The Handling and Distribution of Granular Fertilizers

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Methods of recognizing, defining, and controlling the segregation of dissimilar particles are discussed, with particular reference to the distribution of granular fertilizers. The quality of fertilizer distribution required by the customer is defined in terms of a "scale of scrutiny," and the performance of the distributing equipment is defined in terms of a "scale of segregation." The matching of these qualities requires the quantitative testing of distribution equipment. Several trends in fertilizer technology are likely to reduce the required scale of scrutiny and make the distributing operation more difficult.

The chief causes of process failures or irregularities within the powder handling industries are either the inconsistent flow of process materials or the segregation of dissimilar particles. Seldom do these problems occur simultaneously. A free-flowing powder will flow consistently, but at the same time it will present maximum opportunity for segregation to occur. A cohesive powder will present flow problems but will have little tendency to segregate. Particles handled within the fertilizer industry are generally free flowing and the major handling problem is likely to be one of segregation. Particular attention will be paid to this problem throughout the article.

Generally a particulate blending and handling process is improved, from the point of view of segregation, in three distinct stages.

Recognition That a Problem Exists. The quality of a blend is commonly judged only on its ability to provide customer satisfaction. Thus a pigment is "satisfactorily" blended in a neutral plastic if the customer is unable to distinguish color variations in the pressed product. This is not to say that the blend is ideal, but only that it passes a "go/no go" test of acceptability. In the case quoted, a decision of the plastic/pigment consumer to reduce the thickness of his product could well result in the blend being considered unsatisfactory. Only rarely are routine tests carried out on a blend to quantify its quality on a graded scale. For this reason a blending process is commonly considered satisfactory until commercial pressures force a recognition of the problem of particulate segregation.

Definition of the Problem. The quality of a mixture depends on how closely it needs to be examined. In the extreme case of examining one particle at a time, the mixture can be described as completely segregated, while at the other extreme of examining the entire batch, the mixture will always be perfect. A critical scale of examination called the scale of scrutiny has been defined by Danckwerts (1953) as "the minimum size of regions of segregation in the mixture which could cause it to be regarded as imperfectly mixed." For a sheet of colored plastic the scale of scrutiny will be fixed by the ability of the human eye to distinguish areas of nonuniform color. Similarly, the scale of scrutiny for a medicinal pill will be related to the pill size and for the glass industry to the furnace size. Having defined a scale of scrutiny for a particular process, it is then necessary to define both the tolerable composition limits and the degree of confidence required of these limits for that scale of scrutiny. The mixture quality needed to meet these requirements can then be defined in statistical terms.

Solution of the Problem. It is not yet possible to make a quantitative prediction of the performance of a handling and blending unit at the design stage. Test work on either existing equipment or on a pilot plant scale is necessary to assess any shortfall of the equipment from the defined performance requirements. If an existing unit does not meet performance requirements then it can be improved by applying the following general principles: avoid excessive size differences between particles in the mixture; avoid operations in which particles tumble down an inclined plane; minimize the volume of blend handled in one operation; and blends should not be handled unnecessarily and ideally blending should occur just prior to the point of usage.

An excellent solution to the segregation problem is to avoid it. As segregation is caused by the nonrandom movement of free-flowing particles, the problem can be avoided by making the mixture cohesive. Commonly this is done either by reducing the mean particle size or by the addition of a liquid to form a paste. The concrete mixer is an excellent example of a potentially strongly segregating mixture being reduced to a comparatively simple problem by the addition of water. In transforming the properties of the powder in this way, care has to be taken not to exchange the problems of segregation for those of handling cohesive powders.

In the following sections the three stages in the analysis of a blending and handling unit will be considered as they relate to the distribution of granular fertilizers.

RECOGNITION OF THE SEGREGATION PROBLEM

As indicated by Hignett (1969), primary fertilizers in the United States are increasingly bought in bulk by local dealers and are then "bulk blended" to the farmer's order or to meet recommendations based on a soil analysis. Such a system eliminates the need for an intermediate merchant and reduces the cost of fertilizer to the farmer. In addition, the farmer can be offered a prescription mixture exactly matched to his needs and a rental or contracting service for spreading the blend.

The chief disadvantage of this method is that local dealers can assemble an agglomeration of handling and blending equipment and set up in business with no awareness of the problems of segregation. The farmer has no easy check on the quality of the mixture distributed on his fields and must await uneven crop growth as an indication of poor fertilizer distribution. In extreme cases the promise of a prescription mixture could be grossly misleading and the farmer would be better advised to apply a standard granulated compound fertilizer and eliminate the blending operation altogether. The most sobering demonstration of the potential severity of segregation is afforded by the "Christmas Tree" demonstration discussed by Williams (1963) and illustrated in Figure 1. In this demonstration a mixture of 18–46–0 and 0–46–0 granules was poured from a feed hopper into a rectangular vessel of 1-in. section. The resulting view can be considered

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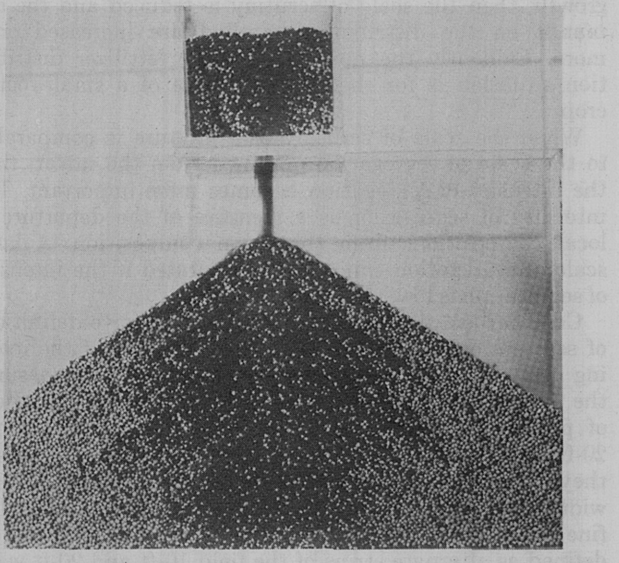

Figure 1. Cross-section of a binary fertilizer mixture illustrating *segregation in a heap.*

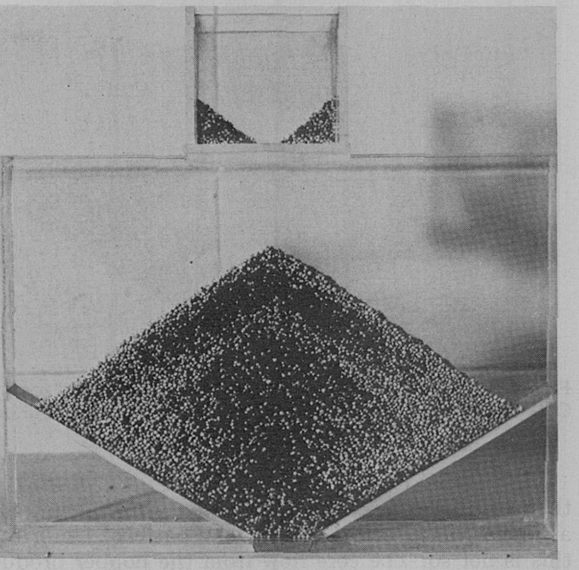

Figure 2. Cross-section of a binary fertilizer mixture illustrating segregation caused by the central loading of the hopper.

as a representative section through a three-dimensional heap.

The very severe segregation of the smaller dyed 0–46–0 granules to the core of the heap is evident, and will occur to a varying degree as long as the granules are free flowing and have a size differential. (The mechanism of this segregation is largely one of the preferential percolation of smaller particles on the moving surface.) It must be emphasized that the granules illustrated were exactly as obtained from a local dealer and that a similar segregation pattern was obtained by using a variety of common granule combinations. In the course of transport from the primary production unit *via* the local blender to the field, the fertilizer undergoes at least three such pouring operations.

The potential for the segregation of dissimilar particles is by no means limited to the pouring operation. Harnby (1967) showed that in certain circumstances the mixing unit itself can classify rather than blend the fertilizer components. The quality of the mixture can also be destroyed in the final broadcasting of the fertilizer on the field. Coventional fan spreaders throw large particles further than small particles, and the central portion of the distributor pass will be rich in the finer fertilizer.

Hignett (1965) and Hoffmeister *et al.* (1964), of the National Fertilizer Development Center of the Tennessee Valley Authority, have been prominent in publicizing the hazards of segregation in local blending units and have carried out quantitative tests on several aspects of segregation. A criticism of their work would be that emphasis has been placed on the elements of the blending and handling process rather than on the integrated process. Ultimately it is the extent of segregation as the particles reach the earth which measures the efficiency of the process and not the quality of the mixture at some intermediate stage.

Consider the problem of transferring a good quality fertilizer mixture from a mixer to the soil. The most common method of doing this would be to convey the mixer discharge to the hopper of a spinning disk applicator, travel to the field, and finally discharge the hopper contents. The applicator hopper can be sectioned in a similar way to the heap demonstration (Figure 2). With a central discharge of the mixture into the hopper there is a predictable segregation of the coarse particles toward the hopper wall. That the mixture has been partially destroyed in this way is not too important. What is important is how the contents of the hopper discharge to the spinning disk of the applicator. This second stage is illustrated in Figure 3. Unfortunately, the segregation within the applicator hopper is preserved by the "core"-type discharge characteristics, and the resulting flow to the spinning disk will be strongly segregated. The extent of the segregation can be seen in the increased concentration of the fine particles at the base of the discharge. It is even possible that a better distribution quality would be obtained by simply layer loading the applicator. In such circumstances the measurement of mixer performance becomes irrelevant.

Taking this series of operations a stage further, the flow of the mixture can be directed into the applicator hopper to avoid the formation of tumbling planes, giving a distribution comparable to that illustrated in Figure 4. In this section some striations are still evident, but the major core-type segregation has been avoided. It would be hoped

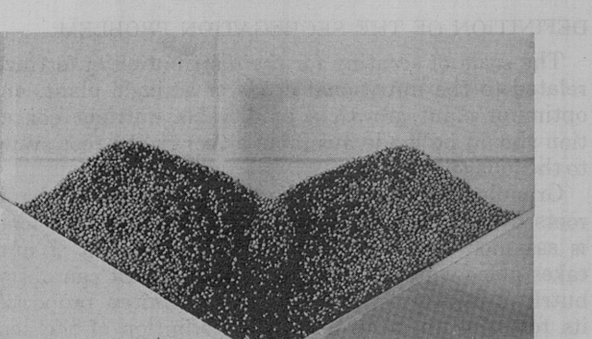

Figure 3. *Core segregation formed at the loading stage* (Figure 2) *is retained on discharge.*

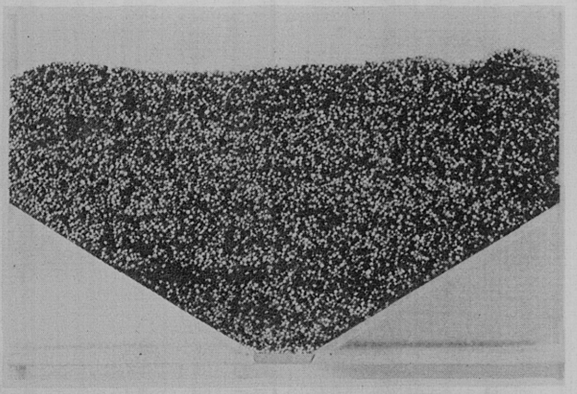

Figure 4. Hopper section charged with binary fertilizer mixture. Core segregation is avoided by the use of a movable pour point.

that a uniform mixture composition would flow from such a hopper, irrespective of the flow pattern. Unfortunately, this is not so. The core flow from the hopper produces an in-flowing slope down which large particles preferentially tumble to discharge (Figure 5). As discharge proceeds, the fine particles percolate toward the sloping base of the hopper and appear in the outflow at the final stages of discharge. In qualitative terms the quality of mixture discharge from the hopper illustrated in Figure 4 is probably superior to that of Figure 2 but will, nonetheless, be far from ideal.

While discharge segregation is not as damaging as loading segregation, care must be taken not to have cumulative accumulation of fines at the base of the hopper by using a partial loading and unloading procedure. The key to this problem is the design of the hopper. It is possible to design the hopper so that the formation of in-flowing slopes is minimized and the mixture quality is largely retained.

As a check on the performance of blending units, state officials commonly sample for mixture composition at the mixture discharge. In the light of the previous discussion no comment will be made on this practice!

DEFINITION OF THE SEGREGATION PROBLEM

The scale of scrutiny for the distribution of fertilizers is related to the nutritional needs of a single plant, and for optimum plant growth a predictable nutrient concentration should be made available either to the root system or to the foliage.

Granular fertilizers are made available to the plant roots by a process of solution and chemical reaction. If it is assumed both that little lateral movement of nutrient takes place within the soil and that a plant can absorb its nutrient requirements from only a limited proportion of its root system, then an initial definition of the scale of scrutiny for crop growth can be made in terms of the root distribution of a single plant.

A single corn plant will have a root system extending over a circle of approximately 8 ft in diameter in its later stages of growth. If the scale of segregation resulting from the distribution process is appreciably smaller than this scale of scrutiny, then the distribution will be satisfactory. The plant will have the ability to adjust to any local concentration variations within the 8-ft circle.

If the root system is not so extensive, as with soya beans, wheat, oats, or barley, then the scale of scrutiny is reduced and the demands on the uniformity of fertilizer distribution are increased. The analogy with the distribution of pigment in a sheet of plastic, as discussed in the introduction, is evident.

The root spread of the plant is dependent not only on the plant type but also on the stage of growth. If the fertilizer distribution is intended as an aid to early-stage growth, then the scale of scrutiny is reduced and the demands on the distribution method are increased once more. Evidently the most demanding fertilizer distribution situation is for the seedling stage of a small-rooted crop.

When the scale of scrutiny of a mixture is comparable to the scale of segregation obtained from the mixer, then the intensity of segregation becomes more important. The intensity of segregation is a measure of the departure of local compositions from the mean composition. A large scale of segregation can often be tolerated if the intensity of segregation is low.

Consider the significance of these qualitative definitions of segregation when applied to the operation of the rotating disk distributor. Hoffmeister *et al.* (1964) measured the segregation resulting from the two pass distributions of potash and triple superphosphate from a fan with a 20-ft throw. Even when using a 10-ft overlap on passes, they found that a central strip of approximately 10-ft width was deficient both in total weight deposited and in fine particles. The scale of segregation in this case can be defined as alternate strips of the field 10-ft and 20-ft wide. This is a large scale of segregation even when compared with the scale of scrutiny associated with corn crops. The intensity of segregation can be deduced from Hoffmeister's distribution records. If a uniform distribution of about 160 lb/acre of the finer potash particles were the ideal, then the actual potash in the intermediate 10-ft strips fell as low as 60 lb/acre, and a corresponding enrichment occurred in the central 20-ft strips. While this segregation pattern is extreme in both scale and intensity, it may still be satisfactory if the crop can tolerate such wide variations in nutrient concentration with no ill effects.

In quantitative terms the agronomist must define the scale of scrutiny, the level of nutrition required, and the tolerance permissible at this nutritional level. Significant work in this direction has been carried out by Engelstad (1963) and by Aldrich and Larson (1961). With these three variables defined, the distribution performance can be assessed.

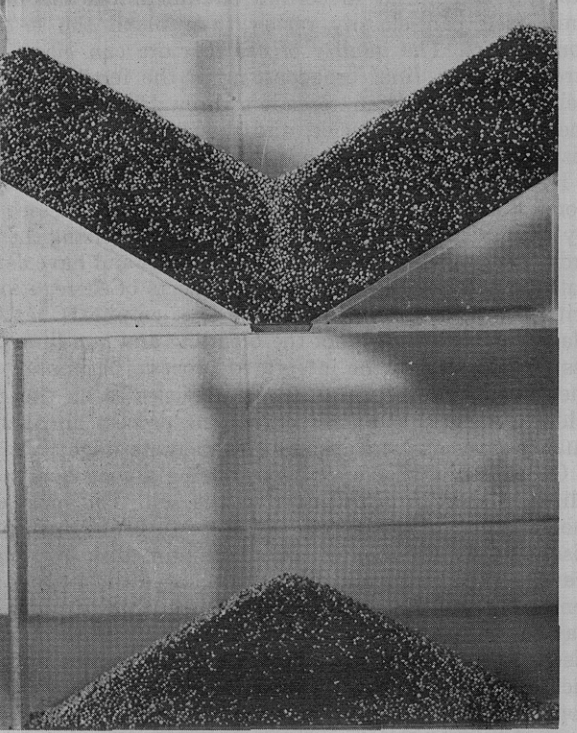

Figure 5. Uniform composition of hopper contents (Figure 4) is partially destroyed on discharge due to formation of in-flowing valleys.

SOLUTION OF THE SEGREGATION PROBLEM

Before embarking on a redesign exercise the question should be asked, "Is there a problem?" Quantitative data relating distributor performance to plant requirements are difficult to find, and the ultimate check on performance generally remains with the farmer. To detect fertilizer maldistribution, he must be able to detect variable crop growth and be able to separate this effect from other variable factors such as topography, drainage, soil characteristics, etc. This is asking a great deal and it is perhaps not surprising that the farmer is generally content with the existing distribution techniques. In customer terms the distribution is satisfactory. If the scale of scrutiny is reduced from the large area of a field viewed by the farmer to the individual plant, then the distribution might well be unsatisfactory. Quantitative work is required to assess the extent of this problem.

If it is assumed that future distribution requirements cannot be met by the existing distribution techniques, then several potential solutions to the problem exist.

Avoid the Problem. To an extent this is already done, as soil nitrogen needs are now commonly provided in the Midwest by injecting anhydrous ammonia rather than by the distribution of nitrogen-containing granules. The use of clear liquids or suspensions to provide the phosphorus and potassium needs complementary to the ammonia distribution has been strongly propounded by Hignett. Liquid fertilizer distribution is not without its problems, but segregation is not one of them.

A Common European Solution. Blend the primary nutrients at the granulation stage prior to local dealer distribution. This limits the range of fertilizer types available but does ensure a uniformity of granule composition. If it can be assumed that such granules are evenly distributed on a weight per unit area basis, then an even distribution of the nutrients is also assured.

Modify the Existing Distribution Techniques. The blended fertilizer reaches the farmer's field after a succession of bulk storage and handling operations. A summary of the many process variations has been provided by Hignett, but the basic sequence of operations for a three-component blend is outlined in Figure 6. Prior to the blending stage 9, the individual components are handled separately and there is no possibility of composition variation, though size segregation within a component can still occur in the succession of transport and storage operations (stages 1–8). Because of this it is unlikely that a dealer could ever size match the components of a subsequent blend, short of including a classification stage. If a size differential between and within components cannot be avoided, then the potential exists for composition segregation to occur between the crucial 9th and 13th process stages.

Minimize Opportunities. Between the creation of the blend and its final spreading, the number of opportunities for segregation to occur should be minimized. In particular, bulk storage and transport operations are to be avoided. The practice of intermediate storage of a blend prior to loading the applicator is a bad one. If intermediate storage is necessary, then bagging is preferable, as at least the scale of segregation is reduced to bag size rather than silo size. The scale of segregation can also be reduced within the applicator by the use of vertical partitions, and in addition the applicator should be designed to provide discharge flow characteristics which minimize discharge segregation. The very convenient and widely used spinner-type distributor, which is fitted to the applicator discharge, is a strongly segregating device. More cumbersome, but potentially more efficient, would be a mechanical screw or drag conveyor feeding a boom at the back of the applicator.

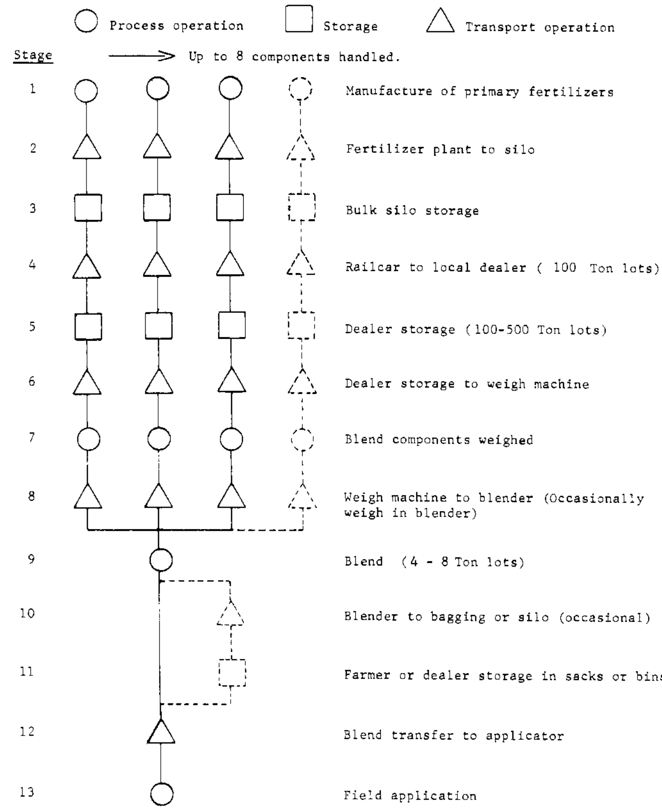

Figure 6. Diagrammatic representation of granular fertilizer distribution sequence.

Use a Different Distribution Technique. It is important to note that while size segregation occurs prior to the blending stage 9, no composition segregation is possible. If the blending stage is deferred to the last possible moment, then the opportunity for composition segregation is minimized. Indeed, in the case of fertilizer distribution there is no reason why the components should not retain a separate identity throughout the process. If a component is distributed separately, then the distribution problem simplifies to one of uniform weight distribution rather than one of uniform weight *and* composition distribution. To avoid excessive spreading costs, the components would be distributed from a compartmented applicator, and perhaps a small-scale blender would be fitted in order to combine component flows just prior to distribution. In this situation the blending operation has been removed from the dealer's blending plant and takes place either at the outflow from the applicator hoppers or on the field surface.

DISCUSSION

This article has emphasized the need to match the performance of a blending and handling unit to the consumer requirements. In more precise terms, if a satisfactory blend is to be produced then the scale of scrutiny applied by the customer should be large when compared to the scale of segregation obtained from the process.

In the case of fertilizer blending, the scale of scrutiny is commonly fixed by the ability of a farmer to detect growth variations over a large area of his land. His scale of scrutiny is large and a large scale of segregation is permissible.

A more realistic scale of scrutiny would be based not on a postgrowth crop inspection but on an assessment of the nutritional needs of individual plants. This would optimize crop growth but would demand a smaller scale of segregation from the fertilizer distribution technique.

For the important maintenance fertilizer additions the simple model of an annual fertilizer application absorbed by individual plants must be modified. The soil retains phosphate and potash additions within the plough layer over many years, and the scale of segregation is determined by the cumulative deposition patterns of many years rather than by a single distribution pattern. As long as segregation patterns are not superimposed year by year then the overall scale of segregation will remain small. That many units meet even a visual scale of scrutiny is probably due more to this cumulative deposition effect than to their efficiency. Despite having a dubious efficiency, existing blending and distribution techniques match up to the farmer's demands for maintenance fertilizer distribution and any effort to improve the distribution efficiency must be justified by the need to further reduce the scale of scrutiny. Several trends in fertilizer technology indicate such a need.

The cumulative application of maintenance fertilizers compensates for the low efficiency of individual applications. If the nutrient is added only infrequently or for immediate availability, then this margin of error no longer exists. The scale of segregation is then determined by the efficiency of a single application. The addition of micronutrients and pesticides to primary nutrient applications falls into this category, as does the application of high availability starter fertilizers. Each of these problems represents a challenge to conventional granular distribution techniques, and a scale of scrutiny should be defined for each case and related to available distribution performance.

Liquid fertilizers will increasingly exert a competitive pressure on the use of granular fertilizers. Segregation is not a problem with liquid fertilizers, and a very uniform distribution is possible. To meet this challenge the granular fertilizer distributor may well have to justify his claim of delivering a prescription mixture to the farmer. At the moment a guaranteed weight and composition of fertilizer is distributed on the field, but there is no guarantee as to the quality of distribution. In the future it is likely that a distribution quality will be required, and that this quality will be related to a scale of scrutiny based on the individual plant rather than a visual inspection area.

A major advantage of the granular fertilizer is that it is available in increasingly concentrated forms. This appreciably reduces the total transportation costs but does mean that at the spreading stage the number of granules distributed on the soil is reduced and the potential for a high intensity of segregation is increased.

The trend appears firmly toward a customer demand for improved distribution quality. Many existing blending units are unlikely to meet this demand.

CONCLUSIONS

There is a need to establish a quantitative criterion of acceptability for the quality of distribution of fertilizers. Such a criterion can be statistically defined in terms of the following components.

A scale of scrutiny. This is a scale of inspection of the distribution and will be dependent on the crop type and the stage of growth.

A required nutrient or additive concentration level. An optimum level determined by agronomical studies.

The plant tolerance limits. The high and low concentration levels which would inhibit plant growth.

These values should be established.

The distribution quality required by the crop should then be compared to the distribution quality produced by existing mixing and handling equipment. In general terms the required scale of scrutiny should be large compared to the scale of segregation produced by the distribution technique.

The methods used to handle and distribute granular fertilizer blends are extremely variable, but it would seem desirable to quantify at least the extremes of practical performance. Test samples should be taken in the field and would be of variable size to take into account the varying scales of scrutiny.

Any development work on distribution techniques is largely dependent on the existence of an actual or potential shortfall in the performance of existing equipment. The potential for development certainly exists and would involve either the modification of existing techniques to minimize segregation or the use of a different distribution technique.

Present state inspection methods can guarantee a farmer a fertilizer weight and composition but give no guarantee as to how well the fertilizer will be distributed. This should be remedied.

ACKNOWLEDGMENT

The author gratefully acknowledges the help and advice provided by Travis Hignett, Tennessee Valley Authority, Lloyd Frederick, Iowa State University, and Jim Penney, ARCO Farm Center, Slater, Iowa.

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Received for review June 10, 1972. Accepted September 11, 1972.