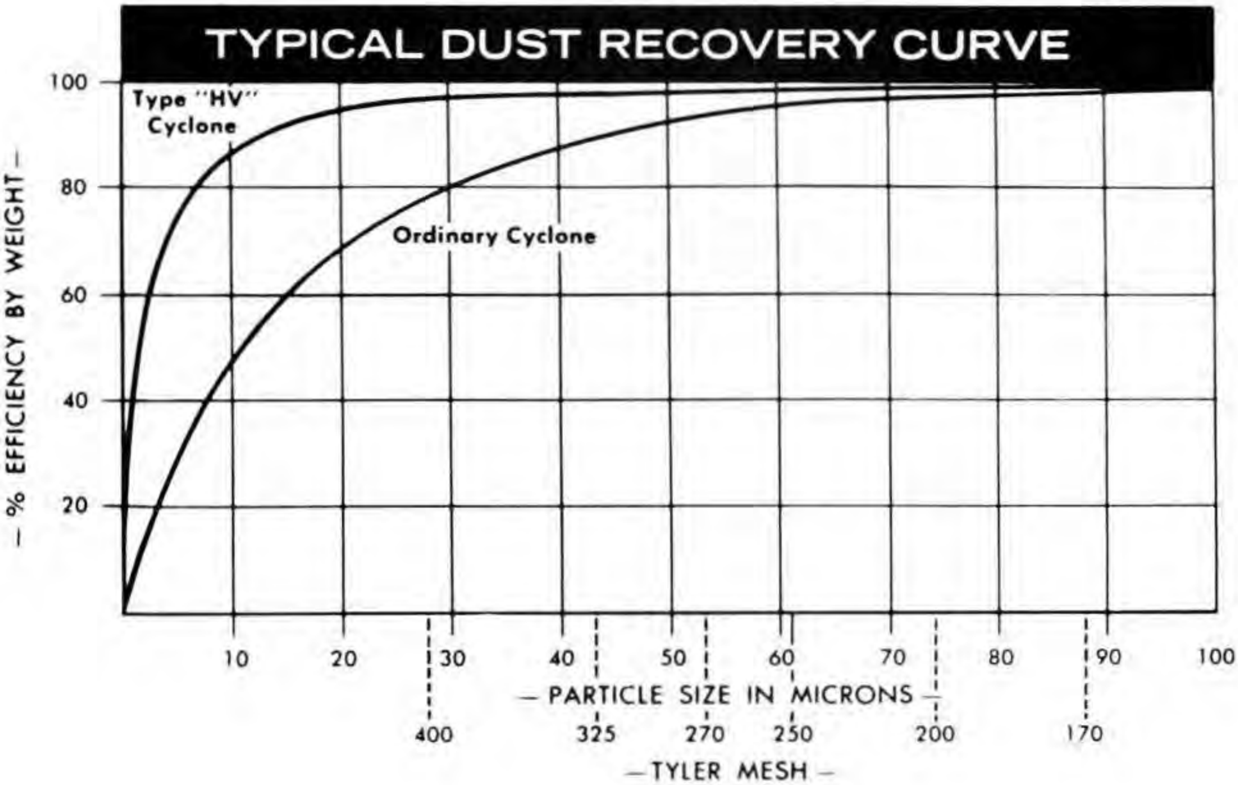

Figure 4. Typical dust recovery curves.

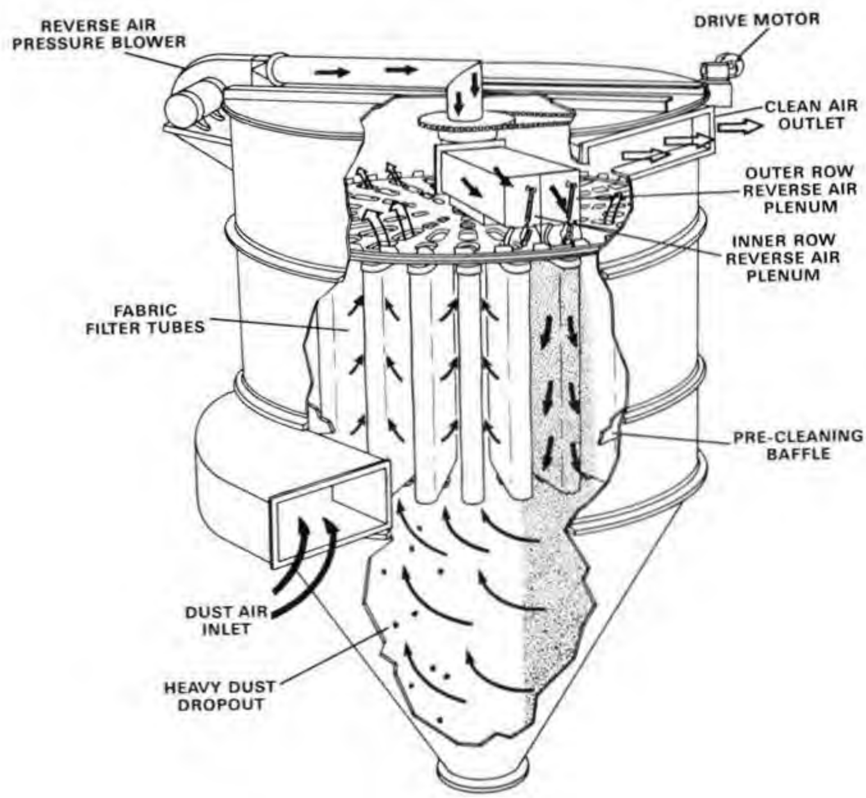

Figure 5. RJ dust filter.

rotates slowly around the top of the tube sheet. This manifold is supplied with air from a blower at a pressure of about 16" water gauge and is equipped with a butterfly valve and trip mechanism, such that cleaning air is confined within the manifold until it comes into alignment with the hold in the tube sheet over the bag to be cleaned. The butterfly valve at that time is opened suddenly to inject high velocity reverse air into the bag. The high velocity air snaps the bag, breaks up the dust cake on the outside of the bag, and the filtered dust particles drop into the hopper.

The Dynamic Module Filter is a rectangular filter made up of 2' wide panels. The media is composed of round tubes 4½" in diameter and up to 8' long, which are mounted on the top tube sheet (Figure 6).

Each 2' x 6' section of the filter encompasses 24 bags which are arranged in rows of 8 each. Protruding into the top of each bag is a small pipe extending from an injector tube that runs across each row. The end of the injector tube is closed in a valve chest on the side of the filter by a quick opening diaphragm valve, similar to a power brake diaphragm which is caused to suddenly open when a small, solenoid valve is activated by a solid state control system. This opens the end of the injector tube to a reservoir of air at about 15 lbs. per square inch. The sudden reverse jet blows off the dust cake that has accumulated on the outside of the bags.

The bags can be cleaned in any frequency that is desired, the duration of the cleaning pulse can be controlled, and you can regulate the amount of reverse air. Another advantage of the filter is that all moving parts are outside of the filter. Also, its modular design allows for construction in virtually any size and the additions of more sections in the future as your air volume requirements change.

Proper hood design and the volume of air to be collected by each hood, has evolved over the years mainly by trial and error. Let's look at a particular example. Suppose we have a room with several people in it. One person is smoking a cigar, and we want to remove the smoke being produced. One approach would be to place a fan in a window pointing outward and provide adequate openings into the room to replace the air removed. This, in essence, is ventilation as opposed to control. Smoke is still in the room but is gradually being removed. Now, suppose we want to control the smoke from only the one person, the cigar smoker. We would supply a separate duct from the fan over to him, put a hood over or around him in such a way that we could control the smoke and draw it into the hood rather than let it escape into the room. We will have then provided spot control and would therefore use less CFM and less horsepower.

Now applying this principle to dust control in your plant, let's take one source of dust, such as a loader beneath a bin which is dumping onto a belt. In this case, when the seed or grain hits the belt, dust is generated and will cloud the immediate area unless a properly

Figure 6. Dynamic Module Dust Filter.

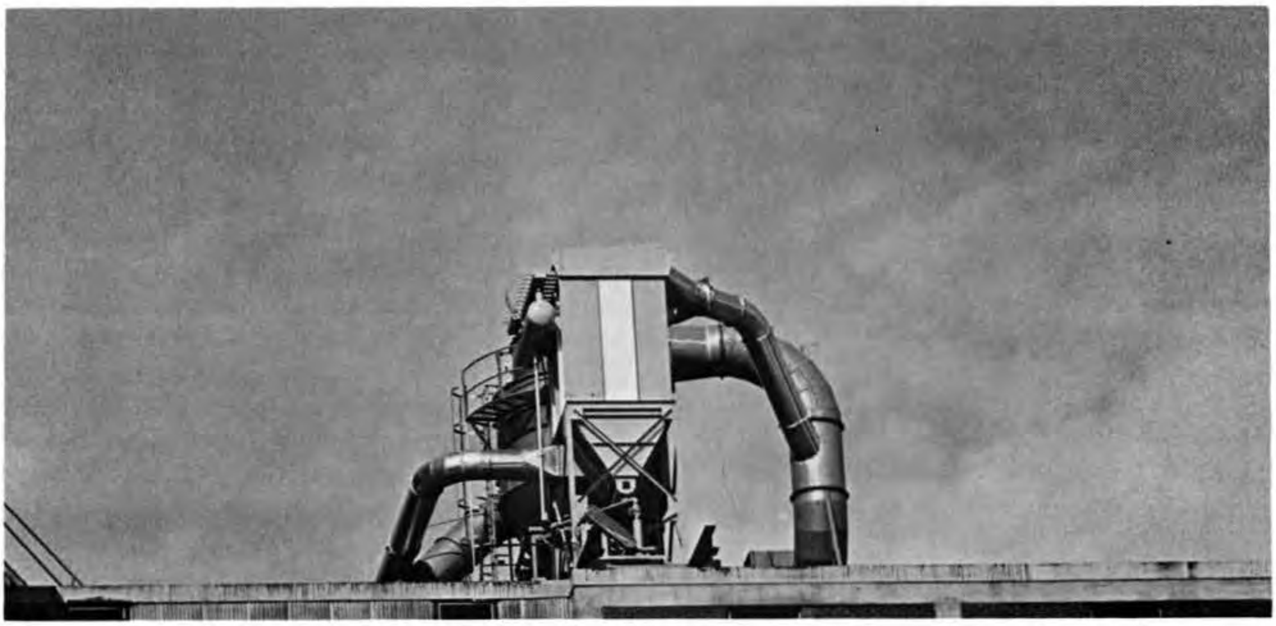

Figure 7. Dynamic Module Dust Filter installation.

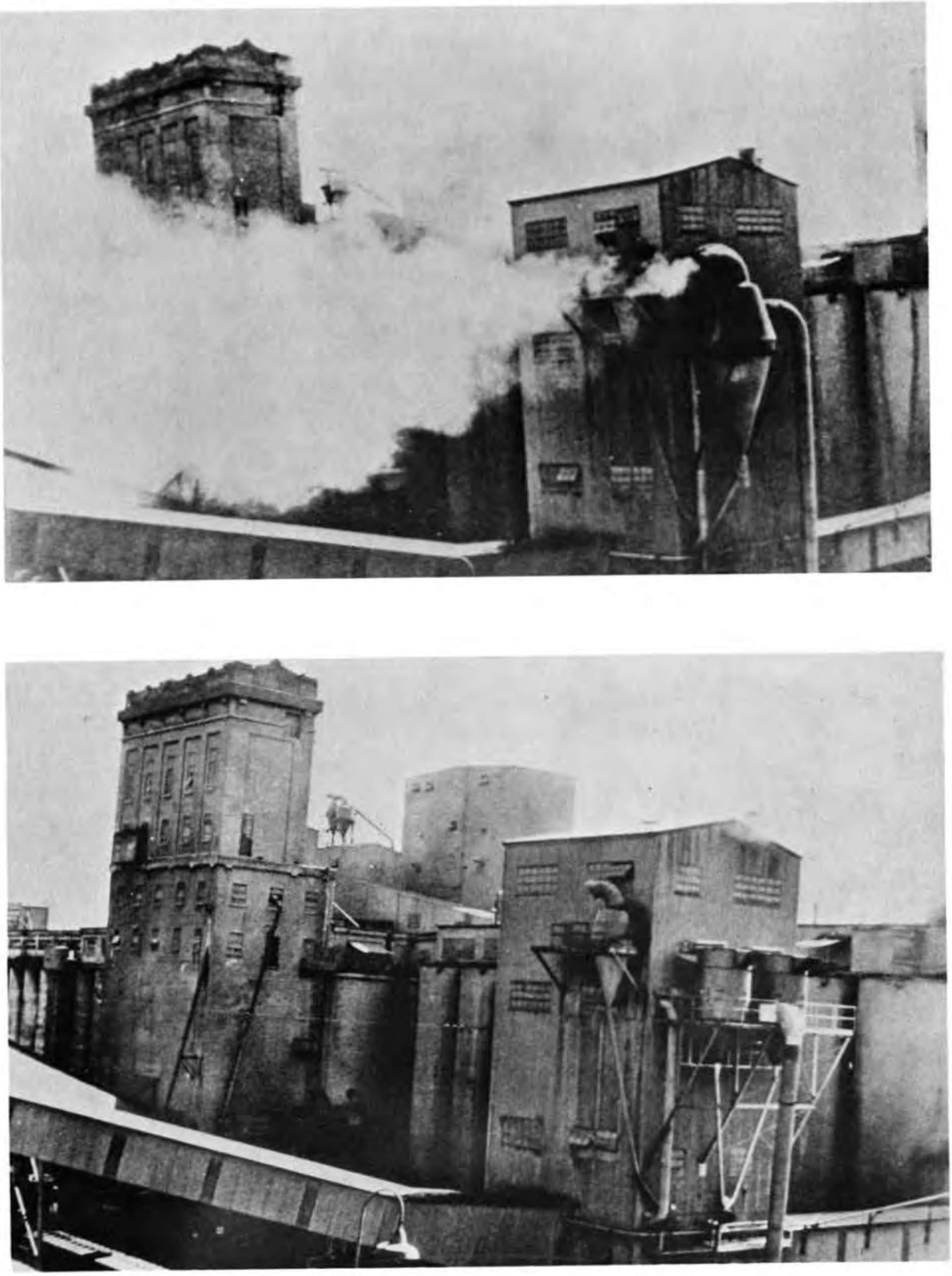

Figure 8. Before (top) and after (bottom) views of an RJ dust filter installation.

Figure 9. Typical RJ dust filter installation.

designed hood with the correct amount of air is applied at this point to capture the dust before it escapes into the atmosphere. The physical size of the hood is determined by a number of factors, including the width and speed of the belt, maximum duct to the grain when the belt is fully loaded, and also the design of the belt loader itself. In some cases, loaders are built so that the grain is released to the belt in a flowing design; in other cases, it is dropped abruptly, which increases the dust load. After determining the physical size of the hood, the next determination is how much air is required, and this is based on past experience, but technically it can be calculated by measuring the open area around the periphery of the hood; that is, the area beneath the hood down to the belt itself, converting this to square feet of open area, then using an air velocity that would be sufficient to overcome any stray air currents in the immediate area, and multiplying these two together which would give us the total air required. Actually, in practice, considerably more air is used than would be arrived at through this formula because, in most cases, there will be more open area after the hood is actually installed than that calculated ahead of time; we provide for this possibility.

This, in essence then, is the basic principle behind designing any hood, such as for belt loaders, belt discharge hoods, or similar unenclosed pieces of equipment. It's based on, first of all, an enclosure that is physically large enough to enclose the area where the dust is being generated and then providing sufficient suction to cause air flow into the hood, or at least prevent the dust from flowing out from underneath the hood.

In sizing hoods or determining the air volume for enclosed areas such as bins or garners, where we are not concerned with stray air currents, the problem is to pull enough air from the enclosure to compensate for the rate at which the bin is being filled, plus a safety factor for any entrained air that comes in with the grain stream.

One last area that each of you probably has in your plant is the truck unloading station. This, in many cases, can be the largest single source of dust you have. Where the dump pit is deep enough, connections are placed on either side to draw air down through the top of the grating. Many older pits are shallow and do not allow for any under-grating duct work. In these case, we have designed a unit as shown in Figures 10, 11, and 12.

The truck enters the pit area, and once it is in position, the motorized hood is swung into place. As the dumping takes place, the dust created is drawn into the hood. When the dumping operation is complete, the hood is swung back to its standby position.

No matter how well a truck pit dust control system is designed, its successful operation is dependent upon the pit area being enclosed and a roll-up door installed at one end to prevent cross winds, as no hood can compete with a 10- or 20-mile-per-hour wind.

Figure 10. Dust hood installation for unloading pit. Hood is in not-in-use position.

Figure 11. Dust hood installation for unloading pit. Hood is swung to in-use position.

Figure 12. Dust hood installation for unloading pit. Hood in use.

Now, after we have sized individual hoods and determined the air volume needed for each dust source, the next problem is to combine these various sources into a single duct, which would run to the dust collector. Here again, we try to study the most economical way to bring the various branch pipes together that would result in the lowest amount of fan horsepower, while at the same time keeping in mind that the duct cannot interfere with the plant operation.

Sizing of the duct work required to connect various hoods together is very simply a case of using a velocity of the air stream in the duct that would be sufficient to keep the dust in suspension. Velocity of 3500 to 4000 ft. per minute has always been acceptable, although in recent years, I believe a little higher is used, perhaps in the 4000 ft. per minute rate. A formula used in all air engineering work is: $Q = VA$. This simply means CFM is equal to velocity times the cross-sectional area in square feet. Let's assume the first hood at the extreme end of our duct requires 1,000 cu. ft. of air. If we want the velocity to be 4,000 ft. per minute in the duct, we divide 1,000 cu. ft. by 4,000 ft. per minute and arrive at a cross-sectional area of the duct of ¼ of a square foot. This area may not be obtainable in a standard pipe size, so we select the diameter to the nearest inch that would give us about this velocity. We then go on to the next hood, add the CFM for the two hoods together, and go through the same formula by dividing the total air volume by approximately 4,000 ft. per minute and again selecting a pipe size to the nearest inch that would give us this velocity.

We proceed in this fashion through the entire system, which could consist, in some cases, of only one hood or it may consist of 30 or 40, and arrive at the final duct size. There is a limitation to the size that we like to use based on the physical size of the duct work that is involved. It becomes very expensive to build and install exceptionally large diameter pipe, so we use discretion in putting a limit on the physical size of any single system. A couple of other factors must also be considered. There is a CFM limitation when using a single filter, and also, it is best to combine hoods that are on equipment that must work together in your plant. It is very wasteful to draw air on equipment that is not in operation.

A few do's and don'ts in duct work are: branch entries should enter into the taper at approximately a 30-degree angle; when two branches are to enter the main duct, they should be a minimum of two pipe diameters apart; duct enlargements and duct contractions should be made by using smooth tapers.

After we have calculated the total air volume of the system, we must then determine the system resistance. The system resistance or losses start at the hood. Here, we normally use 2 to 3" water gauge. This resistance is that which is required to get the air moving to a greater velocity than the surrounding area. Once we have the air inside the duct, then it becomes a matter of using published tables to determine the friction loss of moving air at 4,000 ft. per minute through the duct to the filter. To these two figures, that is, the suction required at the hood plus the friction losses through the duct work, we then add the anticipated loss through the collector to be used. Adding these all up gives the total pressure in inches of water to be developed by the fan. Now knowing the total CFM and static pressure, we then select a fan that fits these two requirements. The fan selection chart put out by a manufacturer will then give us the required speed and brake horsepower.

Over the past few years, I'm sure many of you have entered into discussions as to the disadvantage of having to put equipment in to meet the pollution control regulations. I feel it would be interesting to look at the other side of the coin. Bob Hubbard of Cargill, who for years has been a leader in placing modern pollution control systems in plants, has come up with a list of eight definite advantages. Some of these may relate to your operation:

1. Shrinkage of grain weight is, in large part, due to loss of dust to the atmosphere.

2. Employee moral - not having to work with a respirator or mask.

3. Reduction in plant clean-up labor.

4. Increased life of protective coatings.

5. Reduction in contamination of lubricants; dusts, longer machine life.

6. Reduction in fire insurance premiums.

7. Reduction in personnel accidents.

8. Reduction in insect and rodent population and control expenses.

CONSIDERATIONS IN CLEANING AND PROCESSING SEED

Howard C. Potts[1]

The purpose of this discussion is to bring into focus the specific considerations which should be made before the cleaning and processing operations are begun.

The removal of undesirable materials from a seed lot is an art based on the application of scientific principles. Just as a doctor must know how your body functions when you are well, the processing manager must have a thorough knowledge of good seed. In good seed, emphasis is placed on (1) genetic purity, (2) mechanical purity, and (3) high germination percentage. In seed processing, primary interest is on improving mechanical purity and germination percentage, because these two factors are most often manifested in different physical characteristics of a seed.

What is seed processing? In the broad sense, it encompasses all the steps involved in the preparation of a harvested seed lot for marketing. In common usage, seed processing refers to (1) preconditioning, (2) cleaning, (3) size grading, and (4) upgrading. During this discussion, the common definition of seed processing will be used.

With these facts in mind, it is now logical to state that the purposes for processing seeds are: (1) to remove contaminants, (2) size-grade to improve plantability, (3) upgrade quality, and (4) apply seed treatment materials. To achieve this purpose, the processor simply decreases the percentage inert matter, other crop seed, weed seed, and poor quality seed present in the original lot. Note that these factors which must be affected by processing are the same as those for which seed are examined under the various seed laws, that is, pure seed, inert matter, other crop seed, weed seed, and germination.

The processing of individual lots of seed is divided into three sequential events: (1) pre-cleaning examination, (2) removal of undesirable materials, and (3) upgrading and/or sizing. The first two steps are essential to effective processing of all lots; the third is dependent upon the kind of seed being processed, the nature and kinds of contaminants, the quantity of each contaminant in the raw seed, and the quality standards that must be met.

A basic requisite for effective seed cleaning is the capability of the processor to identify and distinguish the seed to be cleaned from the contaminants that occur in every seed lot. He must also know enough about seed to be able to distinguish between good, healthy seed

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and those of questionable quality, because at some point in the processing operation, he must make a decision concerning which seed he will keep and those that will be removed from the lot. Thus, the processor's ability to render the desired service is affected by: (1) the processing and handling equipment available, (2) their arrangement within the plant, (3) the operator's skill in operating the equipment, and (4) his knowledge of seed characteristics. Notice that the first two of these factors were fixed when the processing plant was built. *Therefore, operational skills and knowledge of seed characteristics are the only variables immediately available to either the processing manager or management to control seed quality.*

The Pre-Cleaning Examination

As previously indicated, the first step in processing each seed lot is the pre-cleaning examination. Before giving any consideration to the equipment to be used in cleaning a lot of seed, a representative sample of the lot should be examined to determine the following factors:

1. Differences in physical characteristics
2. Frequency of occurrence of contaminants
3. Size variation of the good seed
4. Flowability
5. Need for pre-conditioning
6. Damaged seed

There is no significance to the order in which these factors are determined.

The primary purpose of the pre-cleaning examination is to determine the separable components of the seed lot. *Remember: unless there are distinguishable physical differences among the components of the seed lot, no separation is possible.* Thus, it is the components of the seed mixture and not the machine that determines if a particular separation is possible or practical.

Now, let's consider these six factors individually to see how each relates to seed processing. Seed, people, or any solid product, can be separated on the basis of differences of their physical characteristics. There are eight physical characteristics of importance in seed separations. These eight characteristics are: (1) shape, (2) length, (3) size, (4) color, (5) affinity for liquids, (6) electrical charge, (7) surface texture, and (8) specific gravity. Keep in mind that even though physical differences exist and proper equipment is available, it is not what you have but how you use it that determines success in making the desired separation.

Contaminants which have physical characteristics similar to those of good seed are of greatest concern. When examining the seed lot, particular emphasis must be placed on determining the presence of contaminants such as noxious weeds, nematode galls, etc., which could cause the seed to be unusable even though the mechanical purity may exceed 99%. Seeds of noxious weeds, other crops or varieties, common weed seed, damaged seed, and inert matter *similar* in physical characteristics to those of the good seed, are of descending importance in most seed lots.

Contaminating materials obviously much larger, smaller, or lighter than the good seed are not of great importance except when such materials affect seed flowability or when they represent more than about 20% of the seed lot. Seed lots containing a very high percentage of inert matter or removable crop and weed seed normally must be cleaned at a reduced rate of flow to allow removal of these materials and to avoid flooding of the discharge spouts provided for materials removed from the seed mass.

The frequency of occurrence of contaminants refers to the ratio between the desirable seed or characteristics of a lot and the undesirable. When looking at the seed to be cleaned, a thorough examination may reveal an undesirable characteristic, but it usually is the ratio of good to bad that is important, not the fact that a minor, oftentimes correctable defect is noted. This is usually a judgment decision, but we are generally willing to give up or overlook one thing to get something we really want.

Depending upon the quality standards to which the seed must be raised, certain contaminants can be ignored. All clean seed will contain a fractional percentage of inert matter. Many lots of seed contain small amounts of other crop seed or common weed seed because the cost of removing these seed exceeds the value that would be added to the seed after the contaminant is removed.

As an example, if the pre-cleaning examination revealed the presence of one oat seed per handful of wheat seed in a lot of non-certified wheat seed, the occasional oat could be ignored. However, if the wheat seed were to be certified, it would be necessary to remove the oat seed. Thus, the presence of this oat seed would require the use of additional equipment, therefore increasing the cost of processing the certified seed. This same example is equally valid for common weed seed and inert matter, in that the quality standard set by management or, in some cases, by law determines what contaminants must be removed from each seed lot. Ideally, every lot of seed would be 100% pure seed; realistically, 100% purity is not practical, physically or economically.

Variation in size of the good seed is one factor frequently overlooked when examining seed for processing. Research conducted in 1875 showed that the smallest seed in any lot are of little value for reproductive purposes. On the other hand, subsequent research on seed size indicated that the exceptionally large seed, although nice to look at, are not the most desirable for reproductive purposes. Therefore, in seed, what we really want are those large enough to perform their function, but small enough to avoid problems due to size.

For most crops, the better the climatic conditions for seed production, the more uniform the size of the seed. In all species, the more uniform the seed size, the easier the seed are to clean. Effective processors know that different varieties of the same species often differ significantly in average seed size and they adjust the machines accordingly. One of the poorest testimonies to a seed processor is to observe screens marked with the name of a crop. Such marking usually indicates a disregard for the natural variation in seed size and the other variable physical characteristics of a seed lot.

Another factor determined during the pre-cleaning examination is flowability. Flowability refers to the ease and uniformity with which seed will flow in the absence of mechanical force. A large sample of the entire lot must be used to determine flowability, because compaction must be considered in addition to the presence of inert material and natural seed appendages. This sample should be drawn by hand because probes often exclude large pieces of inert materials.

Seed must flow uniformly through the equipment before they can be effectively separated from the contaminants. As a general rule, a lot of seed which has an angle of repose greater than 70 degrees should be pre-cleaned or conditioned before attempting any separation by the air-screen or subsequent processing machines. Anyone who has spent a day or two forcing seed into an elevator or pushing seed through a bin opening will testify for the need of pre-determining the flowability of every seed lot.

Most seed lots which have been harvested and threshed mechanically will flow through a properly designed processing plant. However, an occasional lot of any kind of seed may lack the necessary flow characteristics because of natural appendages on the seed, high quantities of coarse inert matter, high moisture content, or poor threshing. Such lots should be pre-conditioned to improve flowability before attempting to clean the good seed.

A factor related to flowability is the need for pre-conditioning. In seed processing, the term pre-conditioning is used in two different contexts. First, it may refer to any method used to circumvent or remove those obstructions which reduce flowability. If long pieces of plants, such as straw or stems, or large quantities of sand or soil are the cause of poor flowability, these are normally removed with a scalper or aspirator. Drying lots which are high in moisture or which contain green plant materials often will give a lot the desired flow characteristics. Of course, corn must be shelled before processing. There are several techniques which can be used to improve flowability, but the method used will depend upon what you want to remove.

The second meaning applied to pre-conditioning refers to the removal of undesired or unnecessary coverings and appendages from the seed which may interfere with the cleaning process. This type pre-conditioning also serves to improve the appearance of the product. It is customary to hull and/or scarify combine-run seed of many of the small seeded legumes to facilitate cleaning and increase the speed of germination. Awned varieties of oats and barley are normally debearded both to improve flowability and appearance.

The final factor which should be determined during the pre-cleaning examination is damaged seed. There are three main causes of seed damge: (1) insects, (2) disease, and (3) mechanical abuse. Many different things can and do happen to seeds which make them undesirable, or at least reduce their capability to perform as well as undamaged seed.

When insects are active in the seed, the lot should be fumigated before it is cleaned with a fumigant recommended for use on seed. Disease damaged seed are usually lighter in specific weight than healthy seed of the same dimensions. Thus, the presence of more than 2 or 3% damaged seed is an indication to increase the velocity of the final air separation on the air-screen cleaner and the possible need to utilize a specific gravity separator. In most instances, seed lots that require specific processing to remove disease damaged seed should be treated with the appropriate fungicide.

Mechanical damage to seed can be classified into three categories: (1) seed destroying, (2) major, and (3) minor. As the name implies, seed destroying damage is mechanical injury which splits or breaks the seed, such as split beans or cross broken seed, causing such seed to be unfit for planting purposes. Usually, these seed parts can be removed because breaking changes the physical characteristics.

Major damage is damage to the seed coat or covering which is visible to the naked eye, such as cracked or chipped corn seed and machine cut cottonseed. Nothing can be done to remove such seed from the lot unless the damage alters the physical characteristics of the seed. When the undamaged seed have smooth seed coats, the damaged seed can frequently be removed by using a machine which separates on the basis of differences in seed coat texture, *i.e.*, magnetic separator or roll mill. Seed having minor damage, such as pin-holes, are not normally noticed in the pre-cleaning examination. A general rule concerning mechanical damage is that for each seed that is split or broken, there will be three other seed which have suffered major or minor damage.

Techniques for Making Pre-cleaning Examinations

Under optimal conditions, the processing manager will have an opportunity to process a sample of each seed lot, using hand screens and/or model equipment. Organizations equipped to conduct such pre-processing tests are among the most efficient in their cleaning and processing operations. Such testing requires advanced sampling and control over delivery of various seed lots to the processing plant. This type sampling and control is not feasible for processing plants engaged in custom cleaning operations or processing seed coming directly from the field.

An intermediate method of making the pre-processing examination is to conduct a routine purity analysis on a sample of the field run seed. This analysis will provide valuable information on the kind and rate of occurrence of various contaminants. However, such factors as comparative physical differences between the good seed and contaminants, variation in seed size, flowability, and damaged seed must still be determined on the basis of a visual examination.

In spite of the more desirable methods of examination listed above, the pre-cleaning examination is most frequently made by simple visual examination of several handfuls of the field-run seed taken at the time the seed are delivered for processing. To make this examination, the seed are poured slowly from hand to hand or spread into a thin layer on a table or floor, in a well-lighted area, and mental notes made concerning potential separation problems. It should be obvious that this method will result in a higher frequency of lots which are below or above desired quality levels after processing than when more detailed methods are utilized.

Precision of the hand method of examination can be increased if the processor knows the approximate weight of his handful of seed. This can be easily determined if the examiner will weigh several handfuls of seed of the various kinds processed. Greater repeatability can be gained if the operator will close his fingers against the fat part of his hand. For most persons, this will be a sample of one or two ounces.

Regardless of the techniques used for the pre-cleaning examination, it is of vital importance that the processor be thoroughly knowledgeable in seed identification and purity analysis. An experienced operator can closely approximate the percent cleaning loss, mechanical purity of the clean seed, and the probable presence of undesirable seed or characteristics of the processed seed before the seed enter the processing plant by combining his knowledge of seed with that of equipment operation.

The phrase often used by TV star, Flip Wilson, "What you see is what you get," could be considered as a summary to the consideration necessary for seed cleaning and processing. However, our experience both as seed processors and seed control officials, have led us to a slightly different conclusion. Hopefully, you will agree with our conclusion rather than Flip's -- "What an operator considers is what he gets, but those things he doesn't consider will finally get him."

DIAGNOSIS OF SEED QUALITY PROBLEMS WITH TZ TESTS

R. P. Moore[1]

Economically sound decisions, questionable decisions, or wrong decisions--to what extent do you use each in your business? Decisions as how best to bypass factors that downgrade seed quality or to upgrade seed of undesirable quality need to be sound, efficient, and timely. Extra profits are to be realized by sound and timely decisions. Financial adversities accompany unsound and untimely decisions.

Seed producers, seedsmen, managers of foundation seed programs, officials of certification programs, plant breeders, and other individuals or agencies that handle seed must constantly make decisions involving the hidden aspects of seed quality and of the opportunities to improve quality. The need for timely action oftentimes encourages costly, inappropriate decisions. The delay in awaiting growth test results and the inadequate information they provide frequently forces a person to take premature actions in handling the problems associated with the hidden but important aspects of seed quality.

The tetrazolium (TZ) test has been developed and refined as a rapid test to fulfill some of the basic needs for exposing and diagnosing many of the causes for inferior seed quality. The TZ test along with growth test results appear to answer most of the basic questions concerning causes for inferior seed quality. Each test is basically different. Neither test is as well understood as it should be understood. Each of us needs to spend more time trying to develop a more perfect understanding of the test rather than to spend our time trying to point out the imperfections of either test. The extra profits come from an understanding of the merits of a test, the information it reveals, and the use of the desired merits to resolve our seed quality problems.

Time on this occasion permits a discussion of only the TZ test and its use in quality control and for diagnosing causes for questionable or undesirable seed quality. During the past 20 years, I have never evaluated a seed by the TZ method without paying special attention to the possible causes for the disturbances present. Possible causes are often under study for several years before adequate segments of knowledge come together to provide the answer. Several disturbances are rather complex and conditioned by secondary factors. Some of these continue to remain unanswered.

I hear occasional comments that the use of the TZ test for diagnosing causes for embryo disturbance is strictly for experts. This is indeed not true. I have trained several people with a high school education to

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recognize many of the symptoms. It does take training and practice. We gain excellence in most of our activities by training and practice.

The TZ Test

A TZ test on a single sample of seed can provide within 12 to 24 hours the information needed for establishment of the potential germination percentage, soundness of germinable embryos, and evidence for establishment of causes for possible disturbances in quality. Test durations can be shortened to a few hours, or to less than an hour for special needs. Excessive shortening of testing time introduces some loss of accuracy of test results, which may still be acceptable.

The basis of a TZ test is the development of a red stain which permits the analyst to visibly observe the presence and location of sound, weak, and dead tissues. The nature of the patterns of staining permits a diagnosis of causes for the imperfections. Detailed instructions for conducting the test have been published by Grabe (1) and Moore (3, 4, 5).

Seed Preparation

If seeds are not already moist immediately prior to testing, it is usually desirable to moisten with water. The kinds and dryness of seeds determine whether the seeds can be moistened rapidly or slowly. Large-seeded legumes such as soybeans and snapbeans, especially when dry, tend to fracture readily and extensively when subjected to liquid water. The desirable slow absorption of water can be obtained by placement of seeds in a moistened, but not wet, paper towel or similar media.

Staining

Moist seeds of most kinds of small and large seeded legumes can be placed intact into the colorless TZ staining solution. Cutting or removal of seedcoats will hasten the rate of staining. The intact seedcoats of most grass seeds prevent the entrance of the staining solution. The larger grass seeds are usually bisected through the germs to expose the embryonic leaves and roots. Kinds of seeds considered too small for bisecting are usually punctured or cut near the germ.

The time of staining should be adequate to permit the distinction between normal, weak, and dry embryo tissue. The time can vary considerably without adversely influencing the results. Excessive staining time, however, is accompanied by tissue deterioration which prevents acceptable evaluation.

The rate of staining tends to double for each 10 F rise in temperature within a range of approximately 70 to 100 F. The duration of staining must be shortened at a higher temperature so as to avoid excessive deterioration.

The testing solution is prepared by the addition of tetrazolium salt to tap water. Solution strength can vary from approximately 0.1 to 1.0%. The TZ salt costs about 25¢/gram and can be obtained from Nutritional Biochemicals Corp., 26201 Miles Road, Cleveland, Ohio 44128, as well as from several other chemical companies.

Causes of Seed Deterioration

Common causes for seed deterioration vary with the kind of crops, region of production, and methods of harvesting and processing. Common causes include mechanical injury, water damage, aging, heating, freeze injury, diseases, and insects. Accelerated aging tends to accompany and may even conceal some of the other kinds of trouble.

Mechanical Injury

Disturbances resulting from mechanical injury may be external or internal--usually both. The internal injuries, which are usually most prevalent, may be revealed as fractures or bruised tissues, or both. Embryos that are damaged when excessively dry may show normal staining qualities even to the edges of the fractures. When tissues are moist at the time of injury, the areas impacted tend to develop a darker than normal red color immediately after injury. With time, the crushed cells gradually die and are no longer capable of staining.

Water Damage

Mature seeds, especially of large seeded legumes and cotton, are initially and subsequently damaged in many ways by exposure to alternate wetting and drying prior to harvest and during storage. The initial damage in turn promotes accelerated aging and infection. The symptoms are usually associated with various levels of aging within and surrounding the initially damaged areas.

Certain types of water damaged symptoms can be confused with injuries resulting from mechanical fractures or bruises. A trained analyst, however, can usually make correct diagnoses for the majority of seed within a sample.

Water damage of the type being brought into focus on this occasion is especially prevalent in snapbeans, cowpeas, soybeans, lupines, etc. Two general types of symptoms occur. One type involves the obvious fracturing of embryonic tissues, and the other involves deterioration of localized areas of embryonic tissues. Both types of damage may occur within the same embryo.

Fracturing is prevalent in production regions where rapid and extensive drying of mature seeds occurs between the periods of occasional rainfall or other forms of high humidity. The damage results from stresses established within embryo structures by rapid localized absorption of free water. Fractures frequently occur within radicles and at the attachment of cotyledons to the embryonic axis. The nature of the damage varies from different varieties, crops, weather conditions, etc. In snapbeans, the epicotyl or the plumule tend to fracture rather extensively. In soybeans, fracturing tends to be more extensive within the radicle with very little fracturing of the epicotyl and essentially no fracturing of the plumule.

A second type of water damage is caused by alternate wetting and expansion, and drying and shrinkage of seedcoats with exposure of mature or nearly mature seeds to alternate wetting and drying. The nature of the disturbance in large seeded legumes is somewhat as follows. Upon moistening, the seedcoat tends to expand rapidly and irregularly and becomes folded like an accordion. The innermost folds come into contact with localized less moist surfaces of the embryo. The rapid movement of free water from the coat into the adjoining embryonic cells cause various types of disturbances among and within cells. The disturbed cells are first weakened and later die. The phenomena was earlier reported as natural crushing by Moore (7), which, in view of today's knowledge, may need a more appropriate terminology. Additional insights into the nature of this disturbance are likely provided by Iljin (2) and Stadelman (10) in studies with other types of tissues concerning plasmolysis-deplasmolysis phenomena.

Further insights into the nature of water damage, including hollow hearts of peas, are found to be in articles by Moore (6, 9). Such insights resulted from intensive studies with tetrazolium staining, which most seed physiologists have not pursued.

<u>Aging</u>

Aging needs to be considered from two viewpoints, namely chronological and physiological. Chronological age refers to the lapse of time after a given lot of seed matured. Physiological age refers to the degree to which embryo tissues have advanced as a result of aging processes. Such processes are accelerated by high temperatures, high moisture, injuries, and genetic composition. The relationship between chronological and physiological aging is not very predictable without a knowledge of environmental factors to which seeds have been subjected. In TZ testing, we are mainly concerned with the physiological type of aging.

It is desirable to consider two general types of accelerated deterioration associated with localized injured tissues. The other type represents a slower form of deterioration associated with masses of non-injured tissues that are not in close contact with obviously injured tissues.

Accelerated aging is commonly associated with mechanical injuries and weather damage. Centers of damaged areas, if stained before much additional deterioration or aging has occurred, tend to stain dark red. With additional time, the severely injured areas of tissue tend to become dead and fail to stain. A border of deeply stained tissue surrounding a necrotic area represents rapidly aging tissue. With time, the inner layers of cells of the border become dead and the outer periphery of the necrotic zone enlarges by transformation of normal cells into a weakened condition. The extensiveness of the dead and dying tissues reflects the extent of physiological aging of restricted areas.

General aging tends to advance along with localized aging but at a much slower rate. Theoretically, the general aging symptoms progress rather uniformly with initially non-injured embryo tissues. In practice, however, this high level of uniformity of aging is seldom observed. Certain tissues assumed to be non-injured still tend to age more readily than other areas. These areas likely reflect minor disturbances from slight pressures, unequal moisture uptake and release, unequal exchange of air, etc.

In TZ tests, the aged tissues tend to be flaccid and pale red to white in color. Different degrees of aging are reflected. The greyish red color commonly seen on cut surfaces of corn and small grains is believed to be due to a reaction between TZ and sulfur bonds of partially denatured proteins.

Heat Damage

The storage of moist seeds without adequate ventilation to remove heat tends to give rise to blurredness of tissues and a brownish red stain as observed in the TZ test. Damage is often more intense on some structures than on other structures. Radicle tips and plumules of dicots are usually rather sensitive to early stages of heat damage.

Excessively high temperatures in drying cause injuries that also can be readily detected by TZ tests. In case of corn and small grain, the embryonic tissues tend to remain flaccid and to develop an abnormal color.

Freeze Injury

Freeze injury varies considerably in severity. Light amounts of freeze injury in corn, for example, may cause a slightly darker red than normal stain. Severe freeze to high moisture corn tends to kill the embryo. Intermediate levels of damage are reflected by blurredness of tissues and a tendency for a greyish or purplish red stain.

Freeze injury in soybeans tends to produce a bluish red "liquid logged" condition. The damaged area tends to be localized in sections of the seed where free water was accumulated at time of freeze. Soybeans are rather resistant to freezing but can be damaged extensively.

Diseases

Diseases that cause most disturbance in germination tests are saprophytic. The fungi generally require dead or weak tissues as infection centers. Once established, they gradually weaken, kill, and move into nearby tissues. Mechanical and weather damaged tissues serve as commonly encountered infection centers.

In TZ tests, the diseased tissues tend to be soft and mushy and sometimes brownish red. The areas tend to be circular and bordered by a deeper-than-normal red color.

Insect Damage

Damage by chewing insects is obvious. Damage done to soybeans by a piercing insect, the stink bug, deserves special comment. The seeds are damaged while immature. The damaged area tends to be sunken and spongy. The surface tissue on the embryos appears drawn. A small puncture scar can be noted near the center of the damaged area. The tissue stains a dark red color or may fail to stain if sufficient deterioration has occurred.

Summary

The TZ test is unsurpassed in the timely diagnosis and evaluation of seed quality problems. The test is gradually gaining acceptance in the diagnosis of the presence and seriousness of injuries resulting from mechanical impacts, field weathering, aging, heat, freeze, diseases, and insects. It is especially useful in quality control programs for guiding economically sound decisions in reference to harvesting, processing, blending, storing, treating, marketing, and carryover problems and opportunities.

The tetrazolium test, along with the standard growth test, will expose nearly all commonly encountered seed quality problems.

The basic principles of TZ testing can be grasped rather quickly from a few hours of instruction by a competent analyst. Considerable experience is needed for a high level of excellence in its use. College training is not required.

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UPGRADING PHYSIOLOGICAL QUALITY OF SEED LOTS

Charles E. Vaughan[1]

Often the stage is reached in the processing of seed where all of the contaminants, such as weed seed, other crop seed, and inert material have been removed. Yet, the quality of the seed lot may still be below par because the germination percentage is sub-standard or for other reasons. In such situations, the processor may still have several possibilities for improving the overall quality of the lot.

In order to use specific items of processing equipment to improve germination, the processor must be aware of those seed characteristics associated with the physiological quality of seed. These include: seed size, shape, condition of seed coat, specific gravity, and color.

When seed size is used as a basis for improving quality, the processor must first determine which size range of seed must be removed. Generally, the smaller seed are lowest in quality, but this relationship does not always hold. For example: in crimson clover, the extremely large seed are lowest in quality; in white clover, the small seed are lowest in quality; while in red clover, both the extremely large seed and small seed are lower in quality than the seed of intermediate size (Figure 1).

When sizing seed to upgrade quality, two machines are available to the processor. There are more than 200 different sizes and types of screens that can be used in various combinations for sizing of seed with an air-screen cleaner. Often, sizing for quality can be accomplished at the same time contaminants are being removed. The precision grader (width-thickness grader) has also traditionally been used to size-grade seed for quality. Seed are sized for width by using cylindrical screens with round hole openings and sized for thickness by using cylindrical screens with oblong openings. It is desirable to use test screens to determine the percentage of the seed lot that must be removed to obtain the desired quality level in the seed lot.

In recent years, spiral separators have been used to upgrade seed quality in soybeans. The basis for this operation is a difference in the shape of the seed. Diseased and immature soybeans are not as round as mature, healthy seed. This provides a basis for removal of the low quality seed from the lot with a spiral separator, thereby upgrading the quality. Improvement in quality is dependent upon the percentage of malformed seed removed.

Mechanical damage, resulting in cracks in the seed coat, affords opportunity for upgrading quality, particularly in small-seeded crops,

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[1]Associate Professor, Seed Technology Laboratory, Mississippi State University.

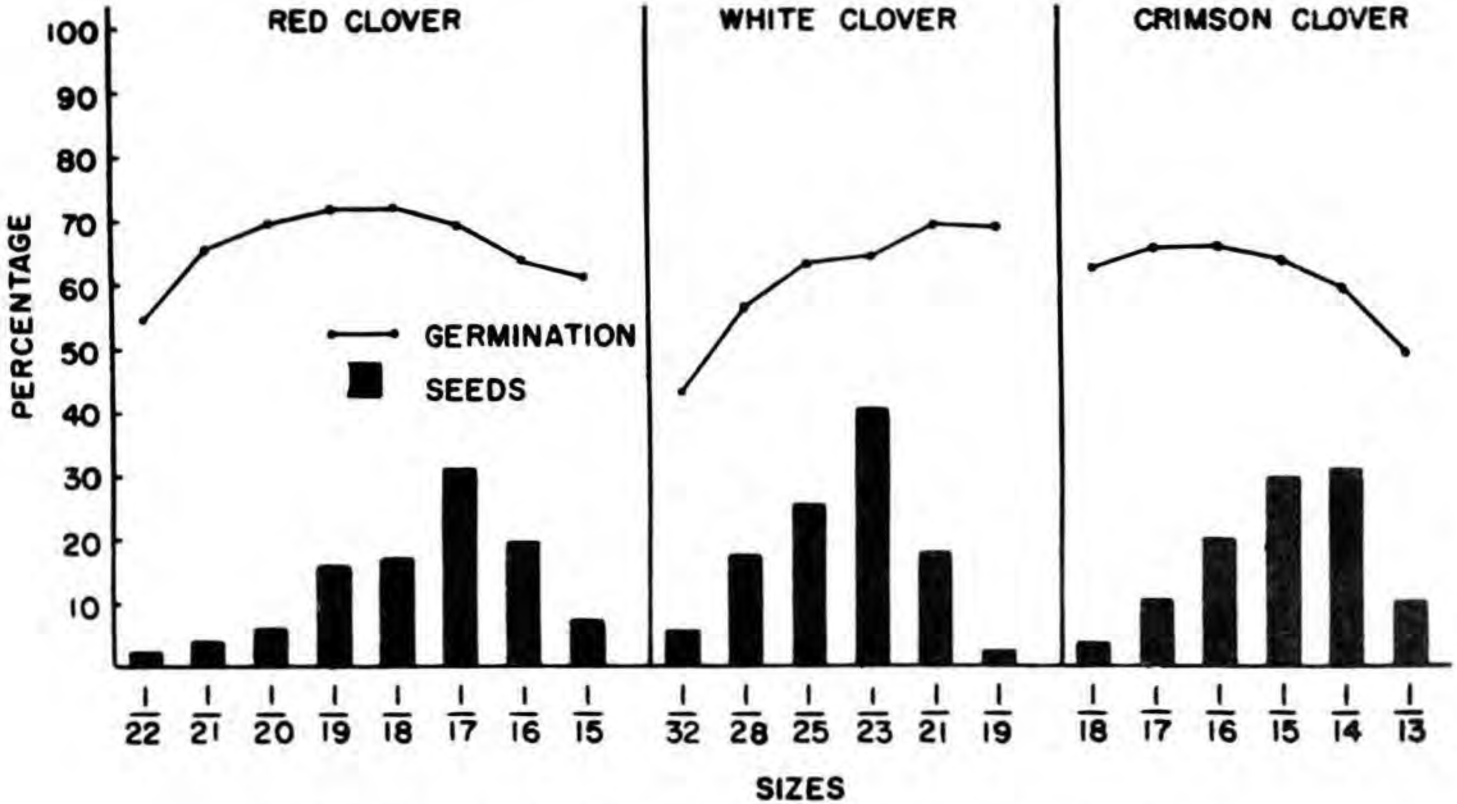

Figure 1. Relation of seed size to germination of red clover, white clover and crimson clover (line graphs), and distribution of seeds among different size classes (bar graphs).

such as the small-seeded legumes. Both the magnetic separator and the roll mill can be used for removing seeds with breaks or chips in the seed coat. Seeds that are damaged mechanically have lower germination percentages than non-damaged seeds.

Another way in which the quality of a seed lot can be improved is by the use of a specific gravity separator. There has been much research work that has demonstrated a close and consistent relationship between specific gravity and viability and vigor (Figure 2). For example, gravity grading can be used to great advantage in upgrading quality of acid-delinted cottonseed.

Some recent work by Seed Technology Laboratory Personnel provides an example of how a specific gravity separator can be used to upgrade quality. Nineteen lots of acid-delinted cottonseed, including nine varieties grown in six states, were gravity-graded into ten fractions each, according to discharge position, by use of an Oliver Model 160 gravity separator. Twenty physical and biological measurements were made on samples from each position to determine their interrelationships, the effectiveness of the gravity separator in upgrading seed quality, and to identify and characterize associations between specific physical and biological seed parameters.

The gravity separator graded the seed into fractions according to differences in volume and total weight of individual seed, which appeared to be the major factors contributing to bulk density. Differences among the fractions were most easily measured in terms of their bulk density (weight per bushel). Seed of lowest bulk density discharged from the lowest side of the deck, and bulk density increased as sample or discharge position moved toward the high side of the deck.

Viability and vigor, as indicated by germination percentage of both untreated and treated seed, cold test reaction, field emergence, and accelerated aging response, followed the same trend as bulk density, *i.e.*, lowest germination-emergence was obtained from the lightest bulk density seed discharging at the lowest side of the deck, and increased as discharge position moved toward the high side of the deck, in proportion to the increase in bulk density (Figure 3). The only difference was a slight decline in germination-emergence of the heaviest fraction of seed discharging from the highest position on the deck. Bulk density was positively correlated with the various germination-emergence parameters. Specific gravity and compactibility of the seed were not closely correlated with the other test parameters and varied only slightly with sample position.

Average length of seedlings and dry weight of radicle-hypocotyl axes and cotyledonary leaves, seven days after planting, generally increased with increasing bulk density.

Free fatty acid content was highly and negatively correlated with both bulk density and germinability (Figure 4). It was highest in seed

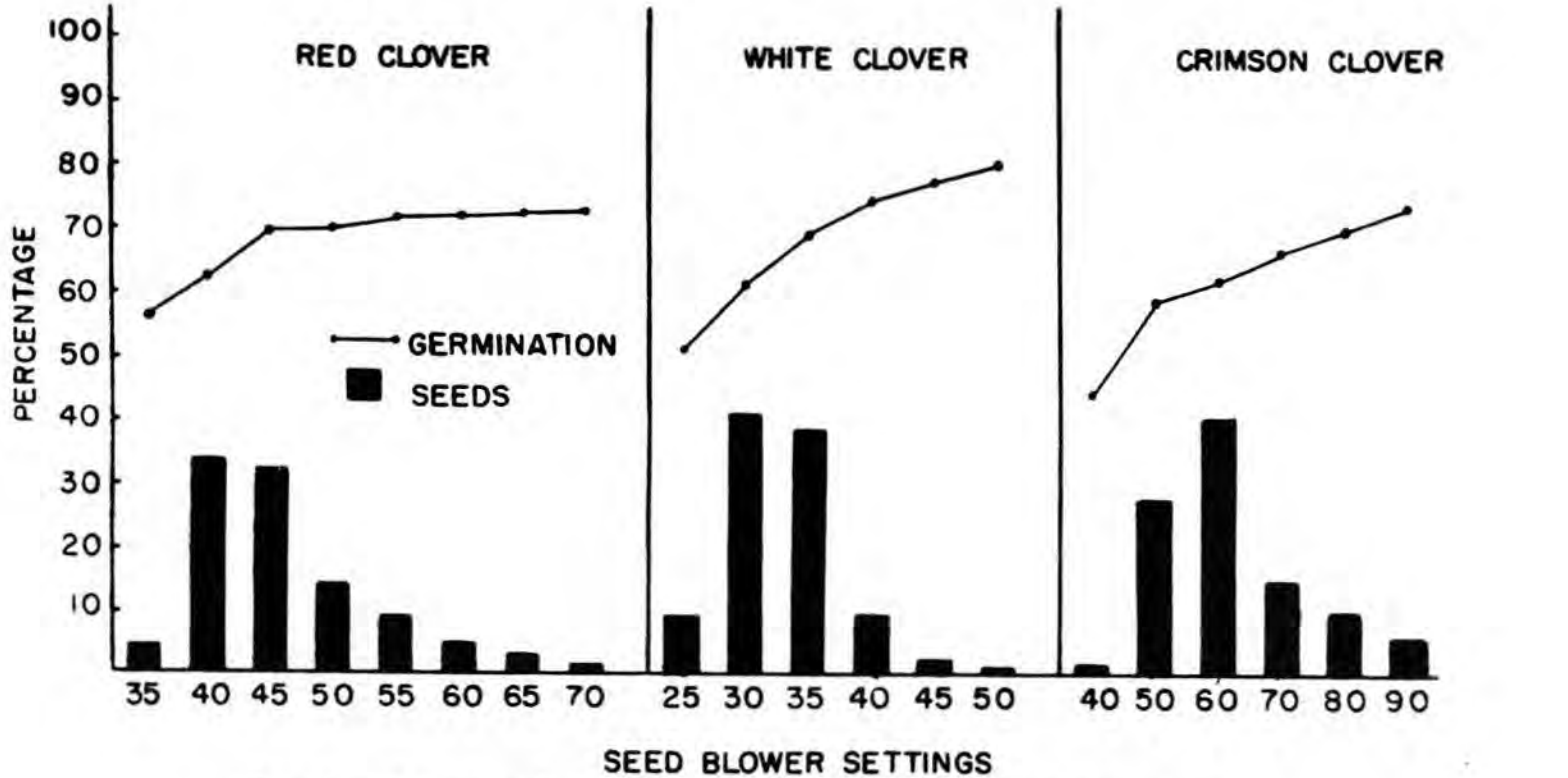

Figure 2. Relation of specific gravity to germination of red clover, white clover and crimson clover (line graphs), and distribution of seeds among different specific gravity classes (bar graphs).

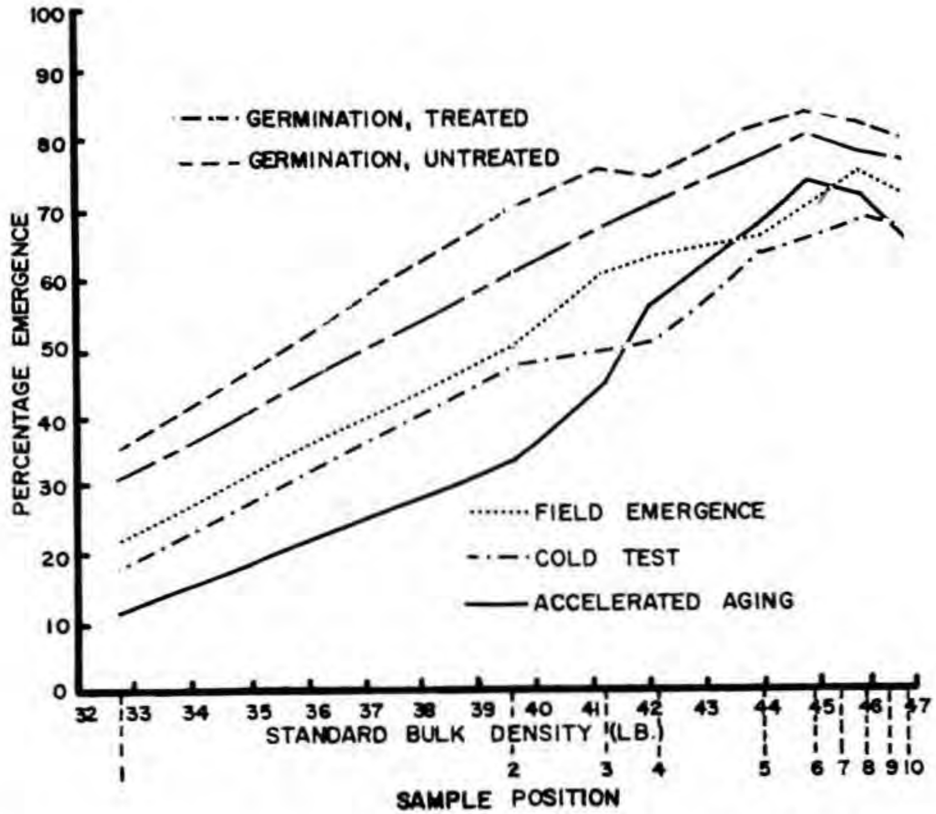

Figure 3. Comparison of emergence from seeds of different standard bulk density in germination tests of treated and untreated seed, cold tests, accelerated aging tests, and field emergence tests.

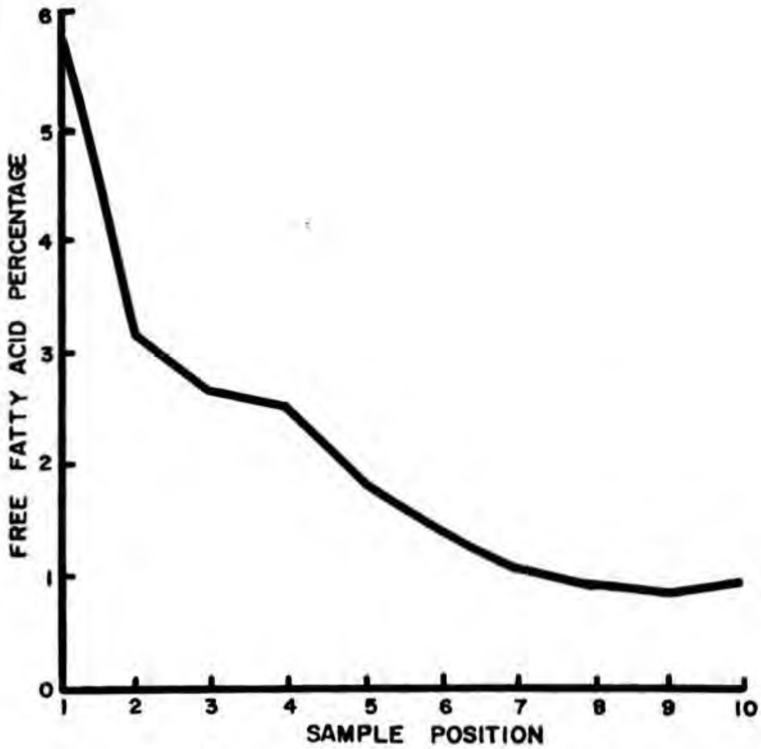

Figure 4. Average percentage of free fatty acids found in seed discharging from the gravity separator at different sampling positions.

from the low sample positions and decreased to minimal values in seed from sample positions 8 and 9. There was slight increase in free fat acidity in seed from sample position 10, corresponding to the slight decrease in germinability of seed from that position. Seed from different lots with a given free fatty acid content varied considerably in germinability; however, a high fatty acid content was consistently associated with low germinability and bulk density.

Incidence of mechanical injury was highest in seed of low bulk density from the low side of the gravity separator deck, and declined to a minimal level in seed from sample positions 6 to 8, after which it slightly increased. However, the percentage of injured seed among sample positions did not parallel either bulk density or germinability closely enough to produce high correlation coefficients.

Based on these results, acid-delinted cottonseed with bulk density below 42 pounds per bushel should be rejected during gravity grading of a seed lot and diverted to commercial use. In this manner, the accepted fraction of the lot would generally germinate above 80%. For higher quality seed, the rejection point should be about 44 pounds per bushel, and the very heaviest seed discharging from the extreme high side of the gravity separator deck should also be rejected.

Recent work at Texas A & M produced generally the same information; however, two other ways in which gravity-grading can improve seed quality were identified. First, the heaviest seed within a gravity group gave consistently higher yield than the lightest seed in that group. Second, seed density exerted a strong influence on the earliness of germination. High density seed, on the average, emerged first. It has also been shown that the first seed to emerge contribute more to yield than those that emerge later.

The trends reported here with cottonseed have also been found with other crops. For example, significant increases in germination percentages have been obtained in sorghum and millet with the use of a specific gravity separator.

Another machine that can be used to great advantage for improving seed quality is the air separator. Air separators are widely used in seed processing as separate systems or structurally incorporated in other cleaning devices. Indeed, air separation systems have been so well integrated in other separators that they have almost lost their identity. The basic seed cleaner, the air-screen machine, has one, two, three, or more air systems that assist in the separation made by these machines.

Air separators - as considered here - can be classified as pneumatic separators, aspirators, and scalping aspirators. Although these three types of air separators are different in appearance, they utilize the same principle of separation.

Air separators are used in three different and distinct ways:

1. General cleaning: Air separators are widely used to clean seed by removing dust, chaffy inert material, pieces of broken seed, immature and shrivelled seed, and other light contaminating material. Air systems in an air-screen cleaner perform this type of general cleaning operation.

2. Specific separations: In some cases, an air separator can be used to remove a specific contaminant that was not removed by previous cleaning operations. The seed mixture should be closely pre-sized before the air separation is attempted.

3. Close grading: Air separators are used to "grade" seed for density or volume weight. Removal of lightweight seed or insect damaged seed from grass, grain, vetch, or cottonseed increases bushel weight (volume weight) and may upgrade germination. The effectiveness of this separation depends on the purity of the seed to be upgraded. For best results, the seed should be thoroughly cleaned on other machines before the final air separation is attempted. It is this close grading that offers the greatest possibilities for improving seed quality.

In a study conducted several years ago, the air separator proved to be an effective machine for improving the germination of various clover seed lots (see Figure 2). Specific gravity, as determined by an air separator, was consistently related to viability. An increase in specific gravity of the seed was accompanied by an increase in germination percentage. The range in average germination percentage from seed of low specific gravity to seed of high specific gravity was as follows for the different crops in the study: red clover 15.9%, white clover 29.3%, and crimson clover 30.0%. The greatest difference in germination percentage between any two specific gravity groups always occurred between the lightest and second heaviest specific gravity group.

The color of seed is another seed characteristic that can be used to upgrade quality. In many seed kinds, as seed deteriorate, they darken in color (Figure 5). By removing the darker, more deteriorated seed within a lot, seed quality may be improved. Color sorters, therefore, have a great potential in providing the processor with the capability for improving the quality of seed lots. Electric color sorters have potential application in three areas of seed processing: research, purification of seed stocks, and upgrading seed quality. Specific data from five different applications show that the color sorter is an effective tool in upgrading seed quality. These are:

Damaged Corn Seed - Four lots of corn seed, two white-seeded and two yellow-seeded, were mechanically damaged by passing the seed through a Crippen Model Scarifier. After mechanical treatment, 5-pound samples of each lot were briefly soaked in a 0.1% solution of fast green to stain damaged areas on the seed. The effectiveness of the color sorter

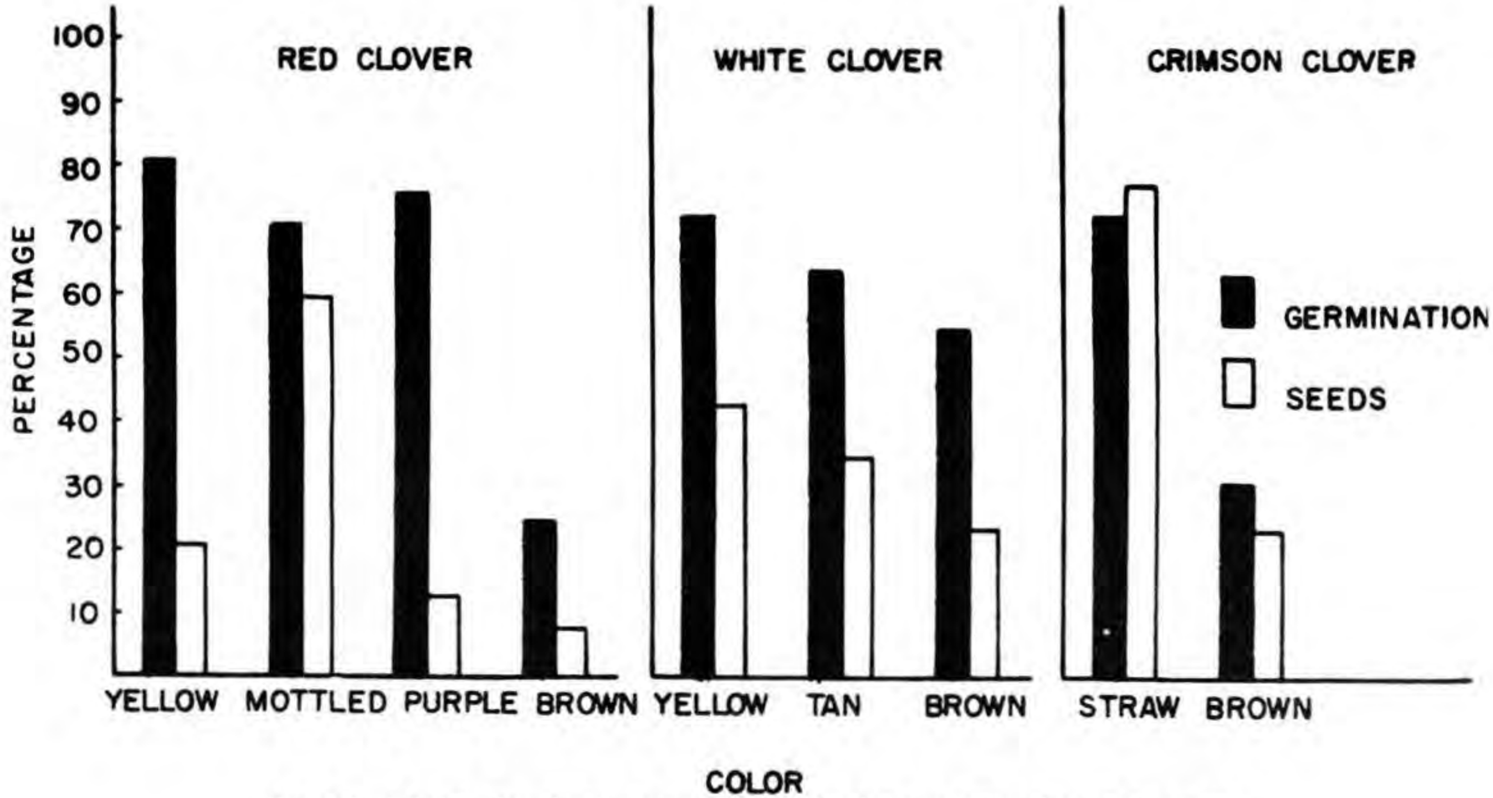

Figure 5. Relation of seed color to germination of red clover, white clover and crimson clover (shaded bars), and distribution of seeds among different seed color classes (unshaded bars).

in separating the mechanically damaged, stained seed from undamaged, unstained seed was then evaluated.

Standard germination percentage of the acceptable (undamaged) seed was 1 to 6% higher than that of the composite, and 5 to 21% higher than that of the rejected seed. The effectiveness of color sorting for removal of damaged seed was even more evident when cold test germination results were considered. The accept fraction had a cold test germination 22 to 29% higher than the reject fraction. These data indicated that color sorting after pre-treatment of the seed with fast green was effective in removing mechanically damaged seed and upgrading both standard and cold test germination percentages.

Mechanically Damaged Soybeans - A lot of Lee soybeans was obtained from Foundation Seed Stocks at Mississippi State University. These seed had been damaged at harvest by excessive threshing cylinder speed. Normal processing procedures could not remove the seed with cracked seed coats, broken cotyledons, and fractures extending into the cotyledons. Also, there was not enough color difference in the damaged areas for detection with electric color sorters. To induce a color difference, the seed were immersed in a solution of indoxyl acetate, removed immediately, and placed in an electric dryer where ammonia fumes, introduced into the intake air stream of the dryer, developed a blue-indigo stain on the damaged areas of the seed.

After drying, the seed were processed on a color sorter to remove the stained seed. Germination percentages of the original and stained seed before sorting indicated a reduction in germination of 12%. This reduction was caused by the staining and drying processes. The damage, however, appeared to be more attributable to seed coats sloughing off from wetting and drying than to any toxic effect of the indoxyl acetate. After electric color sorting, the "accepts" germinated 98% and rejects germinated 36%.

Green Seed from Lee Soybean Seed - Four lots of Lee soybeans that contained 18 to 36% "green" colored seed were obtained from seed stocks in the Seed Technology Laboratory. Seed of Lee are normally buff colored, but in some seasons, some of the seed of Lee and other varieties retain a green color in the cotyledons. It is not known what prevents the cotyledons of these seed from changing to the normal, light yellow color during maturation.

The green seed were separated using a color sorter and germination tests were made to determine if there was any difference in the quality of the green and normal colored seed. The normal buff colored seed germinated 22 to 32% higher than the green seed. These results indicated that there is a pronounced difference in germinability of the buff colored and green seed and that a color sorter can separate them and upgrade germination.

Weathered Cowpea Seed - Two lots of cowpeas were obtained from Foundation Seed Stocks, Mississippi State University. One lot, Bunch Purplehull, a white-seeded variety, had been moderately weathered, while the other lot, Mississippi Silver, was more uniformly damaged by frequent showers and humid weather at harvest time. Both lots failed to meet minimum germination standards for Foundation seed (80%).

Weather damaged seed were removed from both lots and germination tests run on each separately. The germination of the Bunch Purplehull lot was increased from 68 to 84% with a loss of 34% of the lot, and thus qualified as Foundation class seed. Germination of the Mississippi Silver lot was increased only 6% with a loss of 28% of the lot. It did not meet standards even after sorting. The electric sorter performed well where there was a visible difference due to weathering. However, when weathering was severe and uniform, effective separation was not possible.

Deteriorated Clover and Alfalfa Seed - Lots of crimson clover and alfalfa seed were separated into three fractions in two passes through a color sorter. On the first pass, the lightest colored seed (light) were rejected. The accept fraction was further divided by the second pass into rejects (tan seed) and accepts (brown seed).

Germination of crimson clover seed was increased by 8 to 18% over the composite at the expense of seed losses of 24 to 42%. The light colored seed separates germinated 30 to 67% higher than the brown seed separates. Color sorting alfalfa seed increased germination by 11 to 20% over the composite at the expense of seed losses of 26 to 49%. The light colored seed separates germinated 20 to 67% higher than the brown colored seed separates.

The electric color sorters can be a valuable tool for research and commercial processing. They are extremely versatile and accurate when operated properly. Their principal disadvantages are high cost, low capacity, and the need for some specialized training for operators.

A successful processor, then, should look beyond the removal of contaminants in normal cleaning operations to operations that will help in improving the overall quality of the seed.

ANATOMY OF A SEED LOT

C. Hunter Andrews[1]

By definition, anatomy denotes the analysis, structure, or composition of a system. Thus, a lot or quantity of freshly harvested seed may be considered as a "system" whose composition or structure can be defined into one or more of the currently acceptable categories or standard seed lot components, *i.e.*, pure seed, other crop seed, weed seed, and inert matter. In addition to this identifying structural system for seed lots, and possibly of greater importance in the future, each of the component parts can be further examined to produce a completely detailed analysis of the entire lot.

Due to the radical changes in seed production programs of the past decade which include increased farm size units, almost total mechanization, widespread use of chemicals, and stringent quality requirements on seed, a more detailed evaluation of seed lots and seed lot components has become increasingly important.

Although it may be possible to identify all or a portion of a freshly harvested seed mass as a specific seed lot prior to subsequent processing and handling operations, most seedsmen probably do not attempt to define or identify a seed mass with a final lot number until some additional attempt has been made to minimize the presence of objectionable seeds and inert matter through processing and cleaning operations. The ultimate objective of a seed cleaning sequence is to produce at a pure seed component (the primary seed crop) which is as genetically and mechanically pure as possible. Thus, the clean seed component of the harvested seed mass is derived in an orderly and systematic manner.

A series of factors can easily influence the proportions of each of the components of a seed lot. For instance, the occurrence of weed seed and other crop seed may be strongly influenced by previous land history. Inert matter content may be influenced by field conditions as well as harvesting techniques and equipment. In addition, other principles and practices of a seed production program are of prime consideration in determining proportions of seed lot components. For whatever the cause, an increase in percentage of any one of the components of the lot is at the expense of one or more of the other components of the lot. In other words, an increase in percentage occurrence of either other crop, weed seed, or inert matter will reduce the pure seed component and thus lower the quality of the seed lot.

Generally, and usually without extreme difficulty, the primary seed crop of any freshly harvested seed lot contributes 90% or more to the

[1]Associate Professor, Seed Technology Laboratory, Mississippi State University.

pure seed component of the total system. This is obviously true with large-seeded row-crop seed, such as corn, soybeans, sorghum, etc.; however, small-seeded grasses present a more difficult problem. For various reasons, it is quite difficult to obtain high purity percentages in many grasses, and more likely than not, the pure seed component of small-seeded grasses is only 50-60%. The other components, specifically inert matter, are quite higher.

Initially, it was stated that raw seed may be discarded due to factors which automatically lower the quality below acceptable seed standards; however, with few exceptions, most seedsmen follow through with logically and sequential cleaning patterns which result in an acceptable seed product. Past experience has fairly well-substantiated the use of primary cleaning machines for specific crop seed, and flow patterns for successful cleaning through one or a series of machines are quite uniform. Exceptions do occur, however, when conventional cleaning systems fail to eliminate excessive levels of inert matter, weed seed, and in some cases, even other crop seed due to lack of proper machines or operational features. It is at this stage once again that a seedsman is faced with the decision of diverting the seed mass to uses other than for "seed" if it cannot be cleaned to acceptable standards.

Thus, the first consideration given to the seed lot is one of rapid and somewhat superficial mechanical analysis to determine component structure and acceptability as possible seed for planting purposes.

Secondly, more direct consideration and analysis is given to seed lots and seed lot components (specifically the pure seed) once the seed has been identified for commercialization. In other words, production and processing experience enables a large percentage of seed to be successfully produced and cleaned to acceptable seed trade standards. Therefore, the seedsman or segments of the seed industry are capable of producing, cleaning, bagging, and labeling seed kinds and varieties for sale throughout the country.

No doubt most of what has been said is not new to persons in the seed trade; however, it seemed fitting to re-emphasize the essentials in order to arrive at the real essence of the problem at hand. It has been established that a seed mass can be cleaned, bagged, and designated by appropriate lot identity. Thus, it now stands ready for the next detailed analysis. A sample of the seed is taken, which represents the entire seed lot and is submitted to the appropriate seed testing facility for a complete and detailed analysis. The results of these tests provide standard information for labeling purposes required by seed laws.

In the seed testing laboratory, the representative sample is appropriately divided to provide the sub-sample for the purity analysis, the analysis which can be considered as the initial step of the detailed anatomical analysis of the representative sample. Here, a trained analyst closely observes all of the seeds in the sub-sample in order to determine the purity of the sample. In other words, the analyst determines primarily the percentage of pure seed in the sample. Of course, the other components are calculated if they are present, and in some cases, the purity test reveals that the seed sample fails to meet the required seed standards. Other standard laboratory tests follow, namely the germination and noxious weed tests; however, failure to meet purity standards precludes the use of the lot for seed purposes. Thus, the "presumed lot" has failed its first anatomical analysis.

However, assume that the sample does pass the purity analysis; therefore, the pure seed fraction resulting from the purity analysis passes into the next phase of examination, the germination analysis. In part, this test indirectly reveals the internal anatomy of the seed in the lot.

A brief pause here should be appropriate in emphasizing the make-up of the seed in the pure seed component of the representative sub-sample. The Association of Official Seed Analysts (AOSA) Rules for Testing Seeds clearly defines seed types for inclusion in the pure seed fraction. These are specific for particular seed kinds and generally include, in addition to obviously good, sound, healthy seed, such seed types as cracked, damaged or broken seed in excess of ½ the size of the seed kind in question. Also diseases, immature, insect damaged seed, and others which may obviously be of inferior quality are included in the pure seed fraction. Certainly, this type of analysis and judging system evolved in seed testing in order to accurately calculate the germination potential of the entire seed lot which the purity sub-sample represents, for it is the pure seed fraction on which the germination test is performed. Consider, if you will, conducting a germination test on a pure seed fraction in which the analyst has only selected the apparently fully developed, intact, healthy seed as the pure seed component. Then would it not be reasonable to expect a considerably higher germination percent from such a "hand-picked" sample as compared to the actual germination potential of the entire lot? Thus, the pure seed fraction must contain seed of all quality levels so that it, in fact, represents as accurately as possible, the entire seed lot. Then the germination test is designed to reveal abnormal, weak, or dead seeds arising from the low quality seeds of the pure seed fraction as well as the normal seedlings which constitute the germination percentage.

Resuming the sequential steps for seed lot evaluation, the pure seed fraction moves into the germination analysis phase for determination of the germination anatomy. At this time, another trained seed analyst initiates the standard germination test and utilizes procedures for testing seed which are clearly defined in the AOSA Rules for Testing Seed. These procedures stipulate that *optimum laboratory germinating* conditions be provided for the crop kind being tested. Under such conditions and within the alloted germination interval, seeds of all quality levels (broken, cracked, diseased, immature, etc., which were included in the pure seed fraction) are afforded ample opportunity to develop into possibly normal seedlings. Consequently, the final germination result may reflect a germination potential based to some extent upon germination performance of rather weak seeds. Only if these "so-called" seeds fail to develop into normal seedlings under the optimum laboratory germination environment do they detract from the final germination percent. Therefore, due to the modern and standardized testing techniques currently employed in seed testing laboratories, germination test results for most seed kinds are so uniform that they provide a rather misleading indication of the real germination potential of the lot. In fact, seed lots with similar germination, when planted in the field, actually may differ widely in emergence and stand producing potential. While one lot may maintain a field emergence quite similar to laboratory germination results, the second lot may decline significantly in emergence. Review Table 1 for instance, which shows rather uniform germination responses for peanuts but less uniform results in field emergence and other tests.

Apparently, there were existing conditions associated with some seed lots which were either not discernable by optimum laboratory tests, or conditions in the seedbed were so unfavorable that the inferior seed failed to perform as predicted by the laboratory germination test. Therefore, a closer analysis of the physical and physiological structure of the seed lot is in order so that problem areas may be orderly identified and defined.

This is not an attempt to completely discredit the long standing germination test. In fact, it is the most important testing tool available today and should not be discarded. However, the current trend is to include additional, more sensitive tests which will provide valuable information to supplement the germination test results.

To accomplish this detailed and complete analysis of a seed lot, highly sensitive and specialized tests, "*vigor tests*," have been developed and refined in recent years. Certain of these tests are designed to simulate stress or unfavorable conditions of a nature which seed encounter in the seedbed (cold test and accelerated aging test), while others are designed to reveal the physical and physiological conditions of the seed - possibly the internal anatomy of the seed (tetrazolium and enzyme tests and relative growth performance capacities of the seed). Review Table 2 to determine relative performance of soybean seed lots in laboratory tests as compared to actual field emergence.

Considerable research data has been accumulated by many scientists which support the value of many of these tests. Actually, some are being utilized in certain areas of the seed trade at this time with excellent acceptance and results. It is anticipated that more emphasis in the near future will result in wider acceptance and usage.

Table 1. Laboratory, cold test, and AA germination responses compared to field emergence for commercial lots of Spanish peanuts.

Lot No.	Germ. %	Cold Test %	AA Germ. %	Field Emergence %
1	99 a[1]	93 a	96 a	89
2	94 ab	66 b	72 b	78
3	93 ab	66 b	95 a	85
4	89 abc	44 c	51 b	78
5	88 bcd	54 c	46 b	53
6	80 cd	44 c	53 b	74
7	70 d	56 bc	27 c	86

[1]Means within the same column not followed by the same letter differ significantly at the 5% level of probability as judged by DNMRT.

Table 2. Comparison of laboratory performance with field emergence for commercial lots of soybeans

Variety	Germ. %	Cold Test %	AA Germ. %	TZ %	Field Emergence %
Lee 68	88	85	72	64	83
	85	79	56	59	77
Bragg	81	71	48	59	82
	83	65	39	20	76
Dare	92	85	81	69	85
	91	75	78	62	79
Hill	94	84	73	54	91
	92	79	43	44	87
Davis	85	79	59	56	82
	87	75	57	47	75

Just what does the "anatomy of a seed lot" concept mean to seedsmen. First and foremost, it may mean the difference of selling seed or just plain feed grain. Highly mechanized production and processing systems are creating increasing seed quality problems, and these same systems are being called upon to produce higher quality seed. A detailed examination of the anatomy of a seed lot may reveal clues as to additional cleaning procedures for up-grading seed lots to acceptable standards. Additionally, disease, injury, or other problem areas may be identified. Of great importance, results from detailed anatomy examinations could provide critical information as to the true potential of the seed lot so that timely planting dates and rates might overcome costly replanting procedures caused by poor quality seed.

At the present time, a more detailed analysis of seed lots, particularly with *marginal* seed, appears to have considerable merit. Increase in seedling emergence, uniformity of stands, rapid growth, and development of the crop and yield increases are some of the potential benefits of high quality seeds. Therefore, seedsmen should study each seed lot, characterize them well, and eliminate questionable ones in order to market the highest quality seed possible.

PROBLEM IDENTIFICATION AND SOLUTIONS

Charles C. Baskin[1]

Quite frequently, a seedsman does not realize he has a problem until the end product is analyzed. When he gets a report from a testing laboratory or views the results of some of his own tests and finds germination is low or weed seed content is high or inert matter is higher, then he realizes that things have not gone the way he thought they were going and may have no idea where the problem might have occurred.

Problems can and do occur anywhere from the field to the bag, and unless the entire operation is monitored, it may not be possible to identify problems or causes of problems. Suppose the problem is low germination. How many things can you think of that might cause a drop in germination: (1) field exposure, (2) mechanical damage, (3) harvesting at too high a moisture content without drying, (4) improper storage, and others. Or, the problem may be weed content. We may tend to think of this as a processing problem, but most weed seed problems could and should have been prevented in the field. Inert matter, on the other hand, may be a harvesting or processing problem.

Let's examine two problems frequently encountered by seedsmen and how they might be identified and solved.

Problem 1. Soybeans germinate 90% or better at harvest time but germination has dropped into the 60's by April. This problem had occurred for more than one year.

In an attempt to solve the problem, a sample of beans was hand harvested. Since germination was high at harvest, you might ask, why sample from the field? The reason was to determine the amount of deterioration that had occurred prior to harvest. Seed might germinate well at harvest time but be so deteriorated that viability in storage is not maintained. Estimated germination of the hand harvested sample based on a tetrazolium test was 89%.

The second point of sampling was the combine. Samples were collected from the grain tank and truck or grain wagon used to transport seed to bulk storage. Seed were checked for mechanical damage and a second tetrazolium test conducted. Seed had only 7% mechanical damage and estimated germination was 89%.

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[1]Extension Agronomist - Seed and Grain, Mississippi Cooperative Extension Service, Mississippi State University.

Beans were stored in bulk tanks and aerated periodically. Samples were taken in late November or early December before processing. Germination of beans from four storage tanks ranged from the high 80's to the low 90's.

Beans were processed, bagged, and stored on flats in an open warehouse. Samples were taken from the several lots periodically until the beans were sold. These tests up to the time of sale showed germination in the high 80's to the low 90's.

Over a period of several months and numerous tests, we learned very little about where this seedsman's problem of loss of germination of soybeans in storage might be occurring. We might suspect that since a hand harvested sample germinated only 89%, and from deteriorated areas on the bean radicles and cotyledons of the hand harvested beans, that field deterioration might contribute to the problems since the pattern of loss of germination occurred as it did previously. The only recourse is to follow a similar testing program in subsequent years.

Problem 2. Weed seed contamination of bahiagrass seed.

Bahiagrass is widely grown throughout south Mississippi as a permanent pasture grass. Seed are harvested from pastures by direct combining. Very few farmers manage bahiagrass for seed only; rather, seed are a by-product of pastures managed primarily for forage.

In unprocessed seed of bahiagrass, the primary weed seed contaminant was bracted plantain (*Plantago aristata*). Use of hand screens led to a selection of screens that would remove most of the plantain seed.

A closer examination of the weed seed occurring in the bahiagrass seed in this particular area of the state revealed that almost all of the weeds were species that produced seed in the spring (May and June), well ahead of bahiagrass. Good pasture management practices should eliminate these species, or at least keep seed from them from contaminating bahiagrass seed which are not ready for harvest until July.

Meetings with seedsmen and farmers resulted in some farmers improving pasture management practices. The following year, analysis of spot-checked seed lots revealed that combine-run seed from some of these properly managed areas ran as high as 98% purity, with very few weed seeds.

DISEASES AND DESTRUCTION

Woodrow W. Hare[1]

Photosynthesis is the basic process we are talking about anytime we talk about agriculture. It does not make any difference whether we are dealing with the primary product, plants, or with a secondary product, animals, or with the business and management of either: we are talking about the basic process of photosynthesis.

Last year, Dr. Norman C. Merwine, Agronomy Department, MSU, and I got into a discussion, and somehow the question was brought up as to what would happen if photosynthesis stopped today. We examined this thoroughly, did considerable checking, and after looking up some figures, making some allowances, and doing everything short of going to a computer, we came to the shocking conclusion that if photosynthesis stopped today, within one and one-half, or at the outside two years, there would be no life on earth as we know it today, except for things that could live on dead organic matter, such as fungi and bacteria.

Humanoids, those that can be recognized as man, have been on the earth for at least 2.6 million years. Agriculture has developed in the last 10,000 years of this time which is 1/260th of the total time that man-like animals have been upon this globe. In the process of development of agriculture, all of civilization, as we know it today, has been so structured that we have the vast inverted pyramid of civilization resting upon the back of agriculture. It has developed to the extent that here in this nation, as you have already heard today, less than 5 percent of our people are in agriculture producing food and fiber that must support 100 percent of the population.

If we talk about stopping agriculture as we did photosynthesis, the number of people that could exist would be much more difficult to calculate because we would have to take into account the food that could be obtained from the berries and fruit in the fields and woods, and the game, deer, rabbits, etc., that could be caught and used for food. I don't know if there is a place where we could get a reliable estimate, but I take the figure 20,000,000 worldwide as the number of people who could survive without agriculture. I did this partly because I recently read in a reliable reference that there were 1,000,000 Indians in North America before colonization. We can't take this as final because the Indians had agriculture of a sort and did not live by hunting and gathering alone. My guess is that we would reduce the 3½ billion people that survive now on the earth to 20,000,000 (your guess is as good as mine), but certainly there would have to be an astronomical reduction in the number of humans that could survive if we stopped agriculture.

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Stopping agriculture is not likely to take place, as we know. But there are many things that reduce agriculture, and you are aware of many of these factors as well as I. Nevertheless, we are going to focus on just one of those many factors - plant diseases.

Plant diseases - how long have they been known? Let us go back to that man-like creature recognized as inhabiting the earth 2.6 million years ago. If he wandered out into the fields, the forests, or wherever there was vegetation - plants of any kind - it is quite likely that he would have seen root rots, leaf spots, blights, etc., on those plants. There are records in the Bible of plant diseases that are quite well authenticated. There are even some pagan gods involving plant diseases that have been precisely identified. Thus, the records of plant diseases go back to very early times.

How long have we understood plant diseases? Well, quite frankly, we do not understand them today, and I am talking about the professionals now, the plant pathologists. We know a lot more about plant diseases than we did in the past, but we do not understand them. Much more, the general public does not understand plant diseases. There are reasons for this. The main one, of course, is that it is quite easy for the uninitiated to see weeds crowding out a crop or to see an insect chewing on a leaf and recognize what is causing the damage. It is not easy for such a person, however, to recognize the source of damage when the causal agent is a microscopic fungus, bacterium, or nematode, or a submicroscopic virus. Even if the observer is a professional, he will not see what is causing the damage, he will see only symptoms.

Plant diseases are very much influenced by environmental conditions. So much so that particular plant diseases are quite frequently closely associated with a specific facet of the environment. For example, *Aphanomyces*, root rot of English pea, cannot occur unless the soil is saturated at least one time for infection of the roots to take place. This crop does best when there is plenty of moisture during the season and makes its best yield, and these conditions are also favorable for the root rot. The general public ascribes the root rot to the wet weather rather than to the fungus, the actual cause of the damage.

We cannot make a statement that is totally correct in every instance concerning biology. Most plant diseases are favored by excess moisture. This is a general rule, but there are exceptions. Some diseases are favored by dry weather. One of them is powdery mildew of rose. Since it is favored by dry weather and occurs under such conditions, then quite often the layman will attribute the damage to the dry weather rather than to the fungus causing the powdery mildew. Damping-off of cotton is very heavily favored by cool, wet conditions, particularly cool temperature, and it is frequently attributed to the cool temperature rather than to the fungus causing the trouble. *Fusarium* wilt of tomato is favored by hot weather and, again, the damage is quite often attributed to the hot weather rather than to the fungus.

We have made a lot of progress in controlling plant diseases through the years, and this is well evidenced by the fact that we would not be eating nearly as "high on the hog" today if progress had not been made. If we had not controlled the diseases on wheat, rice, corn, etc., we would not have the production of today from those crops. But here I am talking about plant diseases and destruction or "seeding disaster." Why? My point is that today we have, in spite of all of the progress, a much higher potential for destruction by plant diseases than we have had in the past. If you will follow along with me, I believe that I can document my case.

First, I want to point out that although this general view has a lot of agreement among professional plant pathologists, even here in our own department there is disagreement on details of the case and varying points of it. So, I want to stress to you that the following represents my viewpoint. If you don't like what I am saying, don't attack a nearby plant pathologist; come and attack me, because it is my viewpoint. Reaching such a conclusion, after careful consideration of the facts and with what experience I have, I feel there is an obligation to let everyone know about it who I can get to stop and listen. I am so doing today.

As a background, let us take a look as to how things were in the past with plant diseases. I do not plan to go off around the world for cases to illustrate my point, nor even to other parts of the United States. I will stick to my own state of Mississippi and to cases right here in Mississippi. To do this, if you will pardon me, I want to use some personal experiences to illustrate what it was like in the past when agriculture was carried on as it was for a long time before it became fully commercialized and mechanized. I use this personal reference because it fits in nicely. I grew up on the farm when farming was going on as it had been for a long time.

The typical diseases then were the blights, leaf spots, root rots, etc., across the range of plant diseases. What we had at that time was quite similar to the range today. On the farm where I grew up the handling of seeds and plants, however, was much different than we find it today. The seed of most of the crops were saved on the farm for planting that crop the next year. For example, we saved mustard seed, cabbage seed, and bean seed. We also saved cottonseed at the gin and carried it home and stored it for use the next year. We saved seed corn. In fact, there was a system for selecting the corn that was to be used for seed the next year. This also applied to crops that were vegetatively propagated. We saved sweet potatoes for planting the next year, and sugarcane, and strawberries. One particular strain of strawberries, I know for a fact, was kept on this one farm for over 50 years.

This system of propagation led to a wide variety of plant types. Since there was general use of a system of saving seed on the farm, and in quite a number of cases purposeful selection from the corp of the present year, there were different types of plants of a given crop in the community. In a community, if you examined farms A, B, C, and D, you might well find different types of the same crop. For example, corn: I recall that there were a number of recognizably different strains of corn in the community in which I grew up. The owners were proud of these strains and they used care in selecting the seed to carry over to the next year. You could find quite different germplasms of the same crop plant in small local areas, even in the same community.

We did not have bacterial blight of pole bean on our farm. The beans produced luxuriantly up until June or July, so that we got tired of having so many snap beans while we were waiting for other things to come on in the garden. Another disease of beans that we did not have was common mosaic. Although, I was not a plant pathologist at the time, for those diseases that have very distinctive symptoms, I can very clearly remember whether we did or did not have them. Another way for me to determine if a particular disease was present is by the effect on the crop. With bacterial blight and common mosaic on pole bean, there would have been little or no crop produced.

We did not have black rot of cabbage nor did we have pale spot of turnip. We did not have bacterial blight on cotton. We did not even have *Fusarium* wilt on cotton which is a soilborne disease and persists from year to year in the soil. It is spread from one location to another over long distances by contamination of the seed. There may have been a little wilt - I cannot be absolutely certain about that - but at least we did not have enough to damage the crop. We did not have black rot of sweet potato.

If I am beginning to sound like we did not have any diseases at that time, nothing could be further from the truth. There were plenty of diseases. There was scab and brown rot on the peaches, scurf on sweet potato, gray mold on strawberry, leaf spots on cotton, etc. There were lots of diseases then, but they were, in general, those that were not so particularly destructive to a crop. They were also not so specific to a crop, but had wide host ranges and did not, as a rule, wipe out a crop.

Now, let's go to how it is today. The typical diseases of today are just the same as they were then. The only difference, and it may not be real, is that we may recognize today more forms or strains of the organisms that cause the typical diseases than we did at that time. But we cannot prove that those forms were not in existence then. In general, the diseases are the typical gamut of diseases: root rots, wilts, blights, leaf spots, etc. So this is much the same as it was in the past. There is, however, an enormous difference in the way seeds and plants are handled as compared to the past. Now, seed are produced in concentrated areas, in large amounts in one area, by very few companies. I would say that this applies to most of the seed of most of the crops that we use in Mississippi today. Then they are distributed over wide areas. And, the same is true for plants that are vegetatively propagated. If I want to plant turnip seed or set out strawberries today, I go down to the seed store and get seed or plants. I'm sure that the local store gets the seed or plants from large wholesale dealers, who in turn buy turnip seed or the plants in large amounts at one time from specialized growers of seed or plants. You can readily see the change that has taken place. This concentrated growing of our seed or plants in one area allows much more chance for pathogens to get into the crop. Subsequent distribution over a wide area favors wide dissemination of the pathogens very quickly. This is a basic and a fundamental change that has taken place. It is very favorable to the development of diseases and to the spread of these diseases quickly over wide areas.

We have quit saving seed as individuals and, therefore, this leads to a big difference in a most important area, the plant types. The farms, A, B, C, and D we talked about within a local community might all have had different types of the same crop in the past. You will no longer find that true. In general, you will find the best strains of corn planted on farm after farm after farm. You will find the same thing in most of the other crops, one or very few different varieties or strains of a crop are planted in mass over wide areas. Thus, the same germplasm of a particular crop occurs over wide areas. I don't have figures for many crops, but I do have estimates for two. In corn, one particular inbred is in nearly 40% of the hybrids that are used across the United States today. In grain sorghum, one type is used in all the grain sorghum hybrids that are planted across the country. This is an illustration of what I'm talking about: this drift to a system in which we have widespread planting of the same type of germplasm of a particular crop.

I want to show you some examples now that have happened in the past three years here in Mississippi. I am not going off to far places for examples. They illustrate that what I'm talking about is not a forecast for the future but is already happening. The first one is southern corn leaf blight in 1970. You all remember how it spread across the state and the extreme damage to the corn crop. What about 1971? Blast of ryegrass just about wiped out the ryegrass crop in the southwestern quarter of the state. There was a lot of damage from blast in the other areas of the state where it was not quite as severe. In 1972, bacterial blight was widespread on cotton all over the state and was severe. It was favored by relatively cool and wet weather during the middle part of the growing season. We were very lucky that in the latter part of the growing season, August and September, the weather was bone dry. Dry weather is very unfavorable to the development of this disease and may have prevented an enormous loss to the crop this year. We had some losses, but the weather held the losses down.

Now, why are we following this road, this system of development that leads us to this danger from plant diseases? First, and most important, because of economic pressure on the grower. Other speakers here this morning have illustrated very well the economic pressure on our farmers today. The big item is prices and I want to give you one or two examples. Just last week, I read a release from Washington which documented that the average price for a day in the hospital across the United States in 1950 was $15. Today, the average price for a day in the hospital across the United States is $100. In almost anything you examine, the prices of cars, of clothes, etc., you will find this wild upsurge in cost or price from 1950 to 1972, except when you look at the prices the farmer receives for his products. Compare the prices of a bushel of corn in 1950 and 1972, a bale of cotton in 1950 and 1972, a dozen eggs in 1950 and 1972. Even in the price of meat during this period, in spite of all the yelling that you have heard recently about the rise in meat prices, you will not find the comparison like you can in other fields. This squeeze on the farmer in prices, everything else going up, except his produce, has led to the situation where he must get bigger. He must develop high efficiency and volume in his operations to survive. And, of course, many of the smaller farmers have gone out under this extreme competition. This squeeze applies to those who are working for the farmer, including those who are doing research. We are driven to try to produce better systems, better cultures, better fertilizers, better varieties, to help the farmer meet this demand for more and more efficiency to stay in business. And, when we produce something better, including varieties, the farmer must get and use these, or he will go under. He must stay up with the other growers in the use of these better varieties. What does this mean? This means that once a variety is demonstrated as better, it is quickly and widely adopted by the growers and there is widespread planting of the same germplasm of a particular crop.

A second factor here, much less important, is what I call pollution pressure. We have an uproar about pollution of the environment, and this has put certain pressures on agriculture in relation to chemicals. It is now to the stage where you must have approval from Washington before you can use a chemical on a particular crop, and some of our chemicals have been taken off the market. This is fine as long as it is reasonable for prevention of pollution of the environment, but it sets up a system that is quite hard to use in an emergency. It might take some time to get a change processed and approved through Washington in order to be able to use a chemical in a disease outbreak. The chemical companies have reduced efforts to bring out new chemicals because of the extreme cost that it takes to provide all the data and process it through Washington. This may be right, but it has put a handicap on agriculture that we need to be aware of as it concerns plant diseases.

A third factor is the variability of the organisms causing the diseases, which has not changed at all. It is the same as in the past. All biological organisms have this capacity to change, and it goes on all the time. It used to have very little importance on the farms that we talked about, A, B, C, and D, where there might be four different types of a crop. If there were a variation in the organism to a form that was highly pathogenic to the crop on farm A, there might be a different strain of that crop on farms B, C, and D. Thus, the organism could not spread beyond the farm where it originated. The present widespread planting of the same germplasm has changed all this and made this variability tremendously important. Once this happens and there is a highly pathogenic organism that can spread, then you have a very dangerous situation. There is no barrier to the spread of the disease.

We are talking about the potential for destruction or seeding disaster. What are the requirements? We have had resistance to some diseases to hold firm for 50 years with no breakdown because of variability of the organism. We have had other fine resistances that did not last two years because of this variability in the organism. So, it cannot be forecast. But let's go through some of the requirements for destruction by the types of plant diseases. First, consider a *Pythium* disease, which, so far as I know, is the only aerial *Pythium* disease ever described. It is the only one ever shown to spread through the air, even though the distance is only from the soil to a plant immediately above. The typical *Pythium* disease has to start from infection from the soil to a plant part, root, leaf, stem, or fruit, that is touching the ground. We would not expect this group to be a threat for widespread destruction. Most of those in the *Phycomycetes*, or water molds, would be the same way. But there are exceptions. There is one, late blight of potato and tomato, which has demonstrated through the years that it can cause destruction and disaster. It caused the famines in Ireland and it has caused great damage to potato and tomato in the United States. We have an active quarantine on against this disease in this state at this time. It has very flimsy, fragile-looking spores and it does not appear that they could survive over long distances and still be viable, but they can.

So you have exceptions, even where you don't look for them, even in the bacteria. The bacteria must be spread in droplets of water which do not travel long distances. They do not overwinter except in seed or the refuse of the host and do not last after this refuse is gone. You would not think that there would be a threat from one of these that would spread over wide areas. But there are exceptions. There is one, Granville wilt, that will overwinter and last for long periods in the soil without the host plant. Consider another fungus disease, Southern blight, which we have here regularly. We would never expect this type of disease to be a threat because it does not even have a summer spore stage. Rather, the kind we would expect to be a threat is one like brown rot of peach. Each one of the little bumps you see in a rotted spot is composed of hundreds of hyphae that are slightly modified into what we call conidiophores. Each one bears a chain of spores. When you add up the chains of spores on the hundreds of conidiophores in each of the clumps and tack on a five-day cycle from rotted spot to rotted spot, you have the potential for enormous reproduction of this organism. Nowhere else in nature is this capacity for explosive reproduction found except in the bacteria, and they have to have a liquid medium. If these spores can travel for long distances, still be viable when they hit a susceptible host, and are highly pathogenic, then you have the seeds for disaster, especially when there is the wide sweep across the country of a crop that is all susceptible.

Consider one of the rusts. The rusts have an enormous potential for reproduction. Each one of the eruptions on a leaf or stem is filled with thousands of spores. These spores can ride the winds and still be viable when they land on a susceptible plant, so we have had epiphytotics of the rusts throughout the past. A great deal of work has been done over the years to produce resistance so as to head them off. Good success has been made, but the potential threat is still there.

Combine a capacity for rapid multiplication with variability of the organisms. In case there is anyone who does not understand what I am talking about, this means that there are organisms causing plant diseases which have forms that you cannot distinguish with the microscope, or any other kind of test, until you put them on different varieties of the same crop. One form will cause death or disease of certain varieties of the crop and others will not. If you shift to another form, it will produce a different pattern. It will kill varieties that are resistant to the other forms and not attack some varieties which were killed by the other form.

No one should make a talk of this sort without constructive suggestions, so I will advance my suggestions as to what can be done about the situation. First, we need to have more awareness among the plant pathologists about this prospect and what is involved. We must try to make other scientists aware of this threat and include the general public to let them know what we must contend with in the future. We must spread the word.

The second point is seed protection. Many plant diseases are spread by seed, and this situation is involved in the potential we described. Thus, we must use the techniques for clean seed that are known. If you clean up a seedstock and use quarantine procedures, you eliminate many dangerous diseases. But is is very difficult to get seed producers and the general public to cooperate in carrying this out. I can cite an example of one, stem anthracnose on lima beans, that is very prevalent in our area. I do not even recommend growing lima beans. I cannot tell you a seed company from which you can obtain seed that will not have this fungus in the seed. I wrote to a company in the past offering to develop a clean seedstock of any variety they had. I agreed to locate some farmers here to show them how to continue this disease-free seed if the company would contract for the seed. I though they could advertise it as disease-free seed and get a premium price. I could not get this done. Yet we must take advantage of these procedures to protect our seed so that they do not carry disease-producing organisms.

The third item is built-in breeding, and I want to come back to that. So we will omit it for now. the fourth item is rational chemicals. What do I mean by rational chemicals? I mean that we should be rational in this pollution uproar about the use of chemicals. Any that are really dangerous to the environment we should cooperate in seeing that they are not used. We should also raise our voices as loud as we can to stop the barring of chemicals where there is not a real threat to the environment but only an emotional issue involved. We have already had one case of this kind in Plant Pathology. We have lost the use of mercury seed treatments. A single family got into a real pitiful situation because of the misuse of mercury seed treatments. The decision to bar these chemicals was made on an irrational basis. We could make a much more rational case by taking a look at the death toll on the highways during the Thanksgiving holidays, 658, and saying let's bar all vehicles from our highways on that day!

Back to built-in breeding. The ideal situation would be for plant breeders and plant pathologists to develop lines of each crop from different germplasms. Each line would have the marketable product with the same appearance and maturity for harvesting at the same time. The seed from these different strains could be mixed for synthetic varieties. This would give us the variation in germplasm that we used to have on the farms in the past. But this is a solution that we do not have the resources for now and will not have for a while. We will eventually, because we will have to do this, but let's go to a more practical thing that can be done. It will make breeding programs longer and harder but it can be incorporated and used now.

We classify resistances in many ways. In one way, we divide them into two groups. One is vertical resistance, which is resistance to one particular form of an organism and generally quite high. The other is horizontal resistance, which generally is not as high as vertical resistance, but it applies to more forms or all forms of the organism. Consider a variety with vertical resistance. In the field, the crop might not suffer any economic loss from a particular race of a disease. But what happens if you shift to another race? The variety might not be resistant, and there could be a total loss. Horizontal resistance is better. There is much less chance of a drastic loss of production from a disease. What I am advocating is that wherever we can find both the horizontal and the vertical resistance, we should put them into active breeding programs for disease resistance so that we have both of them. And if you can't get vertical resistance at least we should try to have the horizontal resistance. Then, when we do get a variety that has a desirable yield, quality, and type, we may have one that will not go out with a change in the organism so that we have to start all over again.

PRECEPTS OF SEED STORAGE (Revised)[1]

James C. Delouche[2]

Adequate provisions for storage of seed are a common feature of successful seed production-marketing operations regardless of their geographical location. Seeds in storage represent not only a program or company's potential return on a substantial investment in research and development, production, facilities, operation and promotion, but also an input vital for crop production. Proper storage preserves the viability and vigor of seed through marketing and protects the seedsman's investment, profit, and reputation.

A successful seed storage program does not just happen--it must be planned for--just as one must carefully plan for production, promotion, distribution, etc. Planning for seed storage must be thorough and based on a clear concept of the "purposes" of storage, an understanding of the determinants of seed quality, and the processes of seed deterioration, knowledge of pertinent principles of environmental engineering, data on local climatic conditions, and a careful analysis of specific seed storage needs.

Satisfactory storage for seed can be achieved in only two ways: location of the storehouse in a geographical area characterized by a reasonably favorable climate for storage, or modification of the environment immediately around the seed (or within storehouse) to produce conditions favorable for seed storage. Since most seed operations are already located or will be located in areas determined by a host of considerations in addition to their favorableness for seed storage, selection of a storage site strictly on the basis of its favorableness for storage is seldom practical.

Seedsmen who are fortunate enough to be already located in a climate favorable for seed storage need only to dry the seeds to a "safe" moisture content, package, and protect them from rain, dust, snow, rodents, and insects. It should be pointed out, however, that the favorableness of a climate for seed storage is relative and almost wholly dependent on the storage time-frame, *i.e.*, period of storage. Most climatic zones in the U.S. are sufficiently favorable to maintain germination of warm season crops from harvest in late summer or fall through the following planting season (spring or early summer). Seed vigor, on the other hand, can decrease substantially, especially when the seed are of only "average" quality to begin with, unless the storage environment is modified by some degree of "air conditioning."

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[1]Revision of article published in 1968 Mississippi Short Course Proceedings.

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Only a few climatic zones in the U.S. are favorable enough to preserve seed quality (germination and vigor) at a high level through "carry-over" storage (16 to 20 months). For even longer storage periods, *i.e.*, three to ten years, such as might be needed for breeder and selected foundation seed stocks, and some vegetable and ornamental seeds, conditioning of the storage environment is always necessary.

Seed operations located in warm, humid climatic zones such as the Southeastern U.S. are confronted with many storage problems for which "conditioned" storage might be the most effective and economical solution.

Major "Causes" of Seed Storage Problems

Most seed storage problems in the U.S. (and elsewhere) arise out of situations and circumstances as follow:

(1) Low quality seed are placed in storage (the seed may have been deteriorated in the field before harvest, and/or improperly dried, mechanically damaged, etc.).

(2) Inadequately dried seed are placed in bulk storage without proper aeration or packaged at too high a moisture content.

(3) Seed are "carried over" too long.

(4) The kinds of seed stored are naturally "short lived," *e.g.*, seed of onions, soybeans, peanuts.

(5) The seed are stored in poorly ventilated, damp, warm warehouses.

(6) Ambient conditions are very unfavorable for storage.

Seedsmen who are rather consistently plagued with storage problems should "think through" the problems so as to identify the most important contributing factors and to devise the most economical solution. Orderly and effective "thinking through" of seed storage problems and needs requires a good working knowledge of the basic principles of storage derived from research and experience. In this paper, we have tried to condense and summarize the principles and practices of seed storage in nine *precepts* which should provide an adequate basis and suitable context for effective planning and some problem solving. Before considering the precepts of storage, the purposes of, or reasons for seed storage should be reviewed and the storage period defined.

Reasons for Seed Storage

Seed are stored for two reasons: first, since there is usually an interval of time - 1 to 10 months, depending on kind of seed and cropping system - between seed harvest and planting of the succeeding crop, seed have to be kept in some place. Unfortunately, the concern of some seedsmen never extends beyond this spatial requirement. Any place will do - mixed indiscriminately with fertilizers, herbicides, and feed, on a damp concrete floor, in a hot, poorly ventilated building with a leaky roof, etc. The more fundamental reason for seed storage is, of course, to preserve or maintain their physiological quality throughout the storage period by minimizing the rate of seed deterioration.

The Storage Period

Provisions and plans for seed storage are all too often confined to the interval between the completion of processing (and packaging) and the beginning of distribution. This interval is only a segment, although an important segment, of the total storage period. Concentration of managerial and technical efforts, funds, and other resources on the "packaged seed" segment of storage to the neglect of others can be both inefficient and ineffective.

The total seed storage period comprises the following segments in sequential order:

(a) Bulk storage - the period from harvest through packaging, including aeration, drying, and "holding" operations.

(b) Packaged storage - the period between packaging and distribution.

(c) Distribution storage - the period from distribution through sale to the farmers, including time in transit, at assembly points (wholesalers), and at retail outlets.

(d) Farm storage - period between delivery of seed to farm and planting.

The control that an individual seedsman has over the different segments of the storage period varies considerably. In some cases, an individual seedsman directly controls all operations through purchase of the seed by the farmers, while in others, his control extends only through distribution with other seedsmen responsible for storage at wholesale and retail outlets. It is often necessary, therefore, for several seedsmen to work in concert to provide good conditions for seed storage and to work with farmer customers to insure that good storage practices will be followed after the seed are delivered to the farm site.

Seed Deterioration

The purpose of seed storage has been previously stated, *viz.*, to preserve or maintain the physiological quality of seed for the period desired through minimization of the rate of deterioration. Since seed storage is basically concerned with "control" of deteriorative processes, some knowledge of these processes is essential for successful seed storage operations.

The term "deterioration" is commonly applied to both biological and non-biological materials. Yet, it is a rather difficult term to rigorously define, especially as it relates to seed quality. For our purposes here, however, deterioration of seed can be considered as some degree of impairment in function resulting from changes occurring over time - a few minutes or 20 years. Whenever the functional "machinery" in seed is impaired, seed quality is lowered, or - to use another difficult to define term - vigor is reduced.

Characteristics of Seed Deterioration

While it is not possible to rigorously define seed deterioration, we can characterize it in terms that are of some significance in the practical arena of the seed industry.

1. Seed deterioration is an inexorable process. All living things, including seed, degenerate with time and eventually die. While death is inevitable - at least in the light of present knowledge - we can control the rate of dying of seed to our advantage.

2. Seed deterioration is an irreversible process. On the basis of present knowledge, the deterioration of seed must be considered as an irreversible process. We cannot make high quality seed out of low quality seed, although we often try. There are, of course, certain treatments such as with fungicides, which result in "better performance" of seed, but the basic physiological quality of the seed is not improved.

3. The rate of seed deterioration varies among seed kinds, among lots of the same seed kind, and among individual seeds within a lot. These characteristics are discussed under Precepts I and II.

Although the characteristics discussed above might contribute little toward a concept or rigorous definition of seed deterioration, they do define both the limits and direction of efforts in seed storage operations. We are limited by what must be considered - at least for the present - as biological facts. Deterioration of seed cannot be prevented, although its rate can be rather closely controlled. The processes of deterioration cannot be reversed. And, some kinds (species and varieties) of seed are inherently longer-lived than others. Accepting these limitations, efforts must then be directed at minimizing deterioration in quality from the high level attained at the time of maturation by taking all the actions which contribute to a high storage potential for seed, and then providing conditions that permit realization of this potential for the period desired.

Deteriorative Changes in Seed and Their Consequences

In our consideration of some of the characteristics of deterioration in seed, another might have been added: that deterioration is characterized by change. Indeed, in our context, deterioration and change - detrimental change - are almost synonymous. For deterioration is identifiable only in terms of observable or measurable changes in the response-reactions of seed. Conversely, detrimental changes, *e.g.*, loss of germination or vigor, are said to be the result of deterioration.

A detailed review of the literature and discussion of the biochemical and physiological events in seed deterioration would be out of place in a paper of this type and style. Nevertheless, the "graphical" summary of the better documented "events" in seed deterioration and their probable sequence as shown in Figure 1 should be of interest to anyone with responsibilities for seed storage and/or quality control.

In the sequence of deteriorative changes postulated in Figure 1, it can be readily seen that during deterioration, the "performance potential" of seed becomes progressively impaired (reduced) until they lose their capacity to germinate, at which time "performance potential" is *zero*. Since loss of the capacity to germinate is the *last* practically significant consequence of deterioration, the design and evaluation of storage conditions only in terms of "maintenance of germination" is not sufficient. The "lesser consequences" of deterioration must also be considered because collectively they determine the "vigor" level of the seed. And, the vigor of seed determines how well they germinate, emerge, grow, and develop in the farmer's field.

I. LONGEVITY OF SEED IS A CHARACTERISTIC OF THE SPECIES OR VARIETY

Some kinds of seed are inherently long-lived, others are short-lived, while others have an "intermediate" life span. Differences in storability extend even down to the variety level. It has been known, for example, that certain inbred lines of corn are "poor storers" and that this characteristic is inherited (Figure 2).

Inherent differences in seed longevity are facts the seedsman must accept and contend with as best he can. Among the vegetables, onion seed are notoriously short-lived, radish seed are intermediate in longevity, and watermelon seed are relatively long-lived. Soybean and peanut seed do not store well as compared to seed of wheat, corn, cotton, sorghum, and rice. In some cases, seed kinds which have very similar chemical and physical properties differ substantially in longevity. Tall fescue and annual ryegrass seed are similar in structure, chemical composition, and appearance (to the untrained eye). Yet, ryegrass seed store better than tall fescue seed.

Differences in the longevity among seed kinds under identical storage conditions are evident from the data in Table 1.

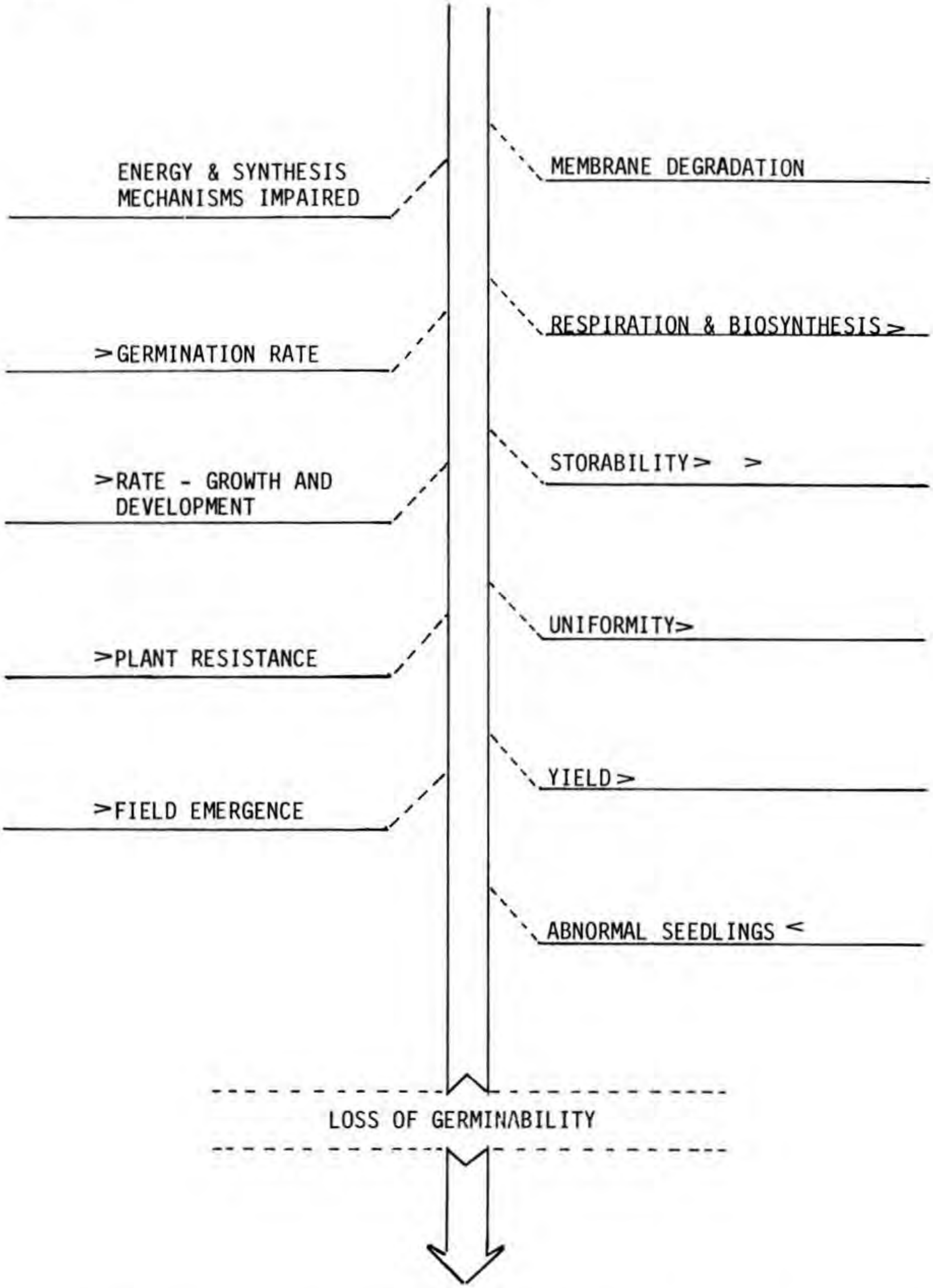

Figure 1. Possible sequence of changes in seed during deterioration.

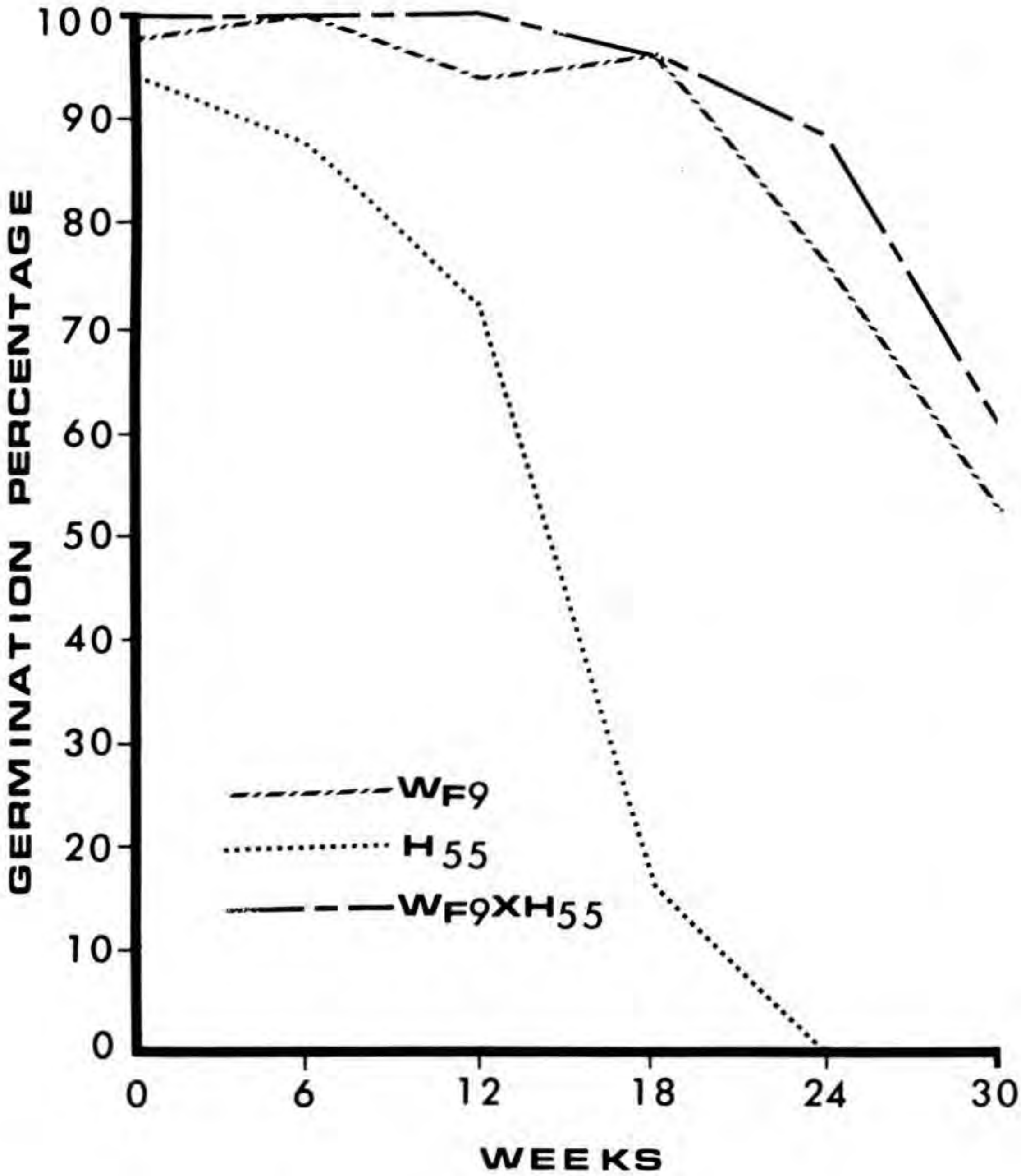

Figure 2. Differences in longevity of seed of two inbred lines of corn and the single cross hybrid under conditions of 86^{0}F and 75% relative humidity. The seed were produced at the same time and in the same place.

Table 1. Germination percentages of high quality seed lots of twelve species during storage under ambient conditions at Mississippi State, Mississippi.

Kind	Storage Period (Months					
	0	6	12	18	24	30
Bean, Snap	98	96	96	90	92	90
Clover, Red	94	94	88	73	60	58
Corn, Field	98	98	96	96	90	85
Fescue, Tall	95	90	85	78	37	12
Lettuce	96	90	82	68	21	2
Onion	96	90	42	6	0	0
Peanut, Shelled*	96	93	60	5	0	0
Radish	98	98	98	98	95	92
Rice	94	92	94	93	90	88
Sorghum	96	96	93	86	82	78
Soybean	96	94	85	60	42	0
Timothy	96	96	86	76	37	0
Watermelon	98	98	96	95	90	88
Wheat	98	97	97	96	92	90

*Peanut seed hand-shelled.

II. HIGH QUALITY SEED STORE BETTER THAN LOW QUALITY SEED

The storage potential of seed is greatly affected by their quality at the time they enter storage, or their pre-storage history. The pre-storage history of a seed lot encompasses all the "events" in the "life" of the seeds from the time functional maturity is reached until they are placed in storage.

Seed are highest in quality at the time functional maturity is attained. Since most kinds of seed reach maturity at moisture contents too high for mechanical harvest, the seed are subjected to the field environment from maturation to harvest. The post-maturation pre-harvest period normally ranges from 1 to 4 weeks for the different kinds of seed. Adverse climatic conditions, especially rain, high humidity, warm and freezing temperatures can result in rapid and severe deterioration of the seed, and so on. The degree of deterioration that occurs in seed prior to harvest determines their quality at harvest and conditions their performance in storage.

In like manner, mechanical abuse to seed associated with harvesting, handling and processing operations, and damage caused by inadequate or improper aeration or drying can have both immediate and residual effects, *i.e.*, performance of the seed might be affected at the time of injury or not until some later time during storage.

In characterizing seed deterioration, we pointed out that the rate of deterioration of seed in storage varies among seed lots of the same kind and among individual seeds within a lot. These variations in storability are, of course, related to the pre-storage history of seed lots. Seed lots with a "good" pre-storage history (minimal field deterioration, mechanical damage, etc.) store well, while those with a "bad" pre-storage history store poorly. Examples of the variability in storability of seed lots of the same kind under similar conditions are shown in Figure 3. Note that germination percentages of the lots were essentially the same at the beginning of storage, emphasizing the fact that a poor pre-storage history or low storage potential is not always reflected in a low germination percentage.

Some very practical guidelines for seed storage can be derived from *PRECEPT II* and associated discussion.

(1) Seed quality *is not improved* by storage, regardless of how favorable are the conditions provided. The best of storage conditions can only *maintain quality*.

(2) Good seed production, harvest, aeration/drying, and processing practices contribute enormously to successful seed storage operations. Planning for storage, therefore, *begins in the field*.

(3) Carry over only high quality seed.

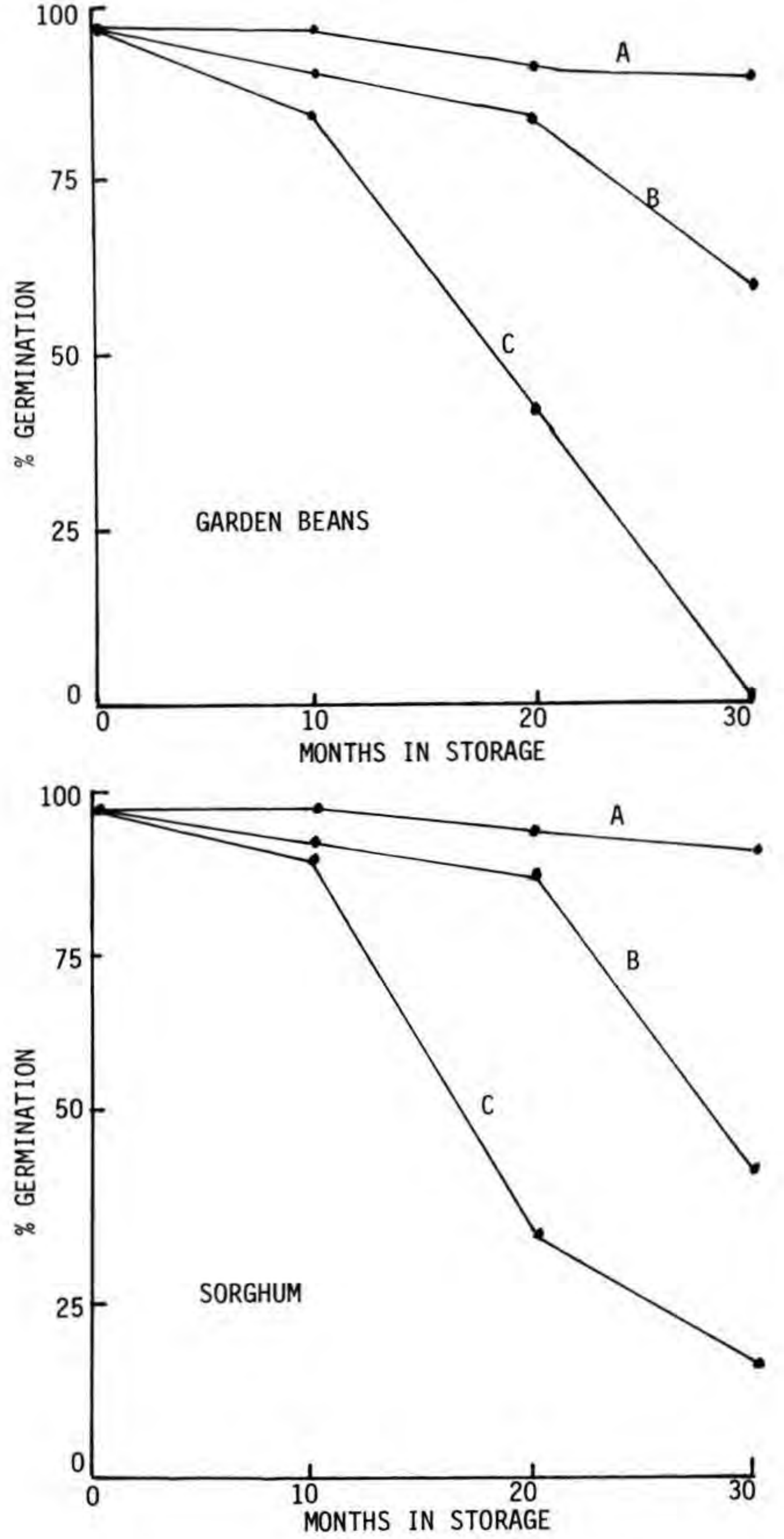

Figure 3. Differences in longevity of three seed lots each of garden beans and sorghum under open storage conditions.

(4) Don't wait until the end of the sales season to start thinking about carryover. Place the desired amount (of the best lots) in the most favorable storage as soon after bagging as possible.

III. SEED MOISTURE CONTENT AND TEMPERATURE ARE THE MOST IMPORTANT FACTORS INFLUENCING SEED STORABILITY

The life span of seed is largely determined by moisture content and temperature. The role and importance of moisture content in the life of seed are illustrated in Figure 4.

The rate of degenerative or deteriorative processes in physiologically mature seed increases as seed moisture content increases.[2] If moisture content is sufficiently high (say, above 18%), biological activity in the seed mass will produce sufficient heat to injure them unless they are well-aerated. High moisture content seed are also more susceptible to heat damage than seed at lower moisture contents. This is especially important during drying operations.

In addition to its direct effect on physiological processes, seed moisture content indirectly influences storability through its influence on the growth, activity, and reproduction of storage molds and insects. These aspects will be considered under *PRECEPT IV*.

Temperature also plays an important role in the life and death of seed. Within the normal range, biological activity of seeds, insects, and molds increases as temperature increases.

Temperature and moisture effects compensate and reinforce each other in various ways. The higher the moisture content of the seed, the more they are adversely affected by temperature. High moisture content seed (usually not yet harvested) can be damaged by below freezing temperatures, while air dry seed (10-18% moisture) are remarkably resistant to low temperature damage. High drying temperatures will damage high moisture content seed, especially if air flow rate is low. As the seed dry, however, their thermal death point increases up the temperature scale.

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[2]As in the case of most rules, there are exceptions. Seed of some aquatic species store better in water or in an imbibed condition than at "air-dry" moisture contents. Seed of some wood plants degenerate if seed moisture content drops *below* a certain level.

SEED MOISTURE CONTENT	
35 - 80%	Moisture content of developing seed; seeds not mature enough for harvest.
18 - 40%	Seeds physiologically mature; respiratory rate high; seed susceptible to field deterioration; heating occurs if seed bulked without adequate ventilation; molds and insects very active; seed susceptible to mechanical damage in harvesting and handling.
13 - 18%	Respiratory rate still high; can get heating at highest levels; molds and insects can be damaging; seed resistant to mechanical damage.
10 - 13%	Seeds store reasonably well for 6 to 18 months in open storage in temperate climates; insects can still be a problem in susceptible seeds; seed susceptible to mechanical damage.
8 - 10%	Seed sufficiently dry for 1 to 3 years open storage in temperate climates; very little insect activity; seed very susceptible to mechanical damage.
4 - 8%	Safe moisture content for sealed storage.
0 - 4%	Extreme desiccation can be damaging to seed; hardseededness develops in some kinds of seed.
33 - 60%	Seeds germinate when they imbibe water to these levels.

Figure 4. Role and importance of moisture content in the life of seeds.

IV. MOISTURE CONTENT OF SEED IS A FUNCTION OF RELATIVE HUMIDITY AND, TO A LESSER EXTENT, OF TEMPERATURE

Seed are hygroscopic. They absorb moisture from the atmosphere or lose moisture to it until the vapor pressures of seed moisture and atmospheric moisture reach equilibrium. Since the vapor pressure of atmospheric moisture (vapor) at a specific temperature and pressure is directly related to the degree of saturation or relative humidity, the different kinds of seed attain specific or characteristic moisture content attained under these conditions is variously referred to as the *equilibrium moisture content* or *hygroscopic equilibrium.*

Establishment of moisture equilibrium in seed is a time-dependent process, that is, it does not occur instantaneously. A period of time is required, the length of which varies with seed kind, initial moisture content, the percentage relative humidity, and temperature. The establishment of moisture equilibrium in alfalfa seed under several levels of relative humidity is illustrated in Figure 5.

Under open storage conditions, seed moisture content fluctuates with *long term* changes in relative humidity. Seed moisture content, therefore, does not rise and fall with the normal diurnal fluctuations in relative humidity (low in mid-afternoon, high in early morning) but, rather, attains a sort of "average" value between these extremes. These responses are clearly evident in the rates of moisture absorption and desorption by ryegrass and alfalfa seed under 24-day alternations between low and high relative humidities (Figure 6). Note that the seeds absorb moisture more rapidly and to a higher level during the second 24-day period (second cycle) at 93% relative humidity than during the first, even though the seeds were at about the same moisture content at the beginning of each cycle. It can also be seen that diurnal fluctuations in relative humidity have little effect on seed moisture content.

Equilibrium moisture content varies among seed kinds. In general, the equilibrium moisture content of "oily" seed is lower than that of "starchy" seed at the same relative humidity and temperature. This phenomenon can be accounted for by the fact that fats and oils do not mix with water. Thus, in a seed with 50% oil content, the moisture has to be concentrated in half the seed, while in a seed containing 10% oil, the moisture is distributed throughout 90% of the seed.

The equilibrium moisture content of seed is also affected by temperature and the extent of deterioration. As temperature increases, the moisture content of seed in equilibrium with a specific level of relative humidity decreases on the order of about 1% moisture (decrease) for each 20 F rise in temperature. Deteriorated seed have a slightly higher equilibrium moisture content than high quality seed.

In seed storage planning and operations, emphasis is most often placed on the controlling influence of relative humidity on seed moisture

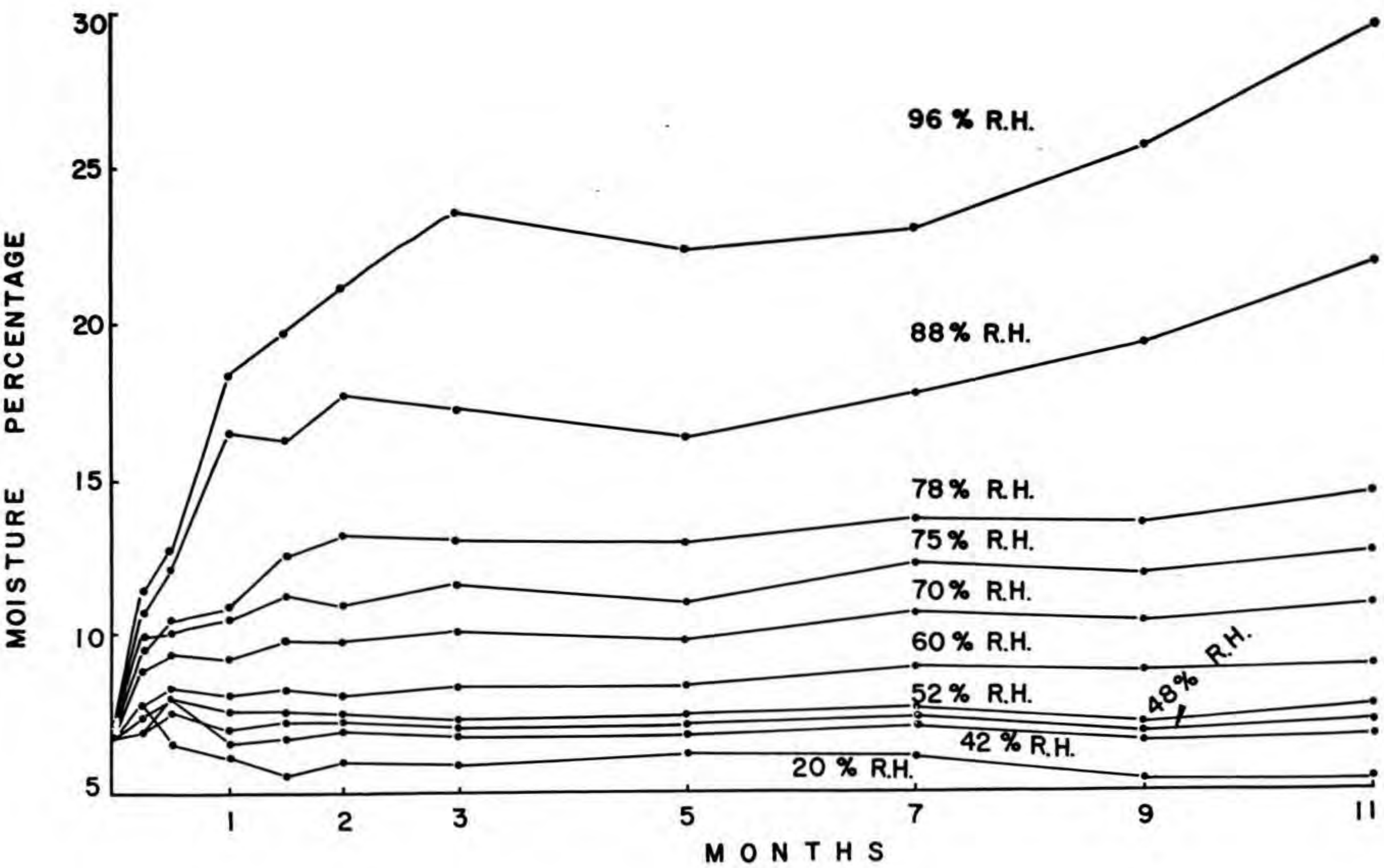

Figure 5. Moisture contents of alfalfa seed stored under different levels of relative humidity over a 11 month period at 68° F. Source: Joo (MSU)

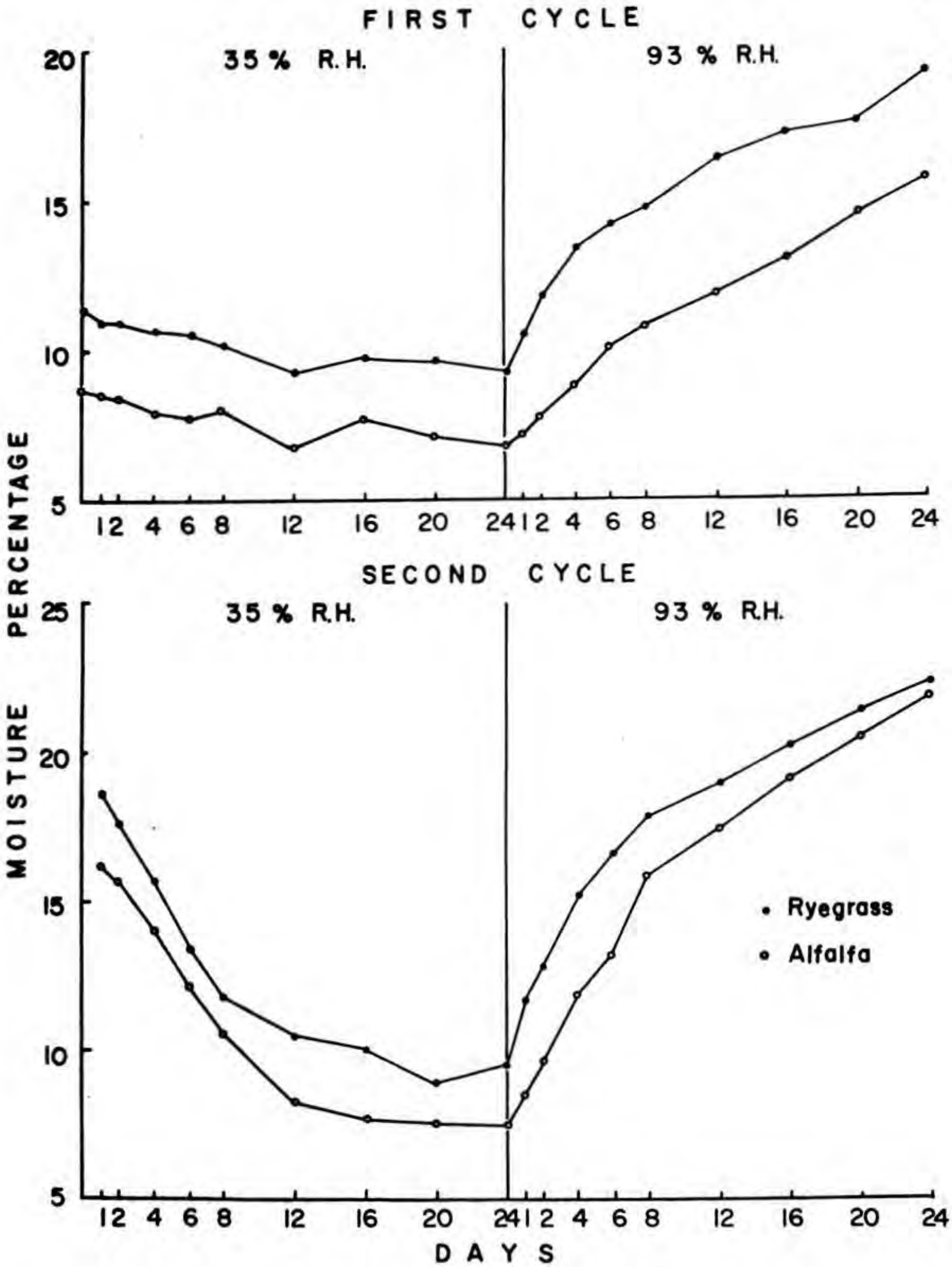

Figure 6. Rates of moisture absorption and desorption by ryegrass and alfalfa seed under flucuating levels of relative humidity.

content. This emphasis is proper during the packaged seed phase of storage provided the packaging material is not moisture vapor-proof. The hygroscopic equilibrium between seed and ambient relative humidity, however, is a two-way street. During the critical days following harvest when seed are in bulk storage or drying bins, the relative humidity of the immediate environment within the seed mass is more influenced by the moisture content of the seed than by "outside" conditions.

The relative humidity within a mass of soybean seed harvested at 16% moisture and loaded into a bulk storage bin is above 80%. It will remain at this level for a considerable period of time regardless of the relative humidity outside the bin unless the seed are dried or adequately aerated. It is important, therefore, to consider both sides of the seed-moisture vapor equilibrium because relative humidity within the seed mass has important effects other than on seed moisture content. The classic and comprehensive works of Christensen and associates (University of Minnesota) have conclusively demonstrated that: (a) storage fungi are a major cause of quality losses - including germinability - in stored grain and seed; (b) the important storage molds cannot grow and reproduce on grain or seed in equilibrium with a relative humidity less than 65-70%; and (c) drying seed or grain to a moisture content in equilibrium with a relative humidity below 65-70% and maintaining moisture content at that level during storage effectively eliminates the storage mold problem regardless of other conditions of storage.

The activity and reproduction of storage insects are also dependent on relative humidity of the microenvironment in the seed mass. Activity of some of the more serious insect pests decreases rapidly as relative humidity drops below 50% and reproduction stops altogether at less than 35% r.h.

The hygroscopic equilibrium moisture contents for important kinds of seed are given in Tables 2 and 3.

V. MOISTURE CONTENT IS MORE IMPORTANT THAN TEMPERATURE

As previously mentioned, seed moisture content and temperature are the most important factors in seed storage. Of these two, moisture content has the greater influence on seed longevity. Well-dried seeds will store quite well at temperatures up to 80 F. And this fact has led to the development of sealed storage of seed. On the other hand, relatively high moisture content seeds will keep well only if the temperature is reduced to 50 F or less.

Several years ago, Harrington[3] proposed several "rules-of-thumb" for seed storage. One of these rules stated that good seed storage is

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[3]Professor of Horticulture, University of California, Davis.

Table 2. Moisture contents of field crop seed at equilibrium with various levels of relative humidity (approximately 77 F).

Kind	Relative Humidity (%)						
	15	30	45	60	75	90	100
Alfalfa	--	6.4	7.4	8.6	13.0	18.0	--
Barley	6.0	8.4	10.0	12.1	14.4	19.5	26.8
Bermudagrass, Hulled	--	8.1	9.2	10.8	13.6	17.2	--
Buckwheat	6.7	9.1	10.8	12.7	15.0	19.1	24.5
Clover, Crimson	--	7.0	8.6	--	13.5	19.6	--
Clover, Red	--	7.2	8.2	9.2	13.2	18.4	--
Corn, Field	6.4	8.4	10.5	12.9	14.8	19.1	23.8
Corn, Pop	6.8	8.5	9.8	12.2	13.6	18.3	23.0
Fescue, Tall	--	8.4	9.8	11.2	13.3	17.1	--
Flax	4.4	5.6	6.3	7.9	10.0	15.2	21.4
Lespedeza, Korean	--	7.2	8.2	9.8	13.5	18.6	-
Millet, Pearl	--	8.5	9.8	12.0	13.7	17.0	--
Peanut	2.6	4.2	5.6	7.2	9.8	13.0	--
Rice, Milled	6.8	9.0	10.7	12.6	14.4	18.1	23.6
Rye	7.0	8.7	10.5	12.2	14.8	20.6	26.7
Ryegrass	--	7.5	10.0	11.2	13.8	17.0	--
Sorghum	6.4	8.6	10.5	12.0	15.2	18.8	21.9
Soybeans	4.3	6.5	7.4	9.3	13.1	18.8	--
Sudangrass	--	8.6	10.1	11.6	13.2	18.8	--
Sunflower	--	5.1	6.5	8.0	10.0	15.0	--
Timothy	--	--	9.5	11.4	13.6	17.2	--
Vetch, Hairy	--	--	--	--	13.0	19.0	--
Wheat:							
Soft Red	6.3	8.6	10.6	11.9	14.6	19.7	25.6
Hard Red	6.4	8.5	10.5	12.5	14.6	19.7	25.0
White	--	8.6	9.9	11.6	15.0	19.7	26.3

Table 3. Moisture content of vegetable seeds at equilibrium with levels of relative humidity (approximately 77 F).

Kind	Relative Humidity (%)					
	10	20	30	45	60	75
Beans:						
Broad	4.2	5.8	7.2	9.3	11.1	14.5
Lima	4.6	6.6	7.7	9.2	11.0	13.8
Snap	3.0	4.8	6.8	9.4	12.0	15.0
Beet, Garden	2.1	4.0	5.8	7.6	9.4	11.2
Cabbage	3.2	4.6	5.4	6.4	7.6	9.6
Cabbage, Chinese	2.4	3.4	4.6	6.3	7.8	9.4
Carrot	4.5	5.9	6.8	7.9	9.2	11.6
Celery	5.8	7.0	7.8	9.0	10.4	12.4
Corn, Sweet	3.8	5.8	7.0	9.0	10.6	12.8
Cucumber	2.6	4.3	5.6	7.1	8.4	10.1
Lettuce	2.8	4.2	5.1	5.9	7.1	9.6
Mustard, Leaf	1.8	3.2	4.6	6.3	7.8	9.4
Okra	3.8	7.2	8.3	10.0	11.2	13.1
Onion	4.6	6.8	8.0	9.5	11.2	13.4
Parsnip	5.0	6.1	7.0	8.2	9.5	11.2
Pea	5.4	7.3	8.6	10.1	11.9	15.0
Pepper	2.8	4.5	6.0	7.8	9.2	11.0
Radish	2.6	3.8	5.1	6.8	8.3	10.2
Spinach	4.6	6.5	7.8	9.5	11.1	13.2
Squash, Winter	3.0	4.3	5.6	7.4	9.0	10.8
Tomato	3.2	5.0	6.3	7.8	9.2	11.1
Turnip	2.6	4.0	5.1	6.3	7.4	9.0
Watermelon	3.0	4.8	6.1	7.6	8.8	10.4

achieved when the percentage relative humidity in the storage environment and the storage temperature in °F add up to 100; examples - 50% relative humidity and 50 F, 60% R.H. -40 F, 40% R.H. - 60 F, etc. Such conditions would provide very good storage indeed! Actually, conditions this favorable are not required for most kinds of field seed unless the storage period is longer than two years.

As is the case with most "rules-of-thumb," which are vastly simplified summaries of many factors and considerations, the temperature + relative humidity = 100 rule can be misleading if taken too literally. The rule implies an equivalence of the effects of temperatures and humidity on seed longevity. According to the precept considered here, the two factors do not have equivalent effects. Data given in Table 4 clearly show that humidity (moisture content) is most important. Thus, when summing temperature and relative humidity to determine quality of storage, one must keep in mind that within limits--storage conditions are better the greater the portion of the sum contributed by temperature.

VI. A ONE (1) PERCENT DECREASE IN MOISTURE CONTENT OR A TEN (10) DEGREE DECREASE IN TEMPERATURE NEARLY DOUBLES THE STORAGE LIFE OF SEED

Precept VI dramatizes and brings into sharp focus the one already stated in *III*, *viz.*, that temperature and moisture content are the most important factors influencing the storability of seeds. This precept, based on Harrington's "rules of thumb," is reasonably accurate, particularly in the middle ranges of seed moisture content and temperature.

The interacting effects of relative humidity and temperature on germination of crimson clover seed during a 12-month storage period are given in Table 5. Compare the germination percentages at 60, 80, and 100% relative humidity for the three temperatures 50, 68, and 86 F.

Figure 7 shows germinative responses of rice in sealed storage at three moisture contents over a 12-month period. Note differences in longevity as related to moisture content.

The effect of various storage temperatures on germination of oat seed over a 9-month period are given in Table 6. At the higher temperature levels (95-104 F), a 3^{o} to 6^{o} increase in temperature had a pronounced effect on longevity of the oat seed.

Germination responses of two lots of hybrid sorghum seed during five years storage at two temperatures and several moisture contents are shown in Table 7. Note differences in longevity of the two lots under the moderate storage condition of 11.2% moisture and 86 F.

Decreasing temperature and seed moisture are the two most effective means of maintaining seed quality in storage. There are, however, some limits and precautions that should be observed in decreasing the levels of these two important factors.

Table 4. Germination of crimson clover andsorghum seed during storage under various combinations of relative humidity and temperature.

RH %	Temp. °F	Months Storage 0	4	8	12	Sum % + °F
		Sorghum				
40	68	95	94	94	95	108
60	50	95	94	94	95	110
40	86	95	94	94	93	126
60	68	95	94	95	93	128
80	50	95	92	47	38	130
60	86	94	94	90	76	146
80	68	95	47	10	0	148
		Crimson Clover				
40	68	88	87	87	90	108
60	50	88	88	88	88	110
40	86	88	88	86	84	126
60	68	88	88	86	90	128
80	50	88	75	22	0	130
60	86	88	82	72	23	146
80	68	88	12	0	0	148

Table 5. Mean germination percentages of crimson clover seed after periods of storage under various combinations of relative humidity and temperature.

Temp. °F	Relative Humidity (%)	Months of Storage				
		0	3	6	9	12
50°	20	90	89	88	90	88
	40	90	88	87	89	88
	60	90	87	90	90	90
	80	90	86	56	8	0
	100	90	70	4	0	0
68°	20	90	88	87	87	88
	40	90	87	90	86	90
	60	90	87	86	90	88
	80	90	34	1	0	0
	100	90	0	0	0	0
86°	20	90	86	87	89	84
	40	90	87	87	88	83
	60	90	87	75	66	23
	80	90	0	0	0	0
	100	90	0	0	0	0

Table 6. Effect of storage temperature on germination of oat seed during nine months storage at 8.7 and 10.7% moisture content.

Temp. °F	Moisture %	Months of Storage		
		3	6	9
86°	8.7	93	98	97
	10.7	93	91	97
95°	8.7	99	93	95
	10.7	83	88	85
98°	8.7	98	96	96
	10.7	89	82	42
104°	8.7	92	88	71
	10.7	89	77	5

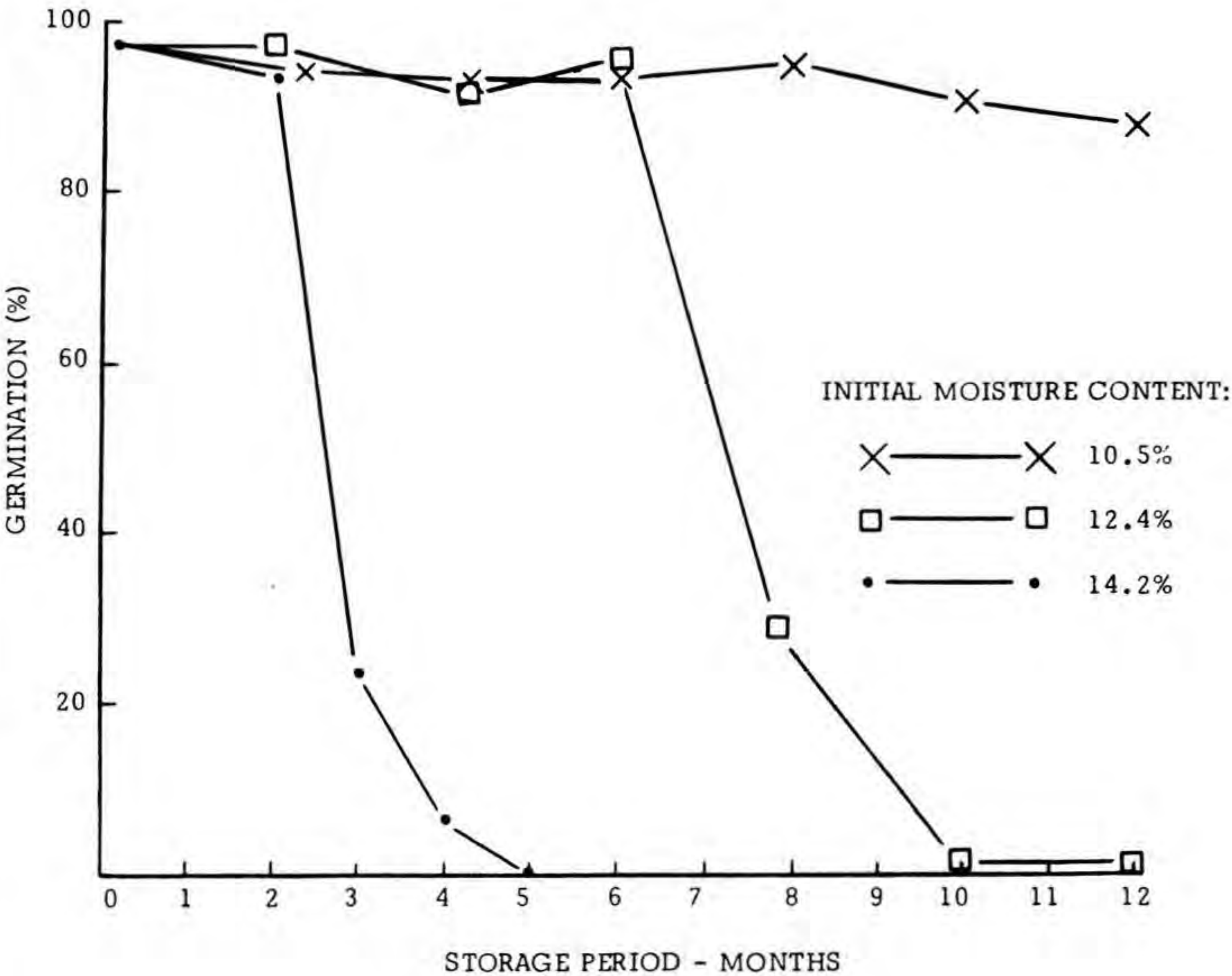

Figure 7. The effect of seed moisture content on the viability of Bluebonnet 50 rice stored at 30^{o} C.

Table 7. Germinative responses of two lots of hybrid sorghum seed stored for five years at different levels of moisture and temperature.

Lot	Temp. °F	Moisture %	Storage Period (years)							
			0	¼	½	1	2	3	4	5
Red	48	12.7	94	94	94	93	87	87	88	82
	86	9.2	94	91	92	84	80	76	74	72
	86	11.2	94	92	87	80	68	64	57	16
	86	14.0*	94	68	0	0	0	0	0	0
	86	16.0*	94	2	0	0	0	0	0	0
White	48	12.6	98	98	95	95	94	94	94	94
	86	9.3	98	97	95	95	95	92	90	90
	86	11.2	98	96	96	92	90	91	86	78
	86	14.0*	98	98	54	0	0	0	0	0
	86	17.0*	98	69	0	0	0	0	0	0

*Moisture content was adjusted by storing seeds over saturated salt solutions. True equilibriums were not established at the two highest levels of humidity (75 and 93%); thus, the moisture content given was that attained after three months storage. Initial moisture content of the two lots was 12.4 - 12.6%.

Excessive desiccation (moisture content below 4%) is injurious to some kinds of seed. Injury can be minimized by slowly increasing moisture content up to 6% or higher prior to planting, but this is seldom practical. Some kinds of seeds (*e.g.*, edible legumes) develop a hardseeded condition under extremely dry conditions which inhibits normal germinative responses. Most kinds of seed are also very susceptible to mechanical damage at moisture contents below 10%. Thus, the seeds should be subjected to minimal handling after they have dried to low moisture contents.

Low temperatures are very effective in maintaining seed quality even though relative humidity might be quite high. Seed moisture content will increase during the storage, but the low temperature will greatly lessen its adverse effects. Removing high moisture content seed from cold storage safely, however, is a complicated problem if the time is late spring, summer, or early fall. As soon as the seed are removed from cold storage, moisture will condense on them just as it does on a glass of iced tea on the patio. Seed moisture content will increase even higher than it is already. As the seeds warm, respiratory rate increases rapidly, molds become active, and in a few days the seeds will drastically decline in germination.

Good cold storage for seeds should not exceed 60% in relative humidity. Most commercial cold storage facilities are designed for succulent or moist materials (potatoes, fruits, meat, etc.) and relative humidity is maintained above 80% to prevent drying of the materials. Thus, the seedsman should be cautious when utilizing commercial cold storage facilities for seed.

VII. DRY, COOL CONDITIONS ARE BEST FOR SEED STORAGE

The general prescription for seed storage is a dry and cool environment. The previous precepts and data discussed indicate just how important are dry, cool conditions. At this point, the question naturally arises: How dry and how cool? It is difficult to answer this question unless three factors are known: (1) kind(s) of seed to be stored; (2) desired period of storage; and (3) physiological quality of the seed.

Seed of most grain crops, *e.g.*, corn, wheat, sorghum, barley, rye, oats, rice, will maintain germination for the 8-9 months period from harvest to planting at a moisture content of 12-13% and normal warehouse temperature except possibly in Southern coastal areas. For maintenance of vigor as well as germination, moisture content should not exceed 12% (relative humidity below 60%) and temperature in the warehouse should not exceed 65 F. In the case of carry-over seed, which means a storage period of 20-21 months, the moisture content of seed of grain crops should be less than 11% and temperature should not exceed 65 F. Since the period of carry-over storage encompasses at least one summer period, temperature and humidity control during the period is most important.

Cotton seed stores about as well as seed of grain crops, and the conditions mentioned above are applicable.

Soybeans and peanut seed are poor storers. For one year's storage (actually 8-9 months), moisture content should be 11 to 12% and the warehouse temperature should not exceed 65 F. Shelled peanuts may have to be stored in a cold room. Carry-over storage should not be attempted unless conditioned storage facilities are available: 65 F and 50% relative humidity or better.

Seed of most forage grass and legume crops will store well for one year at a moisture content of 10-11% at normal warehouse temperatures. When "carried-over," moisture content should be about 10% and temperature should not exceed 65%.

Vegetable seed vary considerably among kinds in their storage requirements. Generally, however, most kinds will store well for one year at a moisture content of 9-11% and a temperature that does not exceed 65 F.

When a storage period longer than 19-21 months is required, conditioned storage is essential for all kinds of seed. Most kinds of seed will maintain quality for 2-3 years when stored at 60 F and 50-55% relative humidity or better. For storage longer than 3 years, conditions should be 50 F and 50% relative humidity or better.

VIII. EFFECTIVE SEALED STORAGE REQUIRES THAT MOISTURE CONTENT BE SUBSTANTIALLY LOWER THAN FOR NON-SEALED STORAGE

In the vegetable seed industry, sealed storage to preserve the viability and vigor of seeds for long periods has been practiced for many years. There is also increasing interest in sealed storage of field crop seed.

One paramount fact must be considered in sealed storage of seeds. Moisture content must be lower (2-3%) than that at which seeds are normally packaged in non-moisture vapor proof containers. With the advent of plastic bags in the 1950's, some seedsmen had rather unhappy experiences packaging seeds in them at the usual moisture content. Hybrid corn, for example, was usually dried to about 13% moisture and packaged in cloth or paper bags, and quality was maintained for 8 to 18 months. When seed of this moisture level were placed in plastic bags and sealed, germination declined very rapidly, especially in the South.

In sealed storage, the atmosphere inside the bag will be in equilibrium with the moisture content of the seed and it will remain at that level. The atmosphere in a moisture vapor proof container filled with seed corn at 13% moisture will equilibrate at a relative humidity of about 65%. Some molds can develop, multiply, and be quite harmful at

65% relative humidity. Also, respiratory rate of the seed is high and remains high. In contrast, the atmosphere surrounding corn seed packaged at 13% moisture in porous containers will rise to nearly 100% at times, but it will also drop well below 65%. The moisture content of the seed will slowly decrease from 13% during the winter and may rise a little above 13% during the humid spring and summer.

Safe moisture contents for sealed storage of seed are generally as follows:

Grain crops	10% or less
Soybeans	9% or less
Forage legumes	8-9% or less
Forage grasses	8-9% or less
Vegetables	8-9% or less

IX. SANITATION IS ESSENTIAL

There are several other recognized procedures for good seed storage that most seedsmen already know. Seeds should be stored in a seed warehouse, not a fertilizer, block salt, herbicide, or feed warehouse. Good sanitation should be a continuous practice. It will minimize storage insect infestations. If storage insects are a problem, the judicious use of insecticides and fumigants, combined with sanitation, will alleviate the problem. The best procedure is not to place insect infested lots in storage with other lots unless all the insects have been killed by fumigation or insecticide treatment.

In warehouses with concrete floors, seed bags should be stacked on wooden pallets to keep them from contact with the floor as considerable moisture can be transmitted through concrete floors. Seed warehouses should also be adequately ventilated (unless they are conditioned) and protected against rodents.

Summary

Seed storage problems have concerned and affected most seed operations at some time. If a problem arises only very infrequently, it is perhaps appropriate to blame it on a troublesome seed lot and go on as before. However, if the problem is recurring, the seedsman should carefully analyze the situation and "think through" his overall storage requirements and facilities in terms of what is known about seed storage. Corrective actions will then be more likely to alleviate the problem and not just the bulk of one's wallet. Seedsmen who are interested in maintaining both germination and vigor should consider establishing "conditioned" storage units.

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