Applied in appropriate amounts, chloro-IPC gave a sucker-retarding effect equivalent to that produced by the conventional MH treatment, and there was no apparent injury. Further evaluation of chloro-IPC under field conditions using commercial varieties is, of course, necessary.

Compounds No. 8 to 11, inclusive, belong to a family of methoxyphenylacetic acids, some of which are known to translocate readily in a downward direction in plants, which is an important characteristic of a sucker-inhibiting compound (*1*, *3*, *5*). Ammonium-3-chloro-α-methoxyphenylacetate reduced sucker growth 97% with only slight epinasty of the petioles. Also included in Table I are compounds that are now being evaluated rather widely as retardants for plants other than tobacco (*4*, *6–8*). These chemicals were relatively ineffective as sucker inhibitors of tobacco. No recommendations are made for the use of any of these or other new chemicals mentioned for sucker control of field-grown tobacco.

Although the method described has been applied to only the tobacco plant at present, with modifications, it may possibly be useful in developing a chemical method for retarding lateral bud growth of other crops, such as chrysanthemums, that are now disbudded by hand labor.

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FERTILIZER CONSISTENCY

Bulk Blending of Fertilizer Material: Effect of Size, Shape, and Density on Segregation

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The tendency of dry-blended fertilizers to segregate during handling and spreading was shown to result chiefly from differences in particle size of the various components of the blend. Variations in particle density had little effect, and shape had practically no effect. Segregation can be held to a minimum by using materials of matching size distribution and by avoiding the coning of blends during handling.

The simple dry blending of granular fertilizer materials is gaining popularity as a method of producing mixed fertilizers. Such blends are distributed widely in bulk (*3–5*) and are being bagged to an increasing extent.

The major technical problem connected with dry blending appears to be that of segregation. Unless certain precautions are observed, the components of blends may segregate severely during handling and distribution. Such segregation not only causes difficulties in sampling and in meeting guaranteed analysis but also results frequently in spotty crop response in the field.

The components of a blend tend to segregate when they differ in physical properties to such an extent that they respond differently to mechanical disturbance. The physical properties of possible significance in this respect have been recognized to be particle size, shape, and density, but little information has been reported as to quantitative effects of these properties on segregation. The need for such information as a guide to the preparation of blends with good handling properties led to the study reported here—an evaluation of the relative contributions of size, shape, and density differences to segregation of granules in dry blends.

Handling procedures that may induce segregation include coning (as occurs when mixtures are allowed to drop into sloping piles in storage areas, hoppers, or truck beds), vibration (as occurs in bulk spreader trucks being driven to and across fields), and ballistic action (as imparted by fan-type spreaders). Since it was recognized that the effects of particle size, shape, and density on segregation might differ with the different handling procedures, each procedure was studied separately. Most of the work pertained, however, to coning and to ballistic action. Exploratory tests indicated that vibration was only a minor cause of segregation; also, work by Smith (*6*) indicated that most mixtures could be transported 30 miles in a spreader truck with little segregation due to vibration.

Size, Shape, and Density of Fertilizer Materials

Size distributions, granule shapes, and granule densities were determined for various fertilizer materials commonly available for bulk blending. Typical measurements are shown in Table I.

All the materials fell almost entirely within the 6- to 16-mesh size range, but the distribution within this range varied widely. For example, a prilled urea and a high-density prilled ammonium nitrate contained 80 to 90% of −10+16-mesh particles, whereas an 18–20–0 (18–46–0) ammonium phosphate and a triple superphosphate had about the same pro-

Table I. Size, Density, and Shape of Some Granular Fertilizer Materials

Material	%, in Indicated Size Range (Mesh) +6	−6 +8	−8 +10	−10 +16	−16	Particle Density, G./Ml.	Shape
Ammonium nitrates							
Regular prills	0	6	65	25	4	1.29	Well rounded
High-density prills	0	0	8	89	3	1.65	Very well rounded
Granulated	1	35	54	8	2	1.50	Fairly well rounded
Stengel flake	0	25	43	28	4	1.63	Irregular flakes
Urea prills	0	1	17	78	4	1.32	Very well rounded
Ammonium sulfate	0	6	46	41	7	1.64	Irregular flakes
30–4–0 (30–10–0) Ammonium phosphate nitrate	0	5	63	31	1	1.27	Well rounded
18–20–0 (18–46–0) Diammonium phosphate	0	5	83	12	0	1.63	Well rounded
Triple superphosphate	<1	29	56	14	<1	2.12	Well rounded
Potassium chloride							
Solution rounded	0	5	29	58	8	1.93	Fairly well rounded
Compacted and crushed	0	14	65	20	1	1.96	Irregular flakes

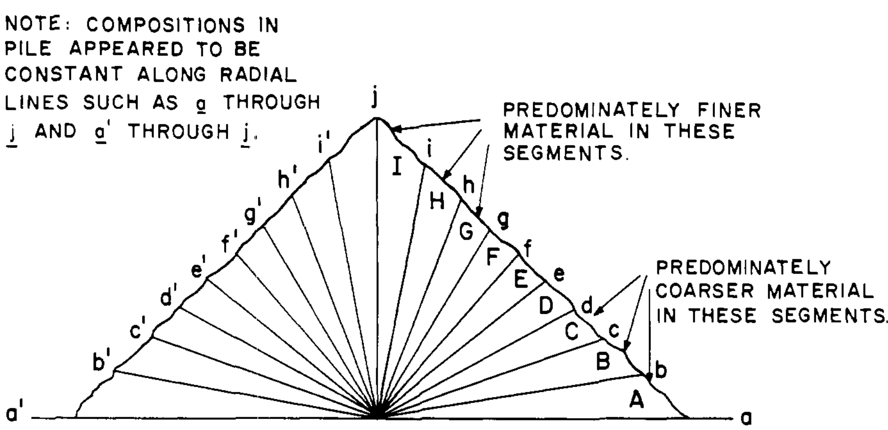

Figure 1. Segregation pattern observed in conical piles of fertilizer

Pile segments A through I correspond to the 10-degree segments analyzed in the segregation tests

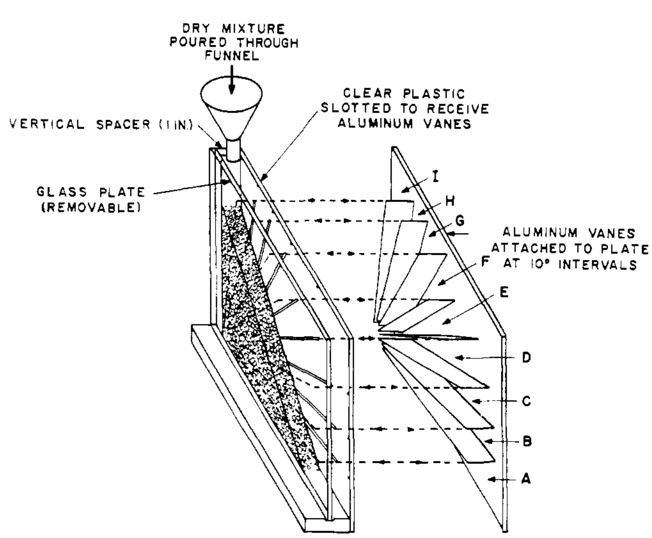

Figure 2. Apparatus for measuring segregation due to coning

portion in the −6+10-mesh range. Particle shape (visual examination) varies from well-rounded in prilled materials to irregular in crushed materials such as Stengel-process ammonium nitrate, compacted ammonium sulfate, and compacted potassium chloride. Apparent densities of granules were measured by mercury displacement; a sample was evacuated in a 10-ml. glass chamber, which then was flooded with mercury. Apparent density was calculated from the sample weight and the volume of displaced mercury. The apparent densities ranged from 1.27 to 2.12 grams per milliliter.

Segregation Due to Coning

Coning of fertilizers, such as can occur in building storage piles, filling bagging hoppers or truck beds, and in other handling operations, is now recognized as being highly conducive to segregation. Duncan and Poundstone (*2*) have recognized the segregation resulting from such handling as a major source of variation in the analysis of fertilizers. These investigators and others have observed that the larger particles in blends roll further down the surfaces of the conical piles than do the smaller particles, with resultant segregation of large and small particles. Similar observations of effects of shape or density differences have not been reported.

Effect of Particle Size. Coning tests were made with mixtures of large and small granules screened from a commercial triple superphosphate. The granules were all of the same well-rounded shape and were of equal density, but each mixture comprised two narrow bands of particle sizes. The mixtures contained equal weights of the following granule sizes (Tyler mesh): mixture 1, −6+8 and −10+14; mixture 2, −6+8 and −8+10; mixture 3, −8+10 and −10+14. The smaller material in each mixture was dyed red to permit observation of segregation in the tests.

In exploratory tests, the mixtures were poured through a funnel held 14 inches above a table. When the resulting conical pile reached a height of 12 inches, it was halved vertically by raising a sheet of clear plastic through a slot in the table. By removing half of the pile, the other half was left in cross-sectional view through the plastic.

It was readily observed that during the building of the pile the larger particles had, on the average, moved farther down the pile than the smaller particles. As a result, the section presented a segregation pattern in which the proportions of the components appeared to be constant along straight lines radiating from the center of the base. An idealized sketch of the pattern is shown in Figure 1, where lines *a* through *j* represent lines of approximately constant composition.

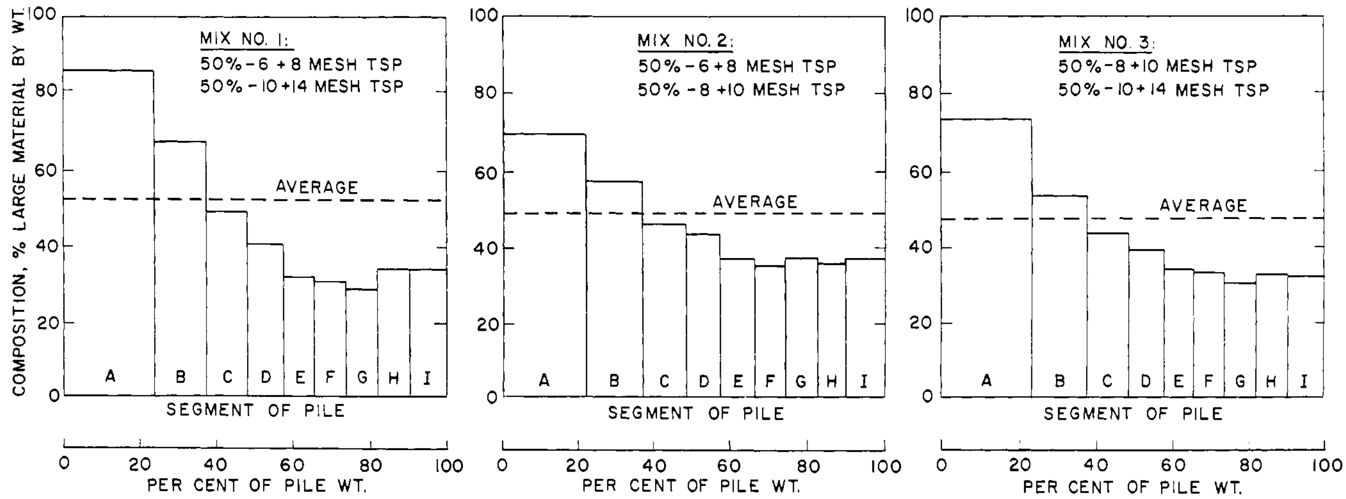

Figure 3. Effects of particle size on segregation due to coning

Tests with well-rounded particles of triple superphosphate

The segregation pattern observed in the exploratory tests governed the design of an apparatus (Figure 2) for quantitative measurement of segregation in conical piles. This apparatus comprised a narrow box, 10 inches high and 14 inches wide with a 1-inch spacing between the front and back walls. The front wall was glass and was removable. The back wall was clear plastic, slotted to receive eight aluminum vanes. In operation, a section of a conical pile was formed by pouring the mixture into the box through a funnel at one end. The vanes then were inserted in the slots to cut the pile into 10-degree segments corresponding to segments *A* through *I* in Figure 1. The apparatus was then turned on its side, the glass plate was removed, and the segments were separated for analysis.

Compositions of the segments from piles of the three mixtures of various sized granules are plotted in Figure 3. The height of each bar in the figure shows the content of large granules in that segment, and the width shows the percentage of the total pile weight represented by the particular segment. Greatest segregation occurred when the size difference was greatest (mixture 1, $-6+8$- *vs.* $-10+14$-mesh). The composition varied from about 85% large granules in segment *A* (the bottom segment) to only some 30% in segment *G*. This degree of segregation could have a striking effect on the plant-nutrient content of a mixture; for example, had the smaller material been urea (46% N) instead of superphosphate [20% P (46% P_2O_5)], the average grade for the pile would have been 23–10–0 (23–23–0), but the grade in various segments would have varied from about 6–18–0 (6–40–0) (lower part) to about 32–6–0 (32–14–0).

Even the smaller differences in granule size of the components in mixtures 2 and 3 caused rather severe segregation. With mixture 2, the segments contained

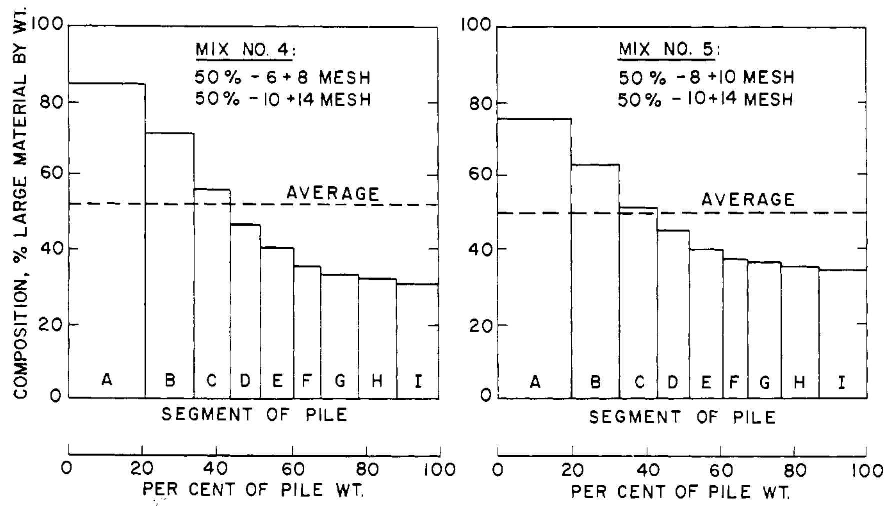

Figure 4. Effects of particle size on segregation due to coning

Tests with irregular-shaped particles of potassium chloride

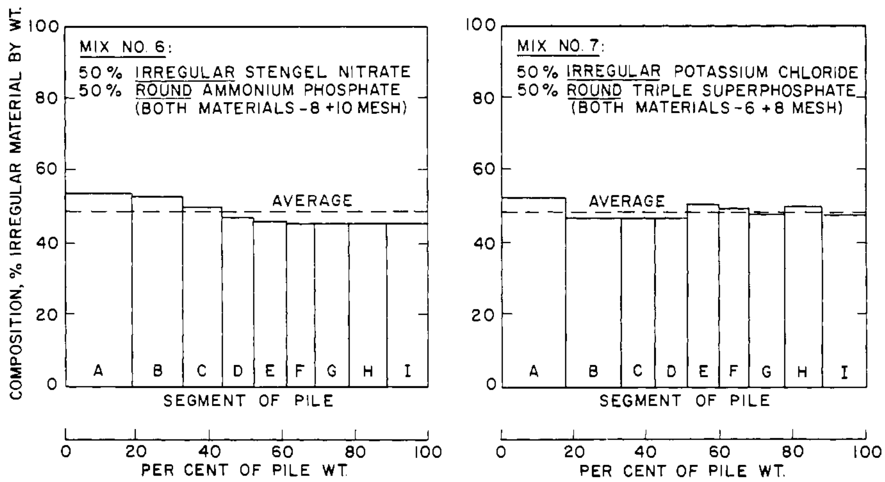

Figure 5. Effects of particle shape on segregation due to coning

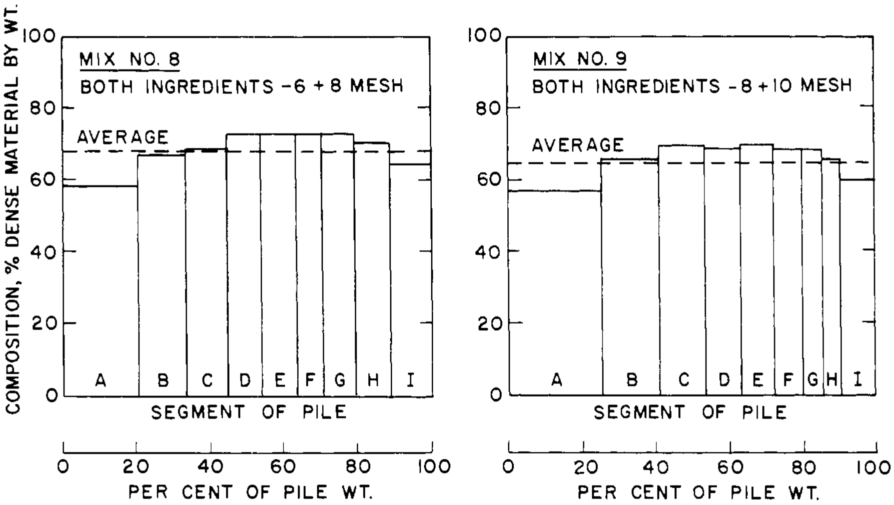

Figure 6. Effects of particle density on segregation due to coning

Mixtures consisted of TSP of 2.12 density and 30–4–0 (30–10–0) of 1.27 density blended in proportions of 50:50 by volume or 63:37 by wt.

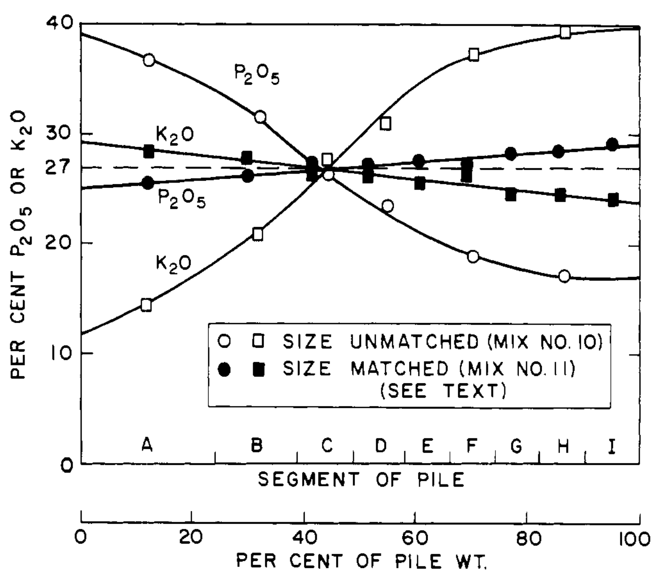

Figure 7. Control of segregation by matching particle-size distribution of ingredients of 0–12–22 (0–27–27) grade dry blend

from 70 to 35% large material—with mixture 3, 75 to 30%.

Effect of Particle Shape. In regard to use of granules of irregular shape in blends, one contention has been that the irregularity reduces segregation while another has been that this promotes segregation. Results of the present work, however, indicate that irregular-shaped granules behave essentially the same as well-rounded granules of equal screen size.

One series of tests was made with mixtures of irregular-shaped granules, large and small, of potassium chloride (compacted, crushed type). The mixtures contained equal weights of the following granule sizes: mixture 4, −6+8 and −10+14; mixture 5, −8+10 and −10+14. If irregular shape were to reduce segregation, these mixtures should segregate less than the corresponding mixtures of well-rounded materials. Instead, the segregation, plotted in Figure 4, was about the same as that with well-rounded granules (Figure 3).

To determine whether irregular shape of granules can, in itself, cause segregation, tests were made with mixtures of two materials differing in particle shape but having the same particle size and density. Mixture 6 contained equal weights of −8+10- mesh irregular-shaped granules of Stengel-process ammonium nitrate and well-rounded granules of 18–20–0 (18–46–0) diammonium phosphate (densities identical, 1.63 grams per milliliter). Mixture 7 contained equal weights of −6+8-mesh irregular-shaped granules of potassium chloride (compacted, crushed type) and well-rounded granules of triple superphosphate (respective densities, 1.96 and 2.12 grams per milliliter).

Results of coning tests with mixtures 6 and 7 are shown in Figure 5. The nearness of composition of the segments to the 50–50 composition of the mixtures shows that the differences in shape did not cause segregation.

Effect of Particle Density. The effect of particle density was determined in tests with mixtures of two materials representing the minimum and maximum densities likely to be encountered: 30–4–0 (30–10–0) ammonium phosphate nitrate with a density of 1.23 and triple superphosphate with a density of 2.12. The granules of both were well-rounded. Mixture 8 contained −6+8-mesh granules of the materials in a 50–50 volume ratio (63–37 weight ratio). Mixture 9 contained −8+10-mesh granules in the same ratios.

In coning tests (Figure 6), the density difference resulted in only a relatively small degree of segregation. The denser material was 5 to 10% deficient in the bottom segment and slightly excessive in upper segments. This is much less segregation than resulted from only small differences in particle size (Figure 3).

Matching Particle-Size Distribution. With the finding that difference in granule size of components is the principal cause of segregation incidental to coning, the next step was a demonstration of the extent to which segregation can be controlled by matching the particle-size distributions of components. Confinement of the ingredients of blends to identical, very narrow ranges of granule size is impractical, but matching of the size distributions of materials should be practical. With components having similar size distributions, particles of different sizes would segregate, but each component should behave about the same and therefore appear in its proper proportion in all parts of the pile. The net result should be uniform analysis throughout the pile.

A mixture of 0–12–22 (0–27–27) grade was made from commercial triple superphosphate and potassium chloride of unmatched size distributions and was compared with a mixture of the same grade made from potassium chloride with its size distribution adjusted to match that of the superphosphate. Screen analyses (Tyler) of the materials are given in Table II.

The mixtures were coned and sampled in the apparatus described; the results are plotted in Figure 7. With the unmatched mixture, the grade varied from about 0–16–10 (0–38–12) in segment *A* to 0–7–33 (0–17–40) in segment *I*; thus, segregation caused extreme departure from the original 0–12–22 (0–27–27)

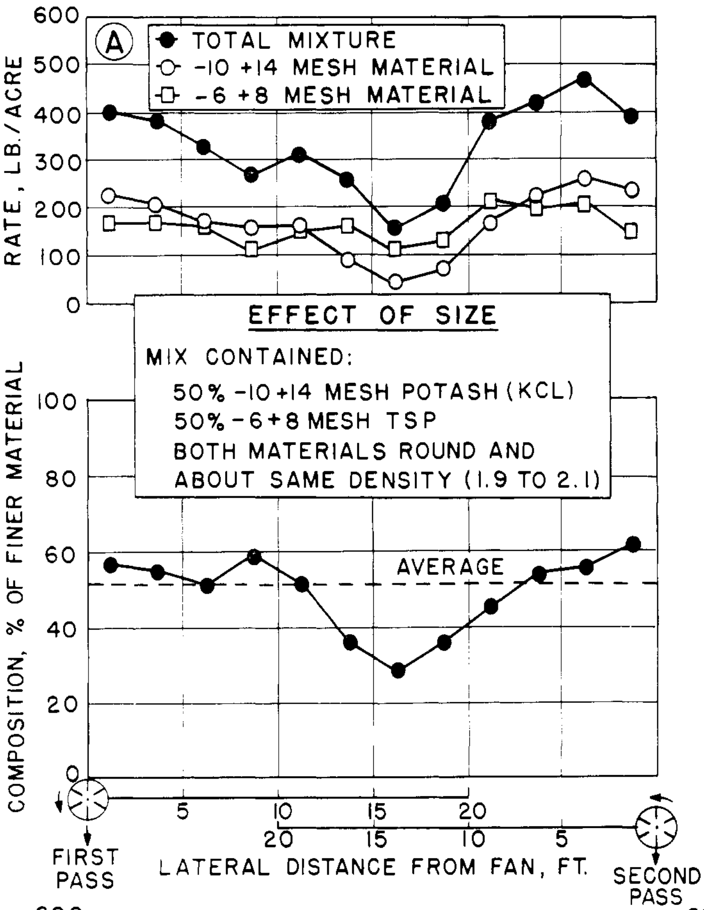

Table II. Screen Analyses (Tyler)

Material	Per Cent −6 +8	−8 +10	−10 −16	−16
UNMATCHED (MIXTURE 10)				
Triple superphosphate	30	55	15	0
Potassium chloride	5	29	58	8
MATCHED (MIXTURE 11)				
Triple superphosphate	30	55	15	0
Potassium chloride	30	55	15	0

grade. With the matched mixture, on the other hand, segregation was much less: at no point in the pile did P_2O_5 or K_2O content depart more than 3 percentage points from the initial 0–12–22 (0–27–27) grade (in most of the pile, the departure was much less). Thus, matching the size distributions greatly reduced variations in grade due to segregation.

Segregation Due to Ballistic Action from Fan-Type Spreaders

Large amounts of dry-mixed fertilizers are distributed with fan-type spreaders.

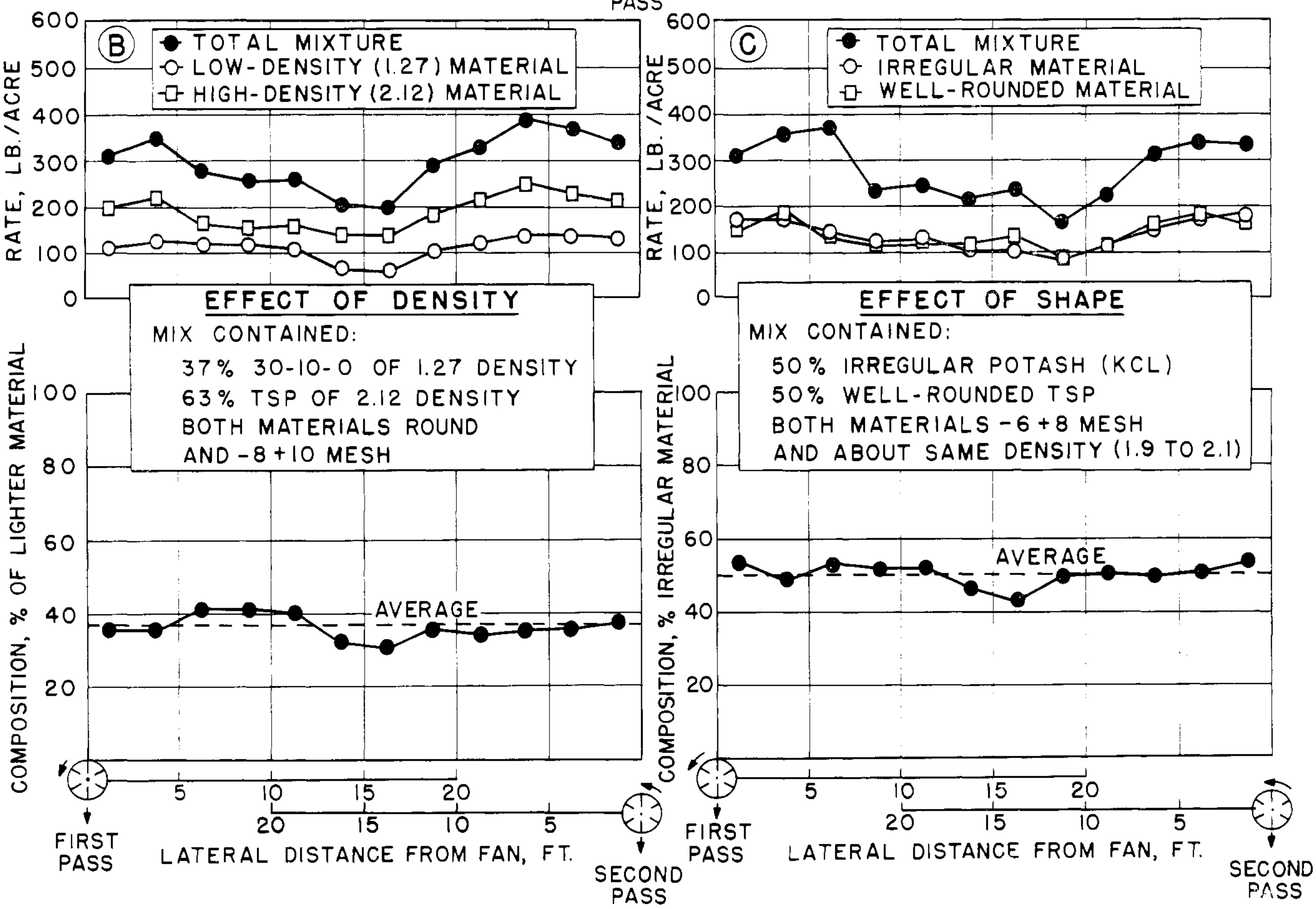

Figure 8. Effects of particle size, density, and shape on segregation due to ballistic action of fan-type spreader

(Distribution patterns for two passes of spreader with spacing of 30 feet)

Such spreaders usually consist of one or two vaned, metal disks (fans) rotating in a horizontal plane, with provision for feeding the fertilizer onto the fan at a controlled rate. The fan imparts an initial horizontal velocity to the fertilizer granule, which then follows a ballistic path to the ground. A tendency of fan-type spreaders to throw large particles farther than small particles has been noted (*1, 6*).

A single, 18-inch diameter, six-bladed fan from a commercial spreader was used in a study of the relative effects of size, shape, and density of granules on segregation. The fan was mounted on a vertical spindle 28 inches above a concrete floor and was belt-driven at 500 r.p.m. Fertilizer was fed by gravity from a hopper onto the fan. The stream of fertilizer was 6 inches wide—about the same as that observed for a commercial spreader. The distance off center at which the fertilizer hit the fan was adjusted to give the best distribution pattern.

To determine the distribution pattern and degree of segregation, a series of 30-inch-wide collection troughs was formed on the floor by laying down strips of kraft paper separated by lengths of 2 × 4 inch lumber on edge. The troughs were formed behind the fan, parallel to what normally would be the direction of movement of the spreader. The troughs extended about 24 feet behind and 25 feet to each side of the fan—essentially the full area covered by the spreader. From the amount and make-up of materials in the various troughs, weight- and composition-distribution patterns were derived.

The feed rate was 100 pounds per minute, which approximated an application rate of 300 pounds of fertilizer per acre (assumed ground speed, 5 miles per hour, with spreader passes at 30-foot intervals—the distance recommended by the spreader manufacturer). As some overlapping of passes is normal in use of the fan spreader, the distribution was adjusted to show patterns that would result from overlapping. These adjusted patterns are shown in Figure 8.

Effect of Particle Size. The effect of particle size was determined by spreading a mixture of equal parts by weight of −6+8-mesh granular triple superphosphate and −10+14-mesh potassium chloride (solution rounded type)—both materials as well-rounded granules of aboutt he same density.

With a single pass of the spreader, the composition of the applied material was reasonably uniform in a swath extending from about 7 feet on the left side of the spreader to about 12 feet on the right. At further distances to either side, the proportion of the smaller material (potassium chloride) dropped abruptly. Although overlapping of passes would reduce the effect of this segregation, part *A* of Figure 8 shows that considerable variation in composition would persist even with a fair overlap. At midpoint between passes, the applied material would contain only 30% smaller material as compared with 50% in the original mixture. To offset this discrepancy by increasing the amount of overlap would not be practical.

Effect of Particle Density. The effect of particle density was studied with a mixture containing 37% by weight of 30-4-0 (30-10-0) ammonium phosphate nitrate of 1.27 grams per milliliter particle density and 63% of triple superphosphate of 2.12 density, about the lowest and highest densities likely to be encountered in fertilizer materials. Well-rounded granules of the two materials were equalized in size by screening to −8+10-mesh prior to mixing. The weight proportions corresponded to equal volumes.

With a single pass of the spreader, segregation was considerably less than in the test of effect of particle size. The swath of uniform composition was wider (about 12 feet to either side of the fan). Part *B* of Figure 8 indicates that moderate overlapping would essentially eliminate the effect of the segregation resulting from this difference in density. Thus, the effects of variations in particle density of fertilizers on segregation by this type of spreader are too small to be of practical significance.

Effect of Particle Shape. The effect of particle shape was studied with a mixture containing equal parts of irregular-shaped granules of potassium chloride (compacted, crushed type) and well-rounded granules of triple superphosphate. The materials had about the same density (1.96 and 2.12), and both were screened to −6+8-mesh.

The test showed that the difference in particle shape did not cause significant segregation in spreading. A slight excess of round material at one edge of the spreader pass and a slight deficiency at the other probably reflected a tendency for the round granules to roll off the spreader disk easier than the irregular ones, but the difference, even without overlapping, was too small to be of practical significance. The distribution pattern with overlapping is shown in part *C* of Figure 8.

Discussion

Segregation in blends can be practically avoided by matching the size distributions of the components, but matching must be rather close. Two materials, both of −6+16-mesh, can segregate severely unless each has about the same distribution of particles in the −6+8-, −8+10-, and −10+16-mesh ranges. As materials available for blends differ widely in size distribution, care must be used in choice of combinations. Also, each material should be handled carefully to avoid size segregation prior to blending. The advantage of buying raw materials of matched size distribution can be lost if the materials are handled in a way that causes size segregation in a storage pile or bin, with resultant uneven withdrawal for blending.

Certain precautions in handling the final blend are well worth the trouble, especially when close matching of size distribution is not feasible. Coning or cascading of the mixture should be held to a minimum. Schemes for doing this can be devised. In building storage piles, movable discharge chutes or hoses are decidedly helpful. In filling truck beds or distributor hoppers, hoses or socks can promote even distribution. Special distribution devices can be used to prevent coning as bagging hoppers are filled. As a final precaution, all handling of blends should be held to a minimum.

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