Granular Spreaders:

Selection,

Calibration,

Testing,

and Use

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Introduction

Granular fertilizer spreaders are very popular for agricultural field use, commercial turf applications, and home lawn use. Several hundred thousand fertilizer spreaders are sold in the United States each year. Many of the people purchasing those spreaders do not know how to select an appropriate spreader for their needs nor how to use the spreader properly to obtain optimum performance.

Proper use of spreaders is important economically and environmentally. Granular materials should be applied in a uniform pattern and at the correct rate. If the rate is too low or if there are low spots in the pattern, the product will likely not be efficacious. If the rate is too high or there are high spots in the pattern, several problems are possible: the application will be more costly than necessary due to the use of more product than necessary; there is a risk of crop damage from overapplication; and excess product can be harmful to the environment. It is advantageous to the applicator and to society to be sure products are applied uniformly at the correct rate.

Much of the research reported in this bulletin has been done on turf spreaders because they are smaller and easier to work with, but most of the principles discussed here are applicable to large agricultural spreaders as well. The information should make it easier for anyone using a fertilizer spreader to select an appropriate type of spreader and to obtain optimum performance from the selected spreader. This bulletin summarizes 24 years of design, study, research, and teaching about fertilizer spreaders.

Definitions

The following definitions are taken from American Society of Agricultural Engineers (ASAE) standard S327.2, Terminology and Definitions for Agricultural Chemical Application and will be helpful in using this bulletin.

Adjustable orifice: A metering device used on gravity flow granular applicators that regulates flow rate by adjusting the open area of an orifice to deliver a desired flow rate.

Agitator: A rotating device located inside the hopper of gravity flow applicators and broadcast spreaders that enhances delivery of granules to the adjustable orifice. Some agitators may prevent granule flow when operation stops.

Angle of repose: The acute angle formed between a horizontal surface and the slope of a pile of granules at equilibrium after being poured from a fixed overhead point. Application rate of many granular applicators varies i inversely with the angle of repose.

Application rate: The amount of any material applied per unit treated.

Broadcast application: An application of a chemical over an entire area of a field.

Broadcast spreader: An apparatus that consists of a hopper, a metering unit, and a distribution device that uses either gravity (drop), centrifugal force (rotary), or pendulum action to spread granules onto the surface of the entire area to be treated. [Note that in this bulletin, a distinction will be made between drop and other broadcast spreaders, with only the latter being referred to as broadcast.]

Bulk density: Ratio of granular material mass to unit of volume (kg/m^3, lb/ft^3).

Coefficient of variation (CV): The standard deviation of a set of data points divided by the mean. In the context of spreader patterns, CV usually refers to the standard deviation of individual application rate values across an overlapped spreader pattern divided by the mean application rate and expressed as a percentage. A completely uniform pattern would have a CV of 0%. The higher the CV value, the less uniform the pattern. CV values of 10% are desired, but

CV values of 20% are generally acceptable with most products.

Drift: The movement of chemicals outside the intended target area by air mass transport or diffusion.

Formulation: The form of a chemical that is supplied to the user, which includes both the active and inert ingredients.

Granule flow rate: Mass of granules flowing from a metering device per unit time, expressed in terms of mass per unit time (kg / min, lb / min).

Granular applicator: An apparatus consisting of a hopper, a metering device, and a device directing the granules to the specific target area such as a row, band, bed, or base of plants.

Gravity flow: A type of granular applicator that uses an adjustable orifice to regulate flow rate and an agitator that assures constant delivery of granules to an adjustable orifice and prevents flow when operation stops.

One-direction application: An application method in which successive adjacent swaths are made in the same direction of travel (racetrack or circuitous application). This method produces a right-on-left overlapping of adjacent patterns.

Pneumatic applicator: An apparatus consisting of a hopper, a metering device, and a distribution device that uses pneumatic conveyance to broadcast granules over the treatment area or to direct granules into parallel bands.

Positive displacement: A type of granular applicator that uses a rotating rotor to regulate flow rate based upon rotational speed, expressed in rev / min, and mass displacement per revolution, expressed in kg / rev (or lb / rev).

Progressive application: An application method in which adjacent swaths are applied in alternate directions (back and forth application). This method produces a right-on-right pattern overlap alternately with left-on-left overlap.

Rotor: A metering device used in positive displacement granular applicators that regulates flow rate by displacing a fixed rate per revolution. Flow rate is affected by rotor speed and displacement.

Single-pass application: An application method in which the applicator applies one pass over the treatment area.

Size guide number, SGN: A number that defines the median particle size of a granular fertilizer material for the purpose of size matching of materials in fertilizer blending operations. The relationship is:

SGN = median particle diameter, mm X 10

Median particle diameter is the diameter corresponding to 50% retained by weight in a cumulative sieve analysis.

Swath, effective width: The center-to-center distance between overlapping broadcast applications.

Uniformity index: A rating of the uniformity of size of particles of a granular material. It is a dimensionless ratio of the particle size corresponding to 95% retained by weight to the particle size corresponding to 10% retained by weight in a cumulative sieve analysis of the material. A material uniformly sized has a uniformity index equal to one. Less uniformly sized materials have a smaller value.

Selection

Spreaders vs. Sprayers

Spreader application of granular fertilizer and pesticides offers several advantages over sprayer application of liquid formulations, especially for home gardeners and home lawn applicators. Granular materials do not have to be diluted or mixed. It is much easier to apply granules evenly than it is to apply liquids evenly with the equipment available to homeowners. Often, product manufacturers supply spreader settings on the bag label so that no calibration is needed. Granular formulations of pesticides are generally safer both to the operator and to the environment, since there is less risk of dermal absorption, less drift, and no contaminated mixing area.

Although spreaders are easier to use than sprayers, there are still many things an operator can do to help achieve a uniform distribution pattern with the correct application rate. Even though granular product manufacturers may provide recommended settings, professional applicators should always calibrate their spreaders for each product.

Figure 1. Example of small, drop spreader.

Types of Spreaders

Most fertilizer spreaders can be divided into two main categories, broadcast and drop. Drop spreaders have a full-width hopper with a series of metering ports in the bottom or rear of the hopper. An example of a drop spreader is shown in Figure 1. Theoretically, an equal amount of product will be metered out of each hole, thus providing a uniform application across the entire width. If the holes are spaced too far apart, banding (and thus crop striping) is possible. The pattern from a drop spreader stops at the edges of the spreader with no taper; thus, adjacent patterns must be abutted exactly with no space or overlap.

Broadcast spreaders typically have from one to three metering ports in the bottom of a hopper from which the product is dropped onto or into a separate distribution mechanism. The most common distribution mechanism is a rotary impeller that flings the material out in an arc. An example of a rotary broadcast spreader is shown in Figure 2. Smaller spreaders generally use one impeller; larger spreaders may have two impellers. Using two impellers helps provide a pattern that is symmetrical from side to side but does not guarantee a uniform pattern. Patterns from a

Figure 2. Example of rotary broadcast spreader.

single impeller can be skewed (i.e. heavier on one side of the centerline than on the other) or can be nonuniform unless the spreader is properly designed and adjusted.

Another type of distribution mechanism is the pendulum type, which consists of a tube that oscillates back and forth in a horizontal arc. An example of a pendulum spreader is shown in Figure 3. Pendulum spreaders generally do not exhibit major skewing, although testing has shown that skewing in the 55%/ 45% (left side to right side) range is not uncommon (38, 43*). There is no adjustment on a pendulum spreader to adjust for skewing. Some pendulum spreaders provide an adjustment that allows a reduction in swath width, but none provides a means of adjusting pattern uniformity. With a pendulum spreader, patterns are typically good, but there is no way to improve the pattern in most cases. The slight skewing typically found with pendulum spreaders is about the same as that found in rotary spreader patterns after the rotary patterns are optimized; thus, pendulum spreaders offer patterns equivalent to the best rotary patterns - without the need for any pattern adjustment.

*Numbers in parentheses refer to appended references.

Figure 3. Example of pendulum broadcast spreader.

Some fertilizer spreaders don't fall neatly into the above categories. Pneumatic spreaders have a central metering and distribution system that meters granules into multiple streams, which are then carried in pneumatic tubes out to evenly spaced points on a boom. At each point, the product is either blown directly to the ground or impacts a deflector that provides some spreading of the product to even out the distribution.

Spreader Operating Characteristics

Broadcast spreaders, unlike drop spreaders, throw granules in a wide pattern that tapers off at the edges. This tapering is beneficial because it makes the spreader more forgiving of minor errors in swath width. Spreader patterns can take several shapes as shown in figures 4 and 5. Trapezoidal and triangular patterns (Figure 4) are most effective because (if centered) they can provide a uniform application when properly overlapped. The patterns shown in Figure 5 are common, but they create problems. Patterns that are M-shaped or W-shaped typically require a double overlap and may not be uniform even then. Skewed patterns result in uneven application even when overlapped.

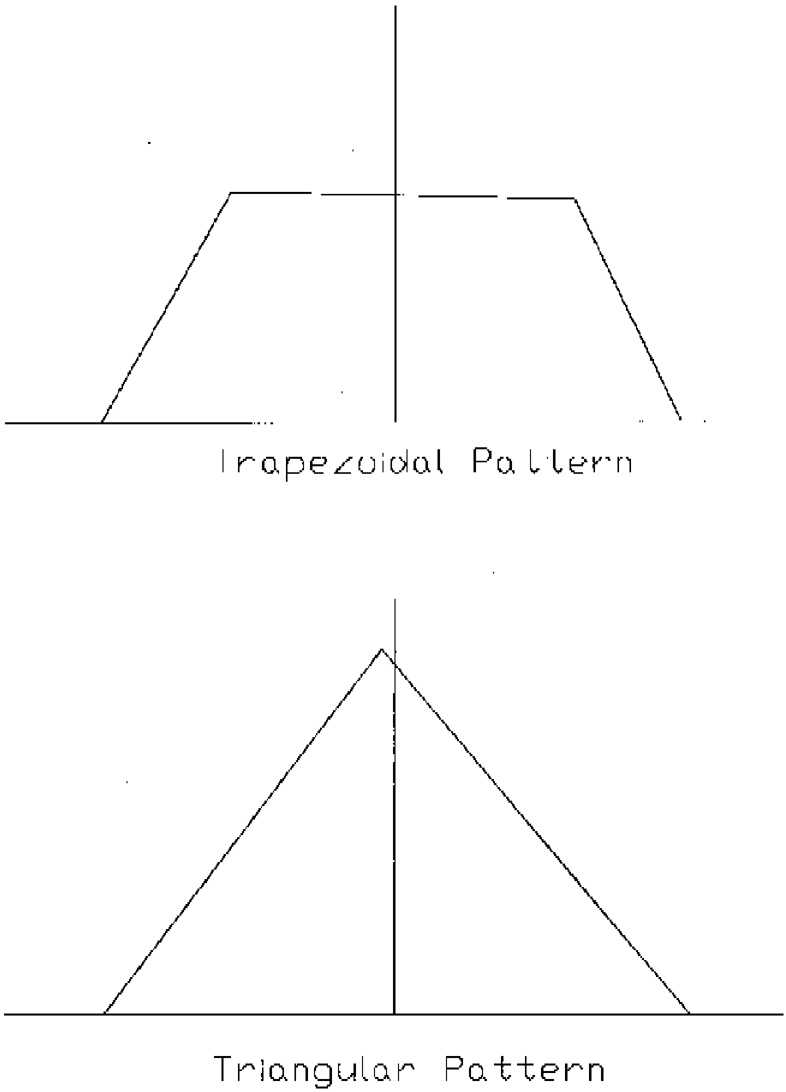

Figure 4. Examples of trapezoidal and triangular spreader patterns.

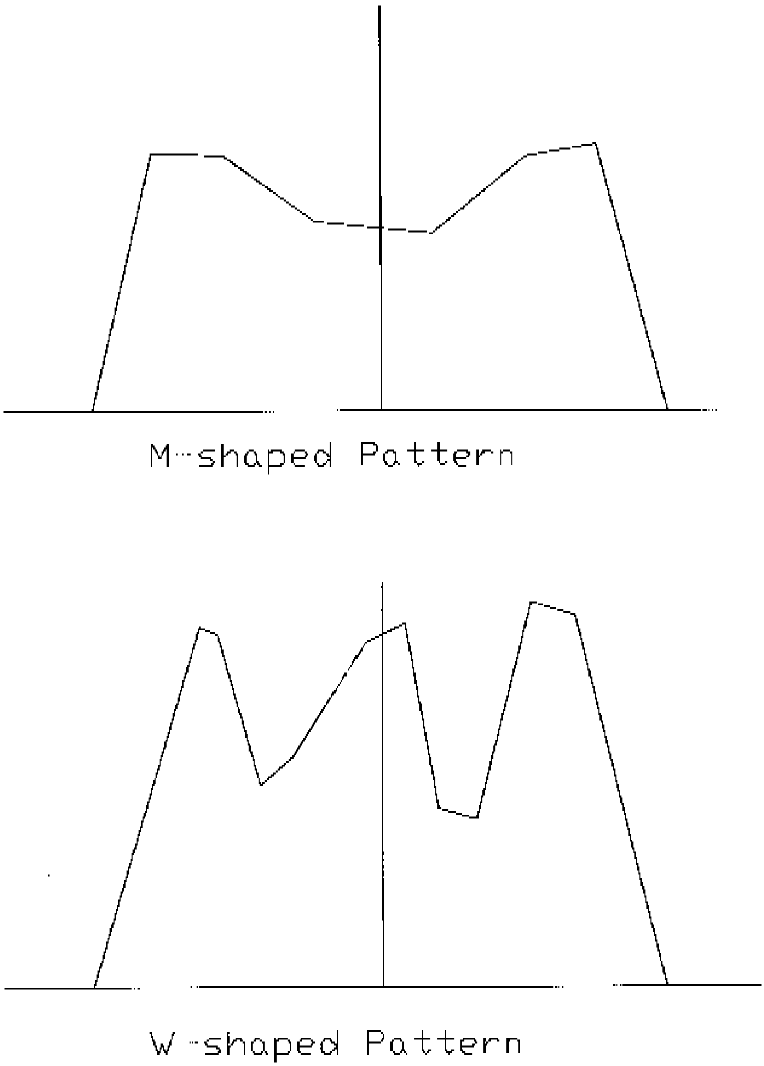

Figure 5. Examples of problem patterns.

Granule and Impeller Dynamics

The most common type of spreader for professional turf use is the broadcast rotary spreader with a single impeller. A brief discussion of granule and impeller dynamics will provide a better understanding of how the system works. First, granules seldom roll on the impeller, even when the granules are smooth and spherical. The granules generally slide out along the fins of the impeller until they are discharged; thus, the coefficient of friction of the granule on the impeller material has a major effect on how long the granule takes to move from the drop point out to the edge of the impeller. For a given drop point, the longer the granule stays on the impeller, the further the granule trajectory will be angled in the direction of rotation.

As the granules leave the impeller and fly through the air to the ground, they do not leave radially as is commonly expected, but tend to leave in a direction that is more tangential to the impeller (see Fig. 6). The exact angle of the trajectory will

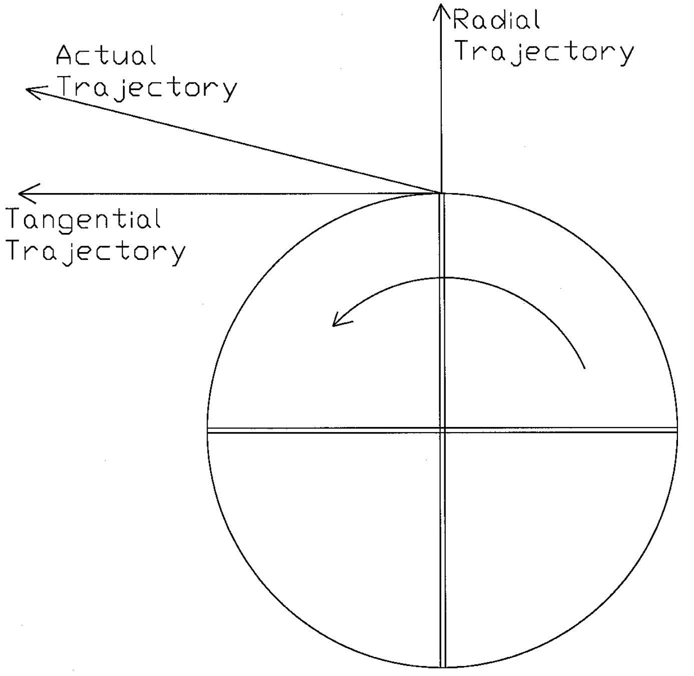

Figure 6. Typical trajectory of a granule leaving a spreader impeller.

depend on impeller configuration, impeller speed, impeller surface, granule characteristics, and relative humidity, but approximately 10° from tangential is typical.

Granules tend to leave the impeller in an arc rather than all of the granules following the same trajectory (see Fig. 7). Even with only one metering point, not all of the product granules will impact on the impeller at precisely the same point; thus, they will leave over an arc rather than all flying to one spot on the ground. Also, differences in size and shape of the granules will cause some to leave the impeller sooner than others. This phenomenon is desirable. To broadcast granules over a reasonably wide area, it is necessary to discharge the granules in an arc. It is important, however, that different sized particles have the same fertilizer or pesticide analysis since a broadcast spreader will tend to segregate particles by size, throwing the larger particles further.

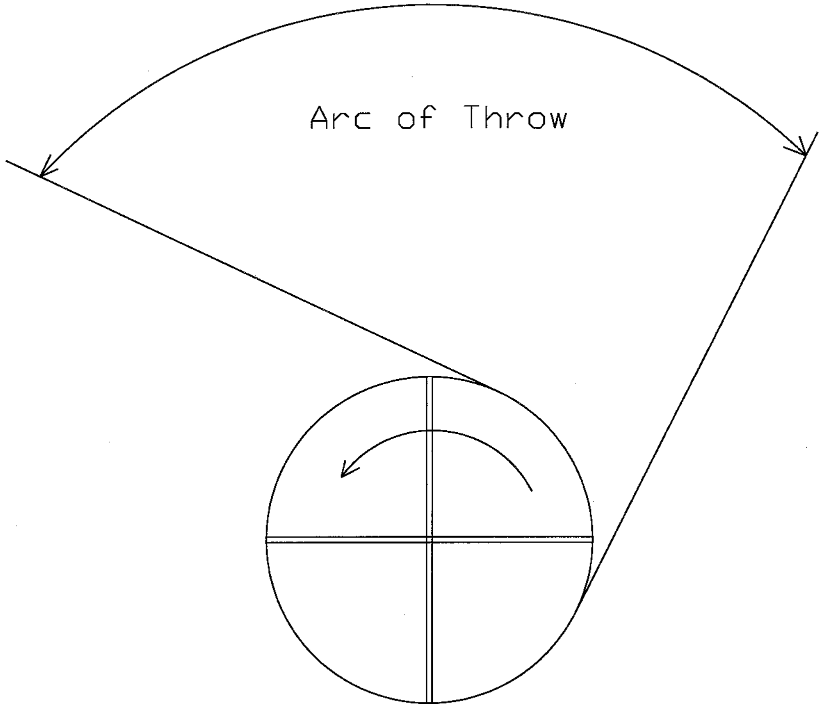

Figure 7. Illustration of material leaving spreader impeller in an arc.

Some spreaders use multiple ports (typically three) to further widen the discharge arc and thus contribute to a uniform, wide pattern. Using multiple ports can, however, contribute to peaks in the distribution pattern. It is common to have three peaks in the pattern from a spreader with three ports (45). Spreader manufacturers have addressed this problem in several ways. Some manufacturers use one wide port (wide in terms of angle around the impeller) to give a uniform flow of material in a wide arc on the impeller (30). This method can work but can lead to inconsistencies in rate calibration compared with multiple ports. Since the effective line of metering is longer, the opening must be smaller in the other dimension to get the same rate, and calibration is thus more sensitive to errors in opening. Another method of smoothing out the peaks from multiple ports is to use a deflector of some type under the metering opening on which the multiple flows impinge and then blend together (45). A third method is to mix more than one fin type on the impeller. If a 4-fin impeller has two straight fins and two curved fins, the three peaks will be changed into six smaller peaks, which will then more closely approach a uniform distribution (45).

Pattern Adjustment

Most professional rotary spreaders provide some means of pattern adjustment to allow the operator to correct for product and environmental differences. Most small homeowner rotary spreaders do not provide any means of pattern adjustment. The most common means of pattern adjustment involves changing the point(s) at which the granules impinge on the impeller. This can be done by moving the impeller itself, by moving the metering port(s) radially or angularly (46), or by moving some type of deflector between the ports and the impeller (30).

One interesting concept is the use of a truncated spiral cone mounted between the ports and the impeller (45). Rotating the cone moves the drop point radially in or out on the impeller while the cone surface also serves as a deflector to even out the distribution pattern. This method gives excellent results. Spreaders with this feature have the best patterns of any professional walk-behind turf spreaders.

Another approach is to rotate the ports in the hopper bottom to move the drop point angularly (46). Rotating the drop point above the impeller may allow the pattern to be improved; however, with some spreaders this adjustment results merely in shifting the pattern side-to-side without any improvement in pattern shape. This method is effective mainly for compensating for material or operational variables in an otherwise optimal pattern.

A different approach is to open or close some of the ports to change the center of the drop zone on the impeller (45). Partially or completely closing one port can change the shape of the pattern but also changes delivery rate, so rate settings must be changed accordingly. Another alternative is to move the fins on the impeller to change the trajectory for a given drop point. This is common on large agricultural spreaders.

Not all pattern correction methods are adequate. Some spreaders have pattern adjustment systems that do not allow enough adjustment to compensate fully for all potential materials (30).

High-speed photography of granules on spreader impellers has shown that granules sometimes jump over the fins on the impellers. This can disrupt the normal arc of release from the impeller and result in a heavy spot in the pattern. Manufacturers have countered this problem by putting a lip on the top of the impeller fins or by using curved channels for fins (45,46).

Alternate Spreader Designs

Most rotary broadcast spreaders throw material in a limited arc to the front or rear of the spreader. It is possible, with small homeowner rotary spreaders, to throw material in a full 360° arc. This is generally not possible with larger spreaders because the thrown material would hit the operator, tractor, etc. Throwing material in a 360° arc eliminates one of the problems inherent in most rotary spreaders - skewing (throwing more material on one side of the pattern than on the other). With a full 360° arc there is no skewing and thus no need to correct the pattern when changing from one product to another. The size of the arc does, however, change with product. With larger granules or higher density granules, the circular pattern will be larger than with light granules. When a 360° pattern is used, it is necessary to overlap adjacent passes enough that the material thrown from one pass reaches the centerline of the adjacent pass (i.e. double overlap) to achieve a uniform overlapped pattern. The effect of a 360° pattern is shown in Figure 8. At least one homeowner spreader

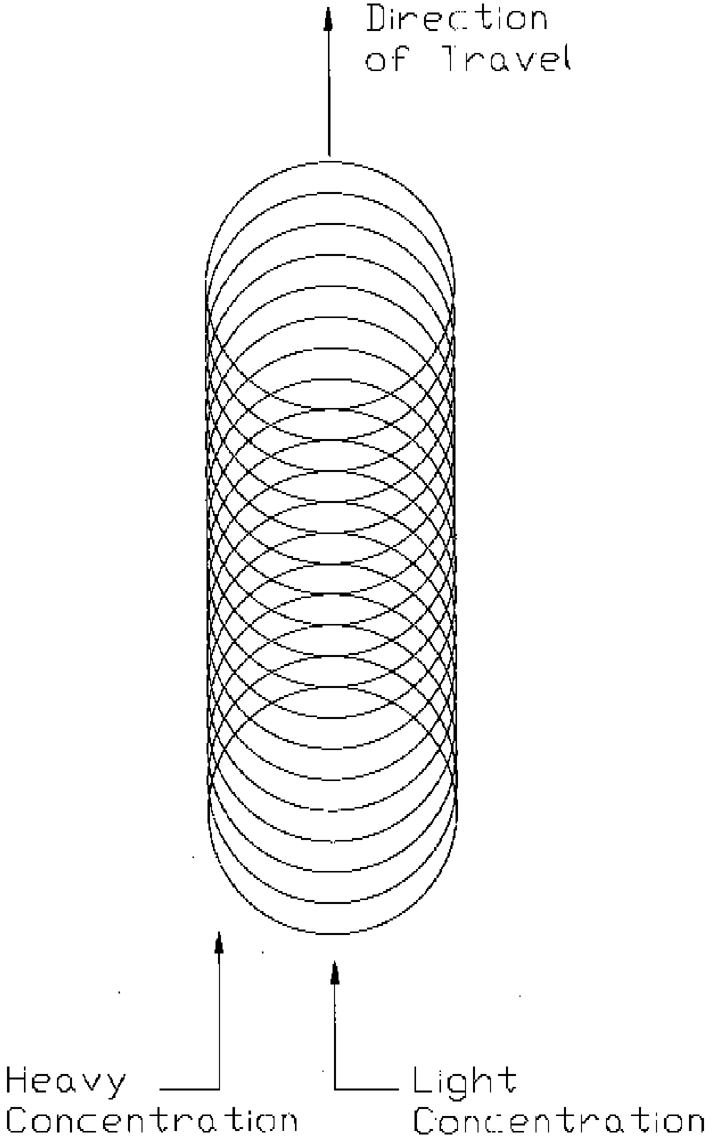

Figure 8. Effect on pattern of 360° throw.

using the 360° principle was marketed (6, 44). The small, low-speed impeller threw material with an effective swath width of only 30 inches. By limiting the recommended products, the manufacturer could recommend a consistent 30-inch swath width without having to correct for product variability.

A hybrid broadcast spreader has been developed that allows a broadcast rotary to act somewhat like a drop spreader (1). The spreader uses four metering ports spaced 90° apart, dropping granules onto a small rotary impeller to give a 360° pattern like that described in the previous paragraph. This spreader goes one step further, however, by using a shroud or skirt around the impeller to distort the pattern in a favorable manner. The shroud is a section of a truncated elliptical cone. As the granules are thrown from the impeller, they hit the shroud and are deflected down as well as in a horizontal angle as shown in Figure 9. The lines in Figure 9 represent equal arcs with equal quantities of

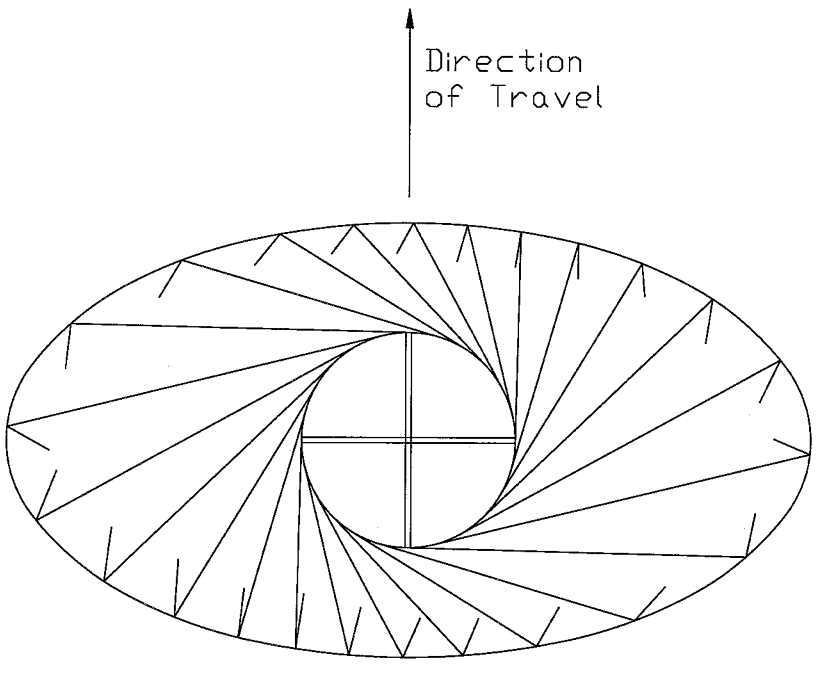

Figure 9. Trajectory of granules in elliptical shroud.

granules. The ends of the lines are closer together at the center, but spread out at the edges because of the bounce off of the elliptical shroud. Note how this compacts the pattern near the center and spreads the pattern out at the edges. This eliminates the need for a double overlap as required for a normal 360° pattern and provides a very consistent trapezoidal pattern with tapered edges.

This design is unique among broadcast spreaders in that it gives the same width and shape of pattern for a wide range of products and has no skewing. It can be used much like a drop spreader and provides almost the same uniformity, but it is lighter, cheaper, and provides a wide pattern. The elliptical shroud spreader provides some tapering and is thus more forgiving of swath width errors than a drop spreader. The first spreader using this design delivered a consistent 42-inch swath width with a wide range of products. This design also dramatically reduces the wind distortion common to other broadcast spreaders. It provides better ground clearance than most drop spreaders.

Drop Spreader Metering

Drop spreaders have a row of ports across the bottom or rear of the hopper. A shut-off bar moves either front-to-rear or sideways to open and close the ports. Limiting the opening determines the rate setting. The shape of the holes as well as the tolerances in the linkage and shut-off bar determine the accuracy of metering. A drop spreader can be very accurate and consistent but not all are. Some drop spreaders have a deflector under the ports to even out the flow from the individual ports.

Not all spreaders have hoppers. One home lawn spreader was sold without a hopper. The products intended for application with the spreader were packaged in standard-sized boxes. A box of product was installed on the spreader and became the hopper, with product from the box metered down to an impeller. Since the actual metering and the distribution were done by metal components on the spreader and the box served only as the hopper, the performance was equivalent to other small, low-cost homeowner rotary spreaders.

Selection Criteria

Factors in selecting a spreader include the size of the area to be covered, characteristics of the granular products to be applied, availability of predetermined spreader settings, need for uniformity, and cost of the spreader (2). The following summarizes some of the considerations in choosing between drop-type and broadcast spreaders:

Distribution uniformity: A drop spreader can be very precise and uniform across the swath width; in general, a broadcast pattern will be less uniform.

Distribution consistency: The pattern from a drop spreader stays essentially the same as long as it is used with compatible products; broadcast patterns vary with product physical characteristics.

Feathering: A broadcast pattern feathers at the edges to accommodate overlap and "forgive" minor errors in swath width; a drop spreader pattern is sharply defined and requires an exact swath width to avoid striping.

Wind effect: Wind usually affects a drop pattern much less than a broadcast pattern since the drop point is closer to the ground and the granules fall straight down.

Granule size: In general, broadcast spreaders can handle larger granules than drop spreaders because broadcast spreaders have a smaller number of larger ports.

Safety to surrounding areas: A drop spreader is considerably safer for surrounding vegetation than a broadcast spreader since the product granules are not thrown out beyond the spreader. There is less drift with a drop spreader.

Ground clearance: A drop spreader normally has the hopper closer to the ground than a broadcast spreader and thus has less ground clearance and is more susceptible to damage from impacting rocks, roots, and other obstacles.

Drive torque: A drop spreader normally has a higher drive torque than a broadcast spreader because of the full-width agitator, so a drop spreader will require more force to push or pull.

Speed effects: With a drop spreader, speed affects rate but not pattern. With a broadcast spreader, both rate and pattern can be affected.

Plugging: Since a drop spreader has many small ports, it is more susceptible to plugging than a broadcast spreader with one to three larger ports. Also, the lower clearance of a drop spreader makes it more likely to plug from wet foliage rubbing on the hopper bottom.

Construction material: Steel has traditionally been used for drop spreaders to achieve the required rigidity needed for precision, although some plastic drop spreaders are available. Broadcast spreaders can use plastic if desired to increase corrosion resistance and reduce cost.

Swath width: Drop spreaders cover only the implement width; broadcast spreaders can deliver a much wider effective swath.

Calibration

Basic Rate Calibration

Rate calibration and determination of pattern and swath width should be entirely separate processes. Even though rate data can be determined from pattern test data, the results are unreliable and can be dramatically incorrect. Before determining a spreader setting for the desired delivery rate, the effective swath width must be determined. For drop-type spreaders, the effective swath width can be measured directly. With broadcast spreaders, the effective swath width must be determined from pattern data. In some cases, this information will be available from the product manufacturer as a part of the product label; if not, pattern testing will be necessary. This will be described later.

Rate calibration is easy with most spreaders and involves no complicated mathematics. Although there are as many calibration methods as there are people recommending them, the method recommended here is the easiest to use. In the most general format, all the operator has to do is find out how long it takes (in seconds) for the spreader to cover a known area, collect the material discharged for that length of time at a given setting, and divide the amount by the area. This will give the rate (in kg / ha, lb / a, lb / 1000 ft^2, etc). The operator can then adjust the setting and try again until the desired delivery rate is achieved. Note that this method does ***not*** require any calculations of speed, flow rate, etc.

Adaptations for Different Spreader Types

Perhaps the easiest to calibrate is a pendulum spreader (38, 43). The spout can typically be removed by loosening two bolts. Once this is done, the output can be caught in a bucket or bag. If using a bucket, it is easier to set the bucket on the ground under the machine and hold a second bucket with a hole in the bottom over the oscillating spreader opening so that the flying granules are caught by the second bucket and funneled down to the main bucket. Some pendulum spreader manufacturers sell bags for this purpose. It is essential that the PTO be engaged and the spreader be operating when the test is conducted; the delivery rate will be much less at a given setting if the spreader is not operating (43).

Most drop spreaders can be calibrated by hanging a pan or tray under the shut-off bar and then pushing the spreader for a predetermined distance while catching the output. Knowing the spreader width and the distance traveled allows easy calculation of the area. When using this method it is very important that the pan not hang on or even touch the shut-off bar because this can not only affect the test results but can permanently change the calibration of the spreader.

With most rotary spreaders, it is more difficult to catch the output. In some cases, the impeller can be removed, allowing the material to drop into a container. In other cases, it may be possible to fasten a bag or tarp around the impeller(s) to catch the product. If these methods are not practical on a given spreader, it may be necessary to put a weighed amount of product in the spreader, drive the measured distance and spread while driving, then weigh the amount remaining. The difference between the two weights divided by the area covered will be the application rate. The spreader must be operating (i.e. PTO-engaged) during the test.

Small spreaders, both drop and rotary broadcast, can be calibrated on a test stand. The typical test stand consists of a table with two vertical tires protruding. The tires are driven by a motor at a speed that will make the peripheral speed equal to the desired ground speed. A catch pan under a slot adjacent to the wheels collects the product falling from the spreader while it is driven by the wheels. It is convenient to have a counter on the drive wheels to count revolutions. A conversion table is used to determine how many revolutions are needed for a given area (e.g. 1,000 ft^2) at various swath widths. If the impeller is removed, a rotary spreader can be tested on a test stand. Generally accepted speeds are 2.75 mph for walk-behind homeowner spreaders and 3.0 mph for walk-behind professional spreaders.

Pneumatic spreaders can be calibrated by catching the output from the individual discharge points in bags or other containers. Be sure to provide for the air stream to exit from the container.

Factors That Affect Rate

Many factors can affect spreader delivery rate. It may be necessary to recalibrate a spreader when any of these factors change.

Humidity

A common misconception is that fertilizer response to humidity is a ramp function, i.e. hygroscopicity increases with higher relative humidity. Fertilizer response to relative humidity is a step function. Every fertilizer product has what is known as a "critical relative humidity" (CRH). This is the relative humidity at which the fertilizer becomes hygroscopic and takes up water from the air. Below its CRH, a fertilizer will remain dry. Once the CRH is reached, the fertilizer will immediately begin to absorb water. The longer the fertilizer remains exposed to air above its CRH and the higher the humidity above the CRH, the more moisture the fertilizer will absorb (33) - until it reaches saturation.

Humidity has two primary effects on delivery rate. First, as the fertilizer picks up moisture, it will become less flowable and its angle of repose will increase. The delivery rate through the port(s) will thus decrease. Also, if the fertilizer picks up enough moisture, it will begin to build up on the spreader in areas such as under the agitator. This buildup around the ports can further reduce the delivery rate, and it can also dramatically increase the force needed to turn the agitator. With a walk-behind drop spreader, the increase in push force can be substantial.

Speed

Speed can have a major effect on spreader delivery rate. Many small broadcast spreaders are gravimetric (meter on the basis of gravity flow), and thus their delivery rate will be constant per unit time. If the ground speed changes, a given amount of material will be applied to more or less area. If, for example, a spreader meters 2 pounds per minute and covers 500 ft^2 per minute, it will apply 4 lb / 1,000 ft^2. If the ground speed is increased 10% so that the spreader now covers 550 ft^2 in a minute, the rate will decrease to 3.6 lb / 1,000 ft^2.

Volumetric metering means that the metering unit will deliver a fixed amount of material per revolution and thus be unaffected by speed. A grain drill and a granular pesticide meter on a row-crop planter are examples of volumetric metering. Most drop-type spreaders are neither gravimetric nor fully volumetric. Some authorities have published statements that homeowner drop-type spreaders are volumetric, thus speed is irrelevant (54). This is incorrect. Research has shown that common drop-type homeowner spreaders are more nearly gravimetric than volumetric (17, 20, 47). Speed does have a major effect on their delivery rate. Increasing ground speed will decrease application rate. The exact relationship between speed and delivery rate will be different for each model of spreader and will be determined by the geometry of that spreader.

Product

Characteristics of the product granules can affect the rate calibration (34, 36). Granule size is important, as is the size distribution. Unfortunately, some product manufacturers use only a top and bottom size specification for their granular products. For instance, they might specify only that 98% of the granules be small enough to pass through a #14 sieve and large enough not to pass through a #20 sieve. If one production run meets the spec but is skewed toward mostly 14-16 size granules and another production run also meets the spec but is skewed toward mostly 18-20 size granules, the two materials will perform very differently in spreaders.

Shape of the product is important, too. Shape can change the angle of repose of a product and thus change how freely the product flows. This, in turn, can affect the delivery rate of gravimetric metering systems.

Moisture content of the product can affect the angle of repose as well as the coefficient of friction of the granules. Eventually, product moisture will stabilize at some level consistent with the ambient relative humidity, but the initial product moisture when the bag is opened may be higher or lower, depending on how it was packaged and stored. Changes in these properties can change the delivery rate.

Manufacturers may make major changes in product and keep the same product name. For instance, a manufacturer might even use different N-P-K sources for one batch because of raw material availability. With pesticides, the manufacturer might substitute a corn cob carrier for a clay carrier and not show any changes on the label. Thus, even though the product name and fertilizer or pesticide analysis are the same, the physical product may be completely different and perform differently in the spreader.

All of the above factors can affect the calibration and delivery rate of a product through a spreader. Some of these factors are normally not checked or controlled by product manufacturers; others (e.g. moisture) can change in shipping and storage. It is important that an operator check the delivery rate for each *batch* of product prior to application. The rate that was correct for the last batch may not be correct for this batch.

Spreader Angle/Handle Height

Unfortunately, something as simple as the height at which the handle is held can have a major effect on spreader delivery rate. This is primarily a problem with plastic drop-type spreaders. With plastic spreaders, the hopper bottom is usually much thicker than with steel spreaders. Since the hopper bottom is thick in the area of the ports, the vertical opening can change as the hopper is tilted (see Figure 10). Since granule flow rate is a function of vertical opening, flow rate can change. People of different heights hold spreader handles at different heights. Homeowner spreaders are used by people 5 feet tall as well as people well over 6 feet tall. This disparity in heights can lead to handle height variations of more than 6 inches. With some plastic spreaders, a 6-inch change in handle height can change the delivery rate by 50% -100%. It is thus important that the delivery rate determination for plastic spreaders be done with a handle height appropriate for the person who will be operating it. In general, spreader settings on bag labels are based on tests with the spreader hoppers level.

Initial Calibration

The initial calibration of a spreader is set at the factory in most cases, but it is sometimes necessary to readjust this initial calibration. For instance, if the rate linkage has worn, the shut-off bar or plate has been damaged, or the rate parts have been disassembled, it is desirable to check and reset the initial calibration.

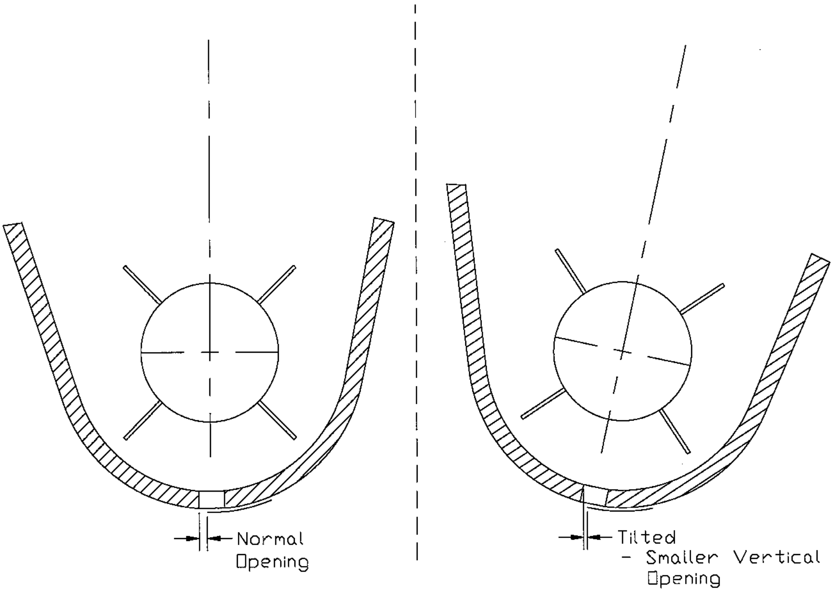

Figure 10. Effect of angle on thick hopper bottom: a) normal angle, b) spreader tilted back 12°.

This is possible with most larger spreaders and with some homeowner models. If recalibration is possible, the manufacturer will recommend a procedure and, in some cases, provide a calibration gage. One common method of recalibrating professional walk-behind rotary spreaders is to insert a gage rod (or the correct size drill bit) into the specified port opening, adjust the rate setting so that the plate just closes on the gage, and then adjust the pointer to the specified mark on the scale. Another common method is to adjust the rate setting until a specified port just barely closes, and then adjust the pointer to the specified mark on the scale. Some drop spreaders are calibrated by using a gage that is held against the edge of the shut-off bar and the hopper bottom (with the spreader inverted). The shut-off bar is adjusted so that the tips of the ports show in a depressed portion of the gage but not at the sides of the gage. The rate plate is then locked down and the pointer moved to a specified mark on the scale. Other methods may be used by other manufacturers. The important point is to be aware of the need to periodically check the spreader's initial calibration using the manufacturer's recommended procedure and then correct as needed.

In addition to the need to calibrate the rate setting itself, initial calibration can also involve other factors. The clearance between the shut-off bar or plate and the hopper bottom can have a major impact on delivery rate and should be held to close tolerances by the manufacturer. For example, one common spreader has a tolerance of 0.003-0.015 inch between the shut-off bar and hopper. If this adjustment is changed in use, the rate calibration can vary considerably. A common problem is granules building up between the shut-off bar or plate and the hopper, causing the bar or plate to be held out from the hopper. This can dramatically increase the delivery rate, especially at lower settings.

Inexpensive homeowner spreaders that have the rate-setting mechanism on the upper handle and a cable down to the shut-off bar or plate are very subject to changes in initial calibration. For example, any stretching or kinking of the control cable or any looseness in the handle bolts will change the initial calibration.

Pattern Testing

Pattern testing is the critical first step to obtaining uniform distribution with broadcast spreaders. A pattern test is necessary to determine the effective swath width and the correct pattern adjustment(s) for optimum uniformity (4, 5, 41). Some manufacturers conduct pattern tests on each product in the spreaders they recommend and then put the recommended widths and pattern settings on the bag labels. With reputable companies, you can generally rely on the label pattern settings. In most cases, however, you will need to conduct your own pattern test for each spreader and product. With walk-behind spreaders, you should conduct a pattern test with each individual operator.

Basic Procedure

The basic procedure for conducting pattern tests is very straightforward. Several collection trays are laid on the ground in a straight line perpendicular to the direction of spreader travel. The spreader is then operated over the line of trays. The material collected in the trays is measured and the resulting data used to calculate the spreader pattern. The American Society of Agricultural Engineers has developed a standard for spreader pattern testing. The procedures outlined here are based on that standard (ASAE S341.2, Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders).

The size and configuration of the trays are important (9, 48). The trays should be small enough that you can get at least 10 trays in the effective swath width. More than 10 trays are better. If the trays are too small, however, the test will be more difficult to conduct, and the results will be biased by the small tray size (9, 48, 49). It is desirable to use as many trays as practical without resorting to reduced tray size. For large agronomic spreaders, the pans can be 12-24 inches wide by about 24 inches long and spaced every 24-48 inches. For most professional turf spreaders, trays that are 11-12 inches wide by 15 inches long work well. They should be spaced 12 inches apart for walk-behind spreaders and 24 inches apart for tractor spreaders. For most small homeowner spreaders, trays 5-6 inches wide by about 15 inches long work well. These should be spaced on 6-inch centers across the full pattern width.

With some very small homeowner spreaders, even narrower trays may be needed to obtain adequate data points.

Trays for small spreaders should be about 2 inches high. Trays for large agronomic spreaders can be up to 4 inches high. All should have internal baffles to reduce the amount of material that bounces out on impact. It is helpful to use baffles that do not reach all the way to the bottom of the trays so that pouring material from the trays is easier.

Removing trays from the pattern to allow the spreader (and tractor) tires to pass through the line of pans is acceptable. The line of trays should extend at least far enough to each side to catch the farthest granules thrown. Collecting material only in the effective swath width is not adequate.

Making more than one pass over the trays for each test can be helpful. This procedure helps average out small run-to-run variations and also results in larger samples to measure. Testing has shown that there are no statistically significant differences in the patterns obtained from single or multiple passes.

Some spreader engineers have been concerned about the effect of the air blast from the tractor exhaust and tractor cooling fan on material in the trays when making multiple passes over a line of trays. The concern is that the air blast from one pass might blow material from a previous pass into or out of some of the trays. Testing has shown that this effect is not significant, even with a very low density material and a tractor with an under-slung exhaust system.

The material from the trays can be measured either by weight or volume. Weighing the samples is more accurate, and electronic scales with 0.1-gram accuracy are inexpensive and adequate for this job. An alternative is to measure the material volumetrically in a small graduated cylinder. Since you are interested only in relative measurements, it really doesn’t matter what units of measurements you use (grams, ounces, cubic centimeters, milliliters).

Data Analysis

Once the material in the trays is measured, the data must be analyzed. One traditional way of analyzing the data is to plot a graph of the pattern on graph paper. This allows you to visualize the pattern, and you can readily detect pattern problems such as skewing, peaks in the pattern, and light areas in the pattern. Given the information from a graph, you can then adjust the pattern settings on the spreader and make another pattern test, repeating this procedure until you obtain the best pattern possible with your spreader and product.

A graph of the spreader pattern allows a rough estimate of the effective swath width. This method of determining swath width is not as effective as calculating an overlapped swath width but is better than nothing. To estimate the swath width from a graph, you should draw a horizontal line through the graph about where you estimate the average rate (of the center section) to be (see Figure 11). Now add a second horizontal line at half that rate. Draw vertical lines down from the points where the half rate line intersects the pattern edges. The distance between the two vertical lines is the approximate effective swath width. The vertical lines

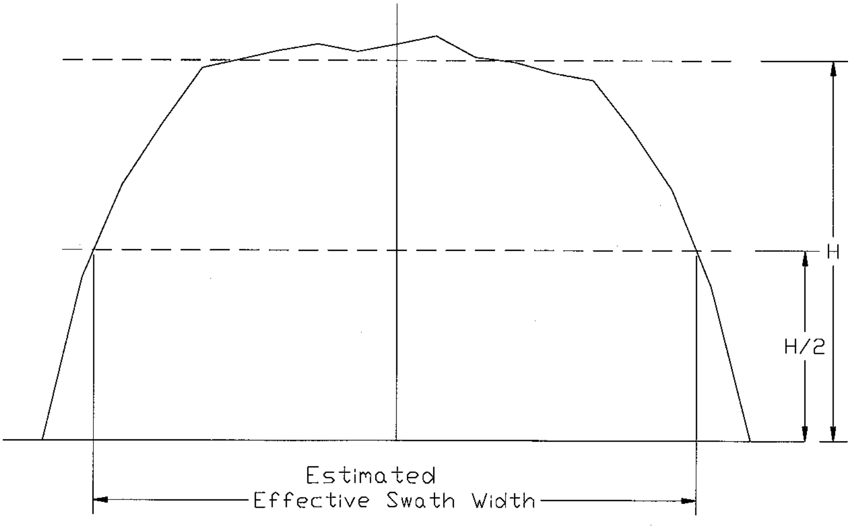

Figure 11. Estimating swath width from a graph.

represent the overlap points from adjacent patterns at the selected swath width. If the pattern is skewed, one vertical line may be further from the center than the other.

It is also possible to mathematically construct overlapped patterns for various potential swath widths. This is done by listing the data from the individual pans for the center swath and then adding in the amounts at each point for assumed adjacent (identical) passes that overlap the center or primary pattern. Depending on the proposed operating mode, you will need to add left-on-left, right-on-right or left-on-right, right-on-left. Three patterns (center plus one on each side) may be adequate, but for triangular patterns or narrow potential swath widths, it will be necessary to add in five or even seven patterns. Enough patterns must be considered that all data points from overlapping passes falling between the overlap points on the center pattern are taken into account. All points beyond that will be a repeat of the points between the overlap points and thus are superfluous for this exercise.

Although overlapped patterns can be analyzed manually, it is much easier to use a computer program. Several programs are available. A program called Spreader.EZ is available from the Louisiana Cooperative Extension Service (10, 14, 15, 19, 51). To use this program, you first enter background information about the spreader, product, test conditions, etc. and the pattern data. The computer will then print several pages of information for you. The first page will be a record of the background information (Figure 12). The second page will show a graph of a single pattern, a record of the apparent delivery rate at each point in the pattern, and a figure for skewing, expressed as % left, % right (Figure 13). The third page of the computer output shows a range of potential swath widths and several overlapped pattern parameters for each. The parameters shown are coefficient of variation (CV), apparent mean delivery rate, and the minimum and maximum points in the overlapped pattern, expressed as percentages of the average delivery rate (Figure 14). The fourth page of the output shows a graph of CV as a function of overlapped swath width (Figure 15). Additional optional pages are possible. Each optional page will provide a graph of the overlapped pattern for a selected swath width (Figure 16).

```
ROTARY SPREADER PATTERN ANALYSIS
  SPREADER.EZ -- DEVELOPED BY
   LOUISIANA STATE UNIVERSITY

                                                  Copyright (c), 1986, 1988, by Richard L. Parish
                                        Louisiana State University and A & M College, Baton Rouge, Louisiana
                                                                 All rights reserved


    TEST CONDITIONS --

         CATCH PANS ARE  11.5  INCHES WIDE BY  15  INCHES LONG
         THE SPACING BETWEEN PANS IS  24  INCHES
         THE DISTANCE FROM THE CENTERLINE TO THE OUTER CATCH PAN IS  30  FEET
         THE NUMBER OF PASSES OVER THE PANS PER RUN IS  3

    SPREADER DESCRIPTION --

         THE SPREADER MODEL USED IS -- Vicon 203
         SPREADER VARIABLES (IF ANY) --Pendulum spreader

    DATA ON PRODUCT BEING TESTED --

         PRODUCT NAME IS 20-2-10
         PRODUCT DESCRIPTION -- Encapsulated fertilizer

    DATA ON INDIVIDUAL TEST RUN CONDITIONS --

         TEST NUMBER = 1
         SPREADER SETTING = 24
         SPREADER OPERATOR = RLP
         DATE OF TEST RUN = 07/19/96
         TEST LOCATION = HRS
         SPREADER SPEED =  4.5  MPH
         TEMPERATURE = 88 DEGREES F
         RELATIVE HUMIDITY = 74%
         OTHER TEST VARIABLES -- Standard test
```

Figure 12. Sample of page 1 of Spreader.EZ output: background data.

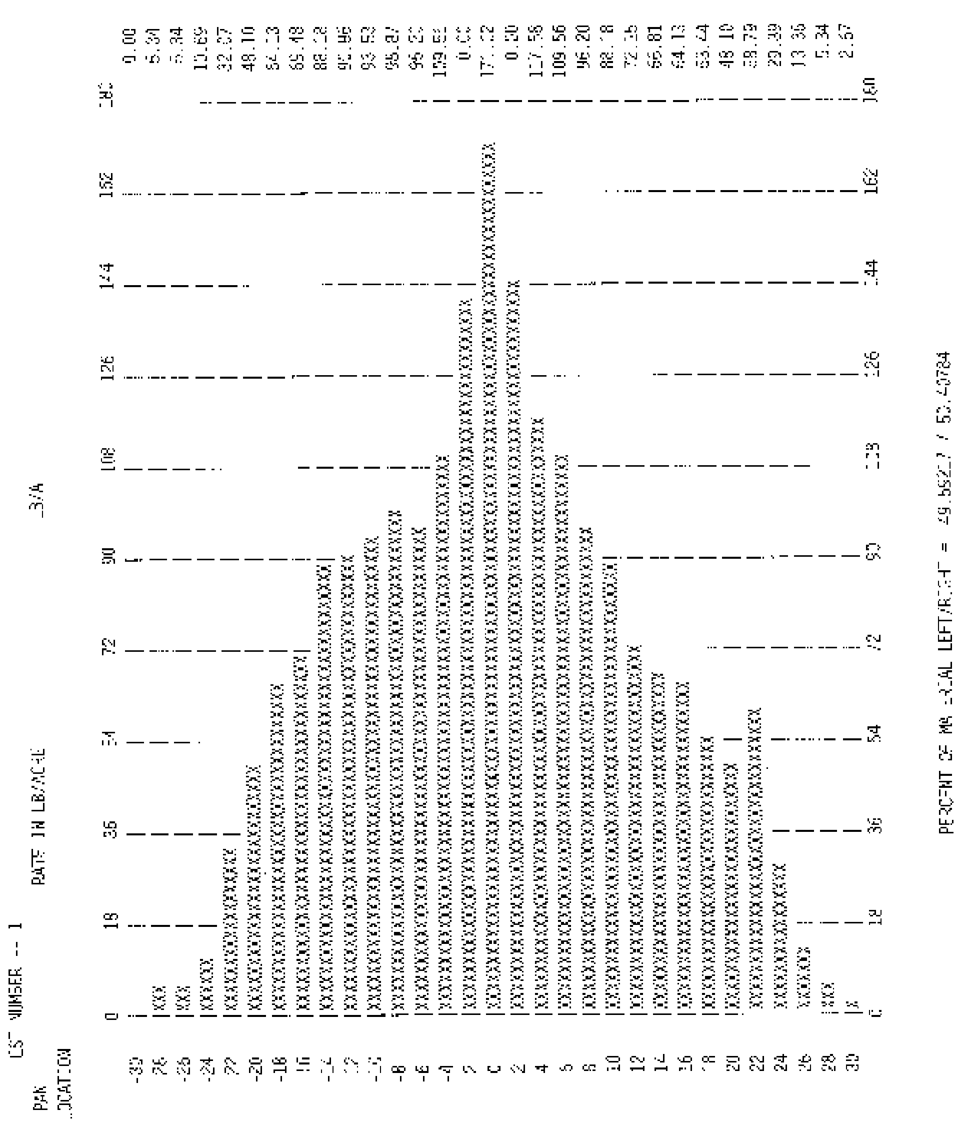

Figure 13. Sample of page 2 of Spreader.EZ output: skewing and graph of single pattern.

TEST NUMBER -- 1 CONTINUOUS OPERATION

SWATH WIDTH, FEET	C.V., %	MEAN RATE, LB/A	MINIMUM RATE, %	MAXIMUM RATE, %
8	6.	516.15	91.	107.
10	10.	416.74	84.	110.
12	8.	345.67	87.	108.
14	6.	299.10	94.	113.
16	10.	258.76	83.	118.
18	14.	232.63	83.	124.
20	16.	207.10	84.	129.
22	15.	190.34	84.	138.
24	11.	173.59	83.	122.
26	10.	161.05	86.	118.
28	12.	149.91	80.	121.
30	12.	139.58	77.	124.
32	13.	131.02	78.	131.
34	15.	123.16	82.	139.
36	16.	116.38	83.	147.
38	19.	110.20	78.	155.
40	22.	104.28	74.	164.
42	26.	99.70	72.	172.
44	30.	94.98	52.	180.
46	34	91.03	47.	188.
48	40.	85.35	25.	200.
50	43.	83.75	19.	204.
52	50.	78.24	14.	219.
54	52.	77.54	14.	221.
56	59.	72.57	7.	236.
58	60.	72.20	7.	237.
60	68.	67.63	0.	253.
62	68.	67.54	0.	253.

Figure 14. Sample of page 3 of Spreader.EZ output: descriptive parameters for potential overlapped patterns.

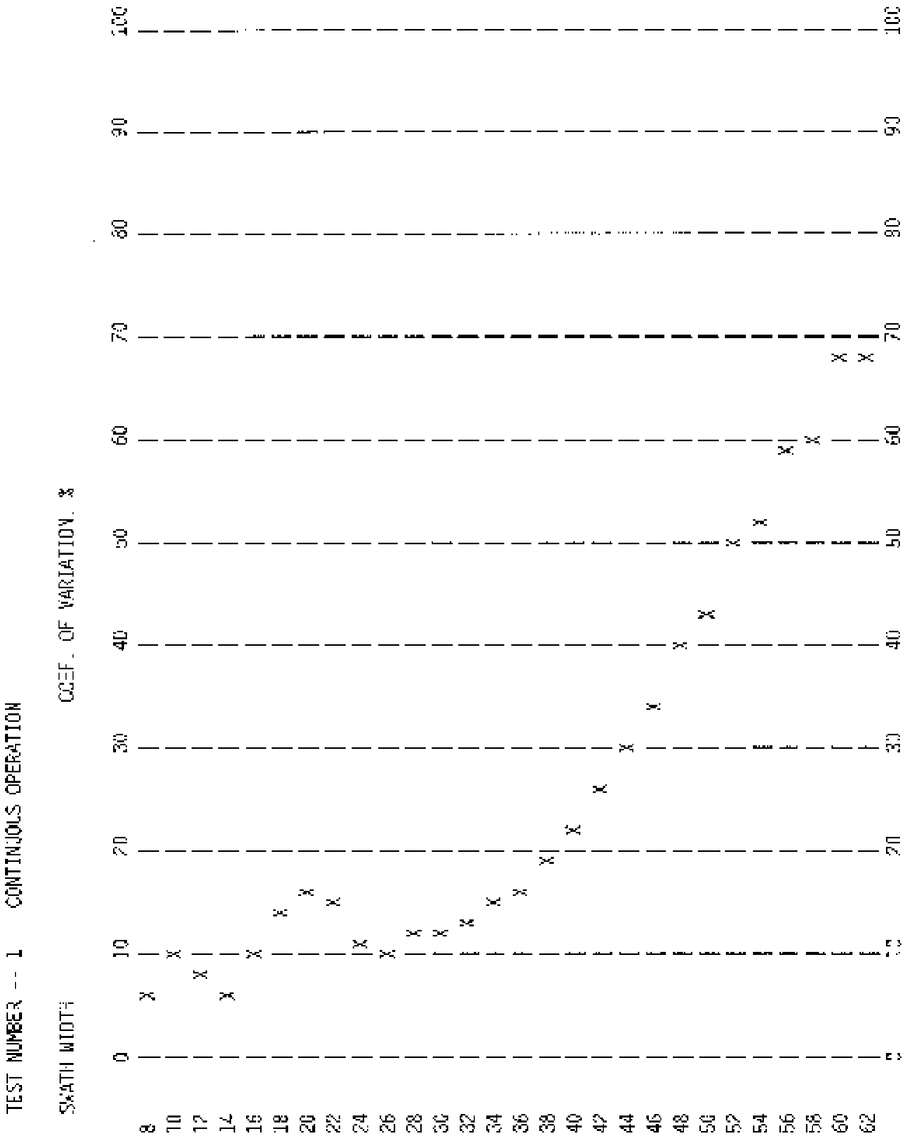

Figure 15. Sample of page 4 of Spreader.EZ output: graph of CV as a function of swath width.

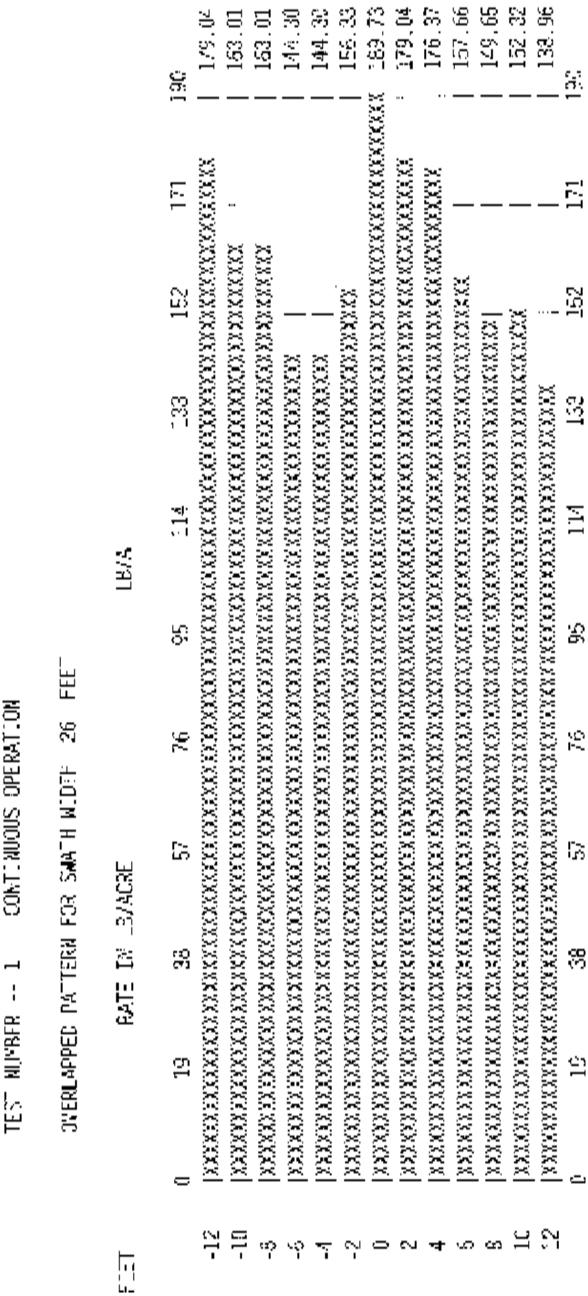

Figure 16. Sample of optional additional pages of Spreader.EZ output: selected overlapped pattern.

Data Interpretation

CV is a measure of the overall uniformity of the pattern. The lower the CV, the more uniform the pattern. If the application rate were exactly the same all the way across the overlapped pattern, the CV would be 0%. A CV value of 10% or less is generally considered acceptable for any spreading situation. With some combinations of spreader and product, it will not be possible to obtain a CV 10% at a reasonable swath width. For most fertilizer spreading and some pesticides, a CV value 20% will be adequate. Obviously, you want the lowest CV possible with your equipment and product, and you should make whatever adjustments are needed to minimize CV.

Although CV gives a good "snapshot" of pattern uniformity, it doesn't provide a full picture. The minimum and maximum points in the overlapped pattern are critical because they determine whether the potential for striping is present. Ideally, the minimum and maximum points should both be as close to 100% as possible. In practice, with many broadcast spreaders a range from a minimum of 80% and a maximum of 120% is about as good as can be achieved. With most products this will be adequate, although some striping is still possible under certain conditions. Greening response of turfgrass (and other crops) to fertilization is somewhat of a step function rather than a continuous ramp function (48). For a given condition of crop, soil, and weather, there seems to be a fertilizer rate below which greening does not occur and above which it does occur. If that critical rate falls within the minimum / maximum range for an application, striping will likely occur. Striping cannot be predicted since there is no way to predict the critical rate for any given condition.

What is acceptable in terms of CV, minimum, and maximum will vary somewhat depending on expectations. If you are top-dressing wheat, more variation across the pattern is acceptable than if you are preparing a golf green for a major tournament. Extraordinary measures may be justified for important or highly visible situations.

As noted earlier, the mean rate figure cited in the test results should not be used to determine the rate setting. It will generally not be as accurate as a separate rate calibration.

Methods of Adjusting Spreader Patterns

If either the CV or the minimum or maximum rates are not acceptable for a given situation, it may be necessary to adjust the pattern and then rerun the pattern test. Several iterations of this may be required to achieve an optimum pattern. General methods of adjusting the pattern of a rotary broadcast spreader were discussed in the section on Spreader Operating Characteristics.

On most walk-behind turf spreaders, the impeller turns counterclockwise (as viewed from the top). With this configuration, moving the drop point on the impeller radially out will shift the pattern to the right since the granules will leave the impeller sooner. Moving the drop point toward the center will shift the pattern left since the granules will stay on the impeller longer. Moving the drop point to the left will shift the pattern to the right, and moving the drop point to the right will shift the pattern to the left. Partially or fully closing off the left port will reduce the amount of material thrown to the right (45). Tractor-powered and vehicle-mounted spreaders operate on similar principles, but the throw will be toward the rear (46).

Some professional turf spreaders provide a way to restrict the throw to one side to provide a one-sided pattern for use along driveways, buildings, etc. These systems typically consist of a shield or deflector that drops down on the right side and should also include a convenient means of closing off the left port. If the left port is not closed, the effect of the shield will be to pile up the material from the right side into a heavy band near the center.

Factors That Affect Pattern

Many spreader, product, and environmental factors can affect the spreader pattern. When any of these factors change, a new pattern test will be needed to assure that a uniform pattern is being achieved.

Wind

Wind will disturb a spreader pattern. Wind from the side is more of a problem than wind in the direction of travel. A side wind will cause the pattern to skew. Although *any* wind is a potential problem, the stronger the wind the worse the problem will be. Also, lighter or smaller granules will be disturbed more than larger, heavier granules for a given wind velocity. A good general rule is to avoid applications when the wind velocity exceeds 5 mph. If you can see tree leaves moving at all, it is windy enough to affect spreader patterns. Neither pattern tests nor actual applications should be made when the wind is blowing.

Granule Bounce

Granules bounce when they impact a hard surface. As noted, collection trays used for pattern testing should be equipped with baffles to minimize granules bouncing out. This still leaves the problem of material bouncing into the trays from the ground or floor. Pattern tests are most often conducted on paved surfaces for two reasons: to allow the material to be swept up after the test and to prevent damage to turf (or other crop) from the high rates often applied during testing because of multiple passes. However, conducting pattern tests on hard surfaces will lead to granules bouncing into trays and distorting the pattern. This problem has been documented in several research studies (27, 32, 40, 50).

The problem is most serious with larger, heavier granules (32, 50). The granules tend to bounce out from the center and accumulate in the outer pans. This has the effect of making the pattern appear wider and heavier at the edges than it really is. Also, research studies have shown that much of the apparent tapering or feathering at the sides of broadcast spreader patterns is actually the result of granule bounce on the test surface, and thus the true pattern in the field will have much less tapering - and be less forgiving of swath width errors (32, 50). Bounce into the pans also makes the apparent rate (based on pan data) much higher than the actual delivery rate. In one research study, more than twice as much material was collected per pan in the outer pans using the standard test on concrete compared with testing an elevated spreader and deep pans that eliminated bounce (32). The effect is negligible with very light products such as vermiculite or small grades of ground corn cob. This problem of granule bounce into the collection trays is the reason a separate rate calibration is recommended rather than using pattern data for rate determination. The effect of granule bounce in distorting the apparent pattern has been shown to be a factor of granule size and is not related to product bulk density.

Several alternative test methods have been suggested as a way of correcting or compensating for the problem. The easiest way to avoid this problem is to conduct the test on turfgrass, pasture, or loosely tilled soil so that the granules will be trapped by the vegetation or soil and will not bounce. This approach can cause other problems as noted previously.

If an artificial test surface is desired, artificial turf or carpet works well in some situations. The material can be placed under the row of trays to reduce bounce, or sections of artificial turf within the overall carpeted area can actually serve as the collectors. This approach works well in theory but has practical limitations, particularly in a humid climate. Potential problems with this approach include the problem of granules sticking in the artificial turf or carpet because of hygroscopic moisture under high humidity. Another problem is the tires of the spreader (and vehicle) grinding material into the carpet.

Granule Type

The effects of granule type on spreader performance have been discussed previously (34, 36). Movement of the granules on the impeller is determined by the coefficient of friction between the granule and the impeller. Trajectory of the granules is determined by the angle and velocity of release from the impeller and the aerodynamic characteristics of the granules. If one batch of granules differs from another in terms of granule size, granule shape, granule density, or granule surface condition, the pattern will change. The granule characteristics of a particular product can change dramatically from one batch to another, either because of deliberate formulation and manufacturing changes, or just overly generous product quality specs.

In general, the larger the granule, the wider the pattern. Granule size is much more important than granule density. Since the mass of a granule is proportional to the cube of the radius, doubling the diameter of a granule will increase the mass by eight times. By comparison, the density of the most dense fertilizers is seldom more than 2-3 times the density of the lightest pesticide carriers. Therefore, if granule size or the range of granule sizes, or the distribution of granule sizes within a range, changes, a new pattern test is indicated.

Whenever possible, it is desirable to conduct pattern tests using blank granules rather than granules containing a pesticide. This will usually not be possible for individual operators since blank granule versions of products are normally not available to them. Whenever blank granules (e.g. ground corn cob, clay, peanut hulls, etc.) are available, they will be safer to handle and will cause fewer environmental problems. Conducting tests with active formulations can create cleanup problems. It is also expensive if the product is wasted. Research has shown that blank granules often have the same pattern characteristics as granular pesticide formulations but generally do not have the same delivery rate (36). Blank granules may also skew somewhat differently because of differences in coefficient of friction on the impeller. Usually, blank granules can be used for pattern testing and then formulated granules for rate testing. Some formulations may affect pattern if the formulation is sticky or wet and changes the coefficient of friction of the granules on the impeller.

Humidity

Ambient relative humidity can have a major effect on distribution pattern shape and uniformity (33). The concept of critical relative humidity has been discussed previously. Most fertilizers and pesticides on fertilizer carriers are hygroscopic at some critical relative humidity below 100%. In addition to changing the flow rate of the material out of the spreader, humidity can cause other problems, particularly with rotary broadcast spreaders.

Humidity can cause fertilizer granules to soften and to become sticky. This can lead to buildup of fertilizer on the impeller surface and fins. The sticky granules can have a considerably different coefficient of friction on a coating of fertilizer built up on the impeller than dry granules have on a clean impeller. Research has shown that different types of fertilizer can cause somewhat different problems. With some fertilizer materials such as ammonium nitrate that are cold water soluble, the granules become soft and moist, but buildup on the impeller does not occur. In this case, the pattern changes with humidity level (above the CRH), but at a given humidity level there is no progressive change; the pattern remains constant at each humidity level. With an impeller turning counterclockwise on a walk-behind spreader, the effect was to skew the pattern to the right.

Other fertilizer materials such as urea formaldehyde and methylene urea formulations do build up on the impeller. Continued use when ambient relative humidity exceeds the CRH results in an ever-thicker buildup and thus progressive pattern deterioration. There is also a progressive change with increasing relative humidity (above the CRH). Figure 17 shows the effect of different levels of relative humidity. Figure 18 shows the progressive pattern deterioration from successive runs at a constant relative humidity. Fertilizer can build up not only on the impeller but also on other parts such as the spiral cone used in the example above (figures 17 and 18).

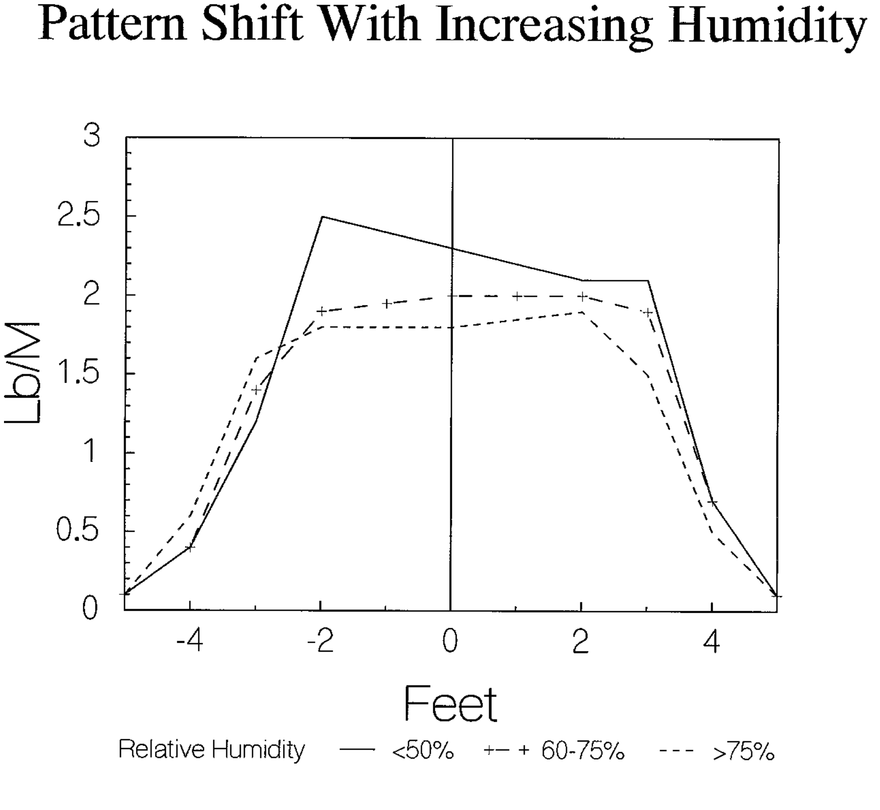

Figure 17. Pattern shift with increasing ambient humidity with methylene urea fertilizer in professional turf rotary.

It is interesting to note that material buildup and resultant pattern change is not necessarily detrimental. In a research study with a methylene urea fertilizer in a common professional turf rotary, the pattern CV was actually lower at high humidity (33). In that case, the initial pattern was skewed to the right, even after full adjustment, and the skewing to the left caused by the buildup resulted in an improved pattern.

An operator needs to be aware of the potential for problems with humidity. It would be well to avoid making applications under high humidity, but this is impractical. High humidity conditions are common in Louisiana. The problem is often compounded by the need to make applications early in the morning

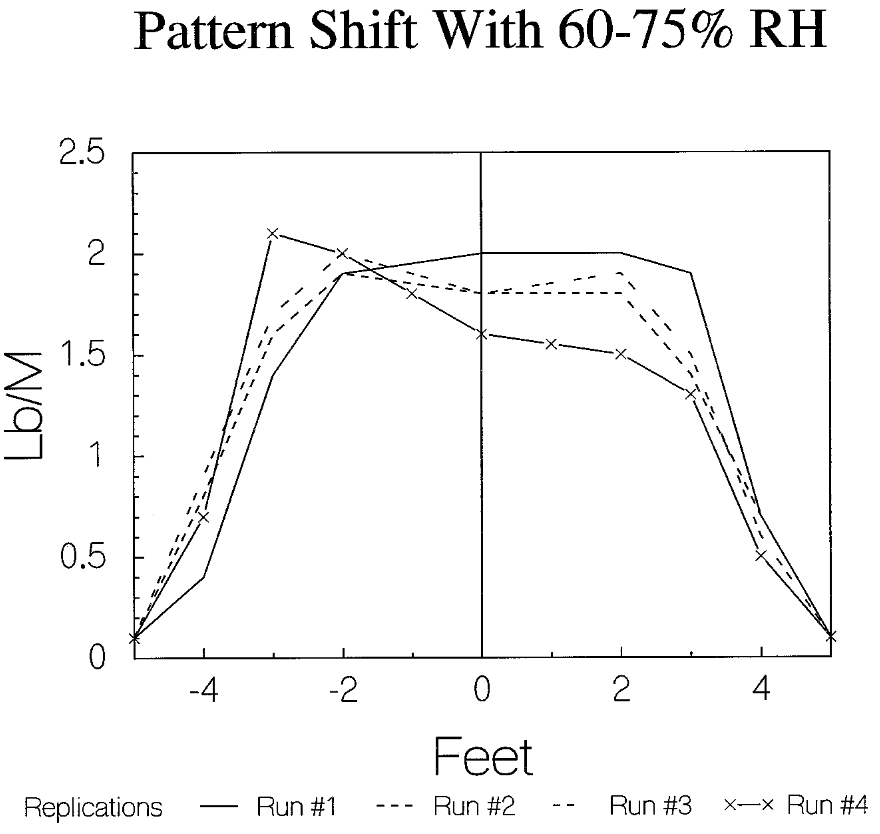

Figure 18. Pattern shift resulting from progressive buildup from methylene urea fertilizer in professional turf rotary spreader at 60% - 75% relative humidity.

when humidity is highest (to avoid wind or, for turf, to avoid interference with people). A spreader setting developed in an ambient relative humidity below the CRH of the product will probably not be correct if used at a humidity level above the CRH. If it is necessary to make applications of a fertilizer or fertilizer-based pesticide at a humidity level above its CRH, a pattern test should be conducted at the higher humidity level. The operator should also be aware of progressive buildup and thus progressive pattern change with some products. This may necessitate frequent cleaning of the impeller or incremental changes in pattern setting as the application progresses.

Speed

Speed of operation can affect pattern uniformity as well as delivery rate (17, 20). On a few spreaders, the distributor (impeller[s] or spout) is driven independently of ground speed by a tractor PTO, a hydraulic motor, or an electric motor. When the distributor is independently driven, ground speed should have little effect on pattern as long as the distributor speed is correct. On other spreaders, the distributor is ground driven. This is true for most walk-behind spreaders and a few others. When the distributor is ground driven, any change in ground speed will change distributor speed. This will often cause a change in effective swath width. In general, if the distributor speed is reduced, granules will not be thrown as far. Note that this is not always true. Because of air resistance, thrown granules tend to have a "terminal velocity." Throwing them off the distributor faster does not necessarily make them fly any further since they are immediately slowed by air resistance. On the other hand, the standard speed may be fast enough that a reduction in speed has no effect on width of throw. In most cases, however, changing ground speed will change the effective swath width of a ground-driven spreader.

Rotary broadcast spreaders can also have changes in pattern shape as well as width if the impeller speed changes. With everything else equal, the faster the impeller turns, the earlier (angularly) the granules will be thrown off. Thus at faster speeds, the granules leave the impeller at a lower angle (relative to the drop point) and at slower speeds, so the granules will ride the impeller farther before being thrown off.

Research studies have shown that, in practice, pattern changes do not become statistically significant until the speed change exceeds approximately 25% (17, 20). A decrease in speed has more effect on pattern quality than an increase in speed (because of the "terminal velocity" factor). If the operating width is held constant as speed changes, skewing will change significantly before either CV or minimum / maximum points change much (17, 20).

Roughness of Surface

The surface on which a broadcast spreader is operated can affect the distribution pattern. This effect is completely different from the problem of granule bounce on hard surfaces as discussed previously. Fertilizer spreader pattern tests are generally conducted on smooth surfaces, but in actual use, spreaders are frequently operated on rough surfaces. A turf spreader, for example, must occasionally operate over tree and shrub roots, rocks, etc. in the turf.

Surprisingly, a rough operating surface had a significant detrimental effect on spreader pattern in a research study (31). Under rough conditions, the patterns consistently skewed to the right (counterclockwise impeller rotation on a walk-behind spreader). Larger, spherical granules were less affected than were small irregular granules. Since the trend seems to be consistent, it would be appropriate to consider surface roughness when determining spreader pattern settings.

A spreader pattern setting is frequently a compromise. One setting might minimize skewing while another setting gives a wider optimum pattern, for instance. Since a single "best" pattern setting is frequently not obvious, it would be appropriate to select a pattern setting that would help correct the expected pattern shift if a rough operating surface is expected.

Impeller/Spout Angle

Virtually all broadcast spreaders are designed to operate best with the impeller or spout level. This may not be the same as having the hopper level. On some spreaders, the hopper is angled down in the back to facilitate filling. It is the impeller or spout, not the hopper, that must be level. If the impeller or spout is out of level side to side, the pattern will be skewed and the spreader will probably throw farther to the high side. A more likely scenario is to have the spreader out of level front to rear. With a pendulum spreader, the primary effect of being out of level front to back will be a change in swath width. With a rotary spreader, both width and pattern skewing can be affected by the impeller being out of level front to rear.

It is important that the impeller or spout be level for pattern testing and also for field applications. Operators should be warned to level tractor spreaders when hitching and to hold the handle of walk-behind spreaders at the correct height to give a level impeller.

Granule Segregation

When a product is a physical mix of two or more components, segregation in application is a potential problem. Larger, heavier granules throw farther than smaller, lighter granules. If, for instance, the nitrogen component of a mixed fertilizer is composed of small granules and the phosphorus and potash components are composed of larger granules, the resulting pattern will have a higher percentage of nitrogen near the center of each pass with a higher percentage of P and K near the overlap points. A similar situation can occur when pesticides are impregnated on one fraction of a mixed granule product. Even though the total application rate may be fairly uniform, the distribution of pesticide across the pattern can be quite uneven.

Alternate Pattern Test Procedures

There are some alternate ways of conducting pattern tests that are easier and faster, but they provide less reliable information. One common method consists of making a spreader pass without collection trays and just throwing the material on the ground. The operator then estimates pattern width by visually examining the throw pattern on the ground. This approach has two major problems. First, the granules will bounce on a hard surface and distort the pattern. Second, it is very difficult to estimate width from a pattern on the ground. The first concern can be addressed by making the pass over turf or over a strip of carpet perpendicular to the direction of travel. While this will reduce bounce, it will also make visual evaluation of the pattern even more difficult. A common error in using this method is to measure the total throw width and then use that as the effective pattern width.

Tests can also be run using many different tray systems (9). One well-known test facility uses no pans; they place dividers on the floor and then sweep up and measure the material between the dividers. Other test facilities have used smaller or larger collection trays. Research studies have shown that using smaller (narrower) collection trays results in higher CV values for the same pattern (9). Statistical theory has been used to verify and quantify this observation (49). The apparent effective swath width can also be very different with different collection trays.

A research study was conducted comparing greening response of turfgrass to spreader patterns obtained from different types and sizes of collection trays (48). The pattern test results from 11.5-inch wide trays best predicted the greening response of the turfgrass.

Pattern Estimation

Pattern shape and effective swath width can be estimated without actually measuring the material in the collection trays. The material in the trays can be poured into a series of test tubes or small vials and then the containers lined up in order. The height of material in the containers becomes an approximate graph of the spreader pattern. For this method to be effective, it is necessary to make several passes or use a higher rate setting (or use larger pans) so that the amount collected is large enough to readily differentiate visually. Once a pattern is established in this manner, the operator can detect and correct any major pattern problems. Effective swath width can be estimated using the method described previously for determining effective swath width from a graph. This method is less accurate than measuring the material and analyzing the results, but much more accurate than just throwing material on the ground.

Another method of pattern estimation has been suggested for use with pendulum spreaders, but research has proved that it does not work (39). The suggested method is to operate the pendulum spreader briefly with the tractor stationary and mark the outermost throw point on each side of the spreader. The effective swath width was claimed to be half the total throw distance. This method *does not* work. Testing showed that this method resulted in a predicted width that was less than the effective swath width. This error in swath width results in a high and unacceptable CV.

Use of Spreaders

Operating Modes

Spreaders can be operated in different modes. Selecting the correct mode has a significant effect on the quality of the overlapped pattern from broadcast spreaders. Operating mode is not generally a concern with drop spreaders, as long as the correct swath width is used.

Back-and-Forth vs. Circuitous

The two most common modes for spreader operation are one-direction or circuitous (Figure 19) and progressive or back-and-forth (Figure 20). The circuitous mode of operation results in the right side of a pattern overlapping with the left side of the adjacent pattern (Figure 21). The back-and-forth mode results in the right side of the pattern overlapping with the right side of the adjacent pattern (Figure 22). In theory, the back-and-forth mode should exaggerate skewing problems and the circuitous mode should partially compensate for skewing problems. In practice, it makes very little difference *if the pattern is decent to begin with.* Research has shown that a circuitous mode of operation offers a statistically significant improvement in overlapped pattern uniformity when an overlapped pattern based on back-and-forth operation is very poor (28). When the back-and-forth spreader pattern is generally acceptable (CV 20%), there is statistically no advantage to using the more cumbersome circuitous mode of operation.

The circuitous mode can be used to help correct bad spreader patterns, but it should be used for this purpose only after all possible adjustments have been made. There is no problem with using a circuitous pattern, but it is generally more cumbersome in the field.

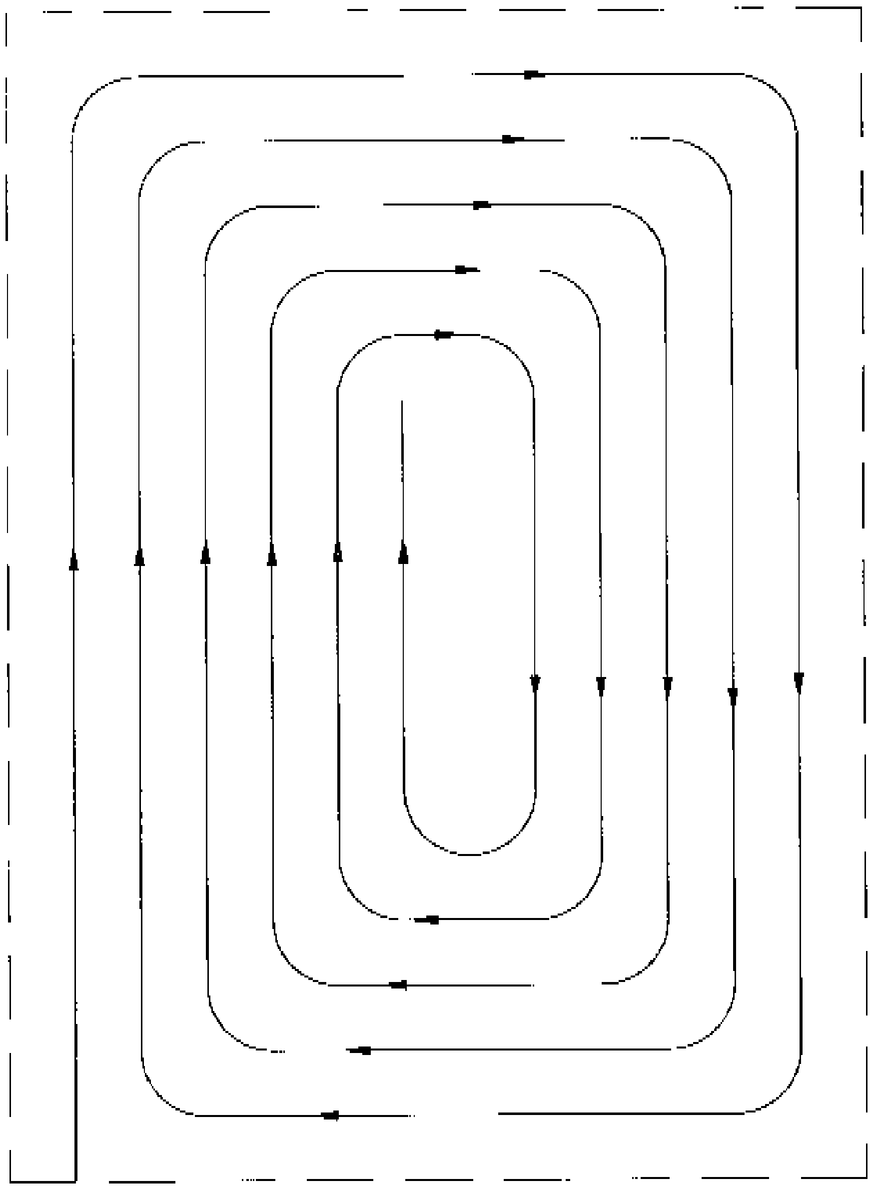

Figure 19. One-direction or circuitous mode of operation.

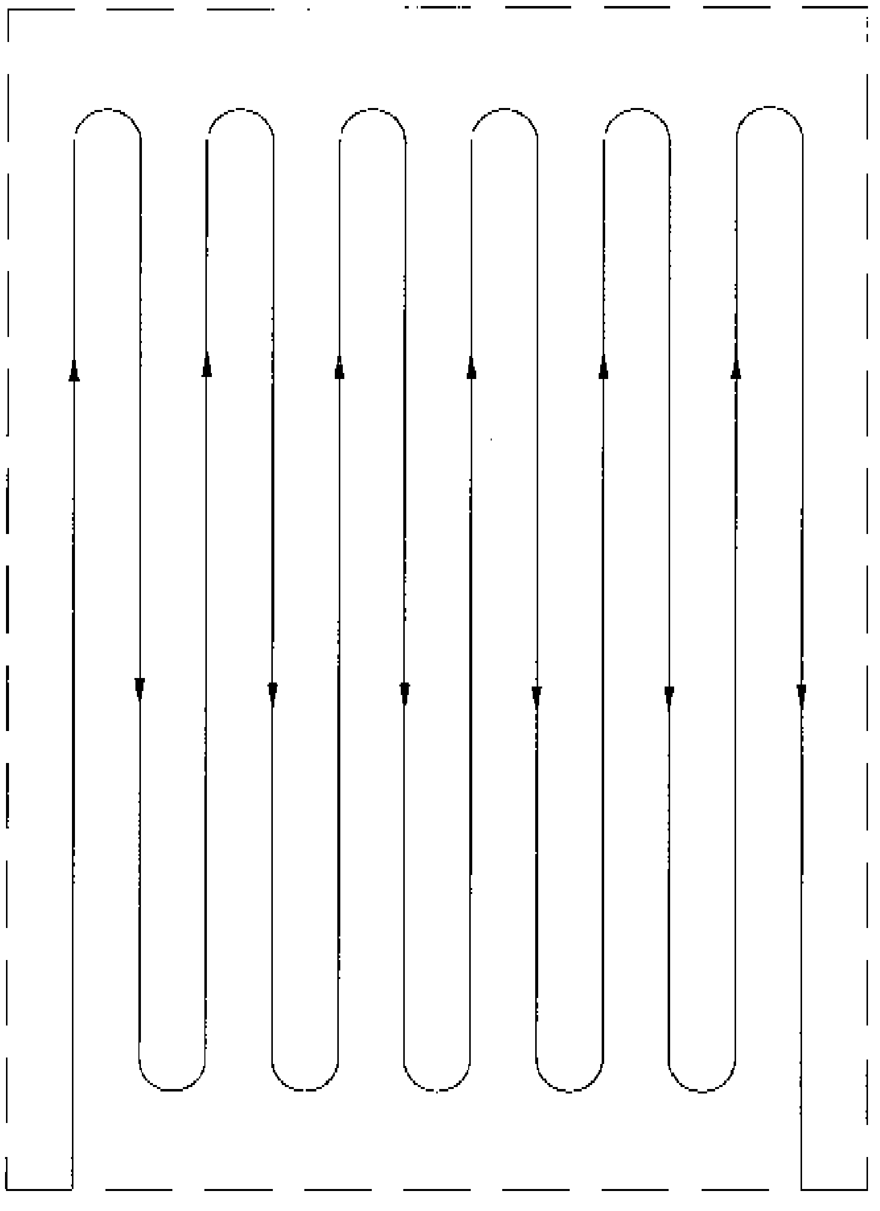

Figure 20. Progressive or back-and-forth mode of operation.

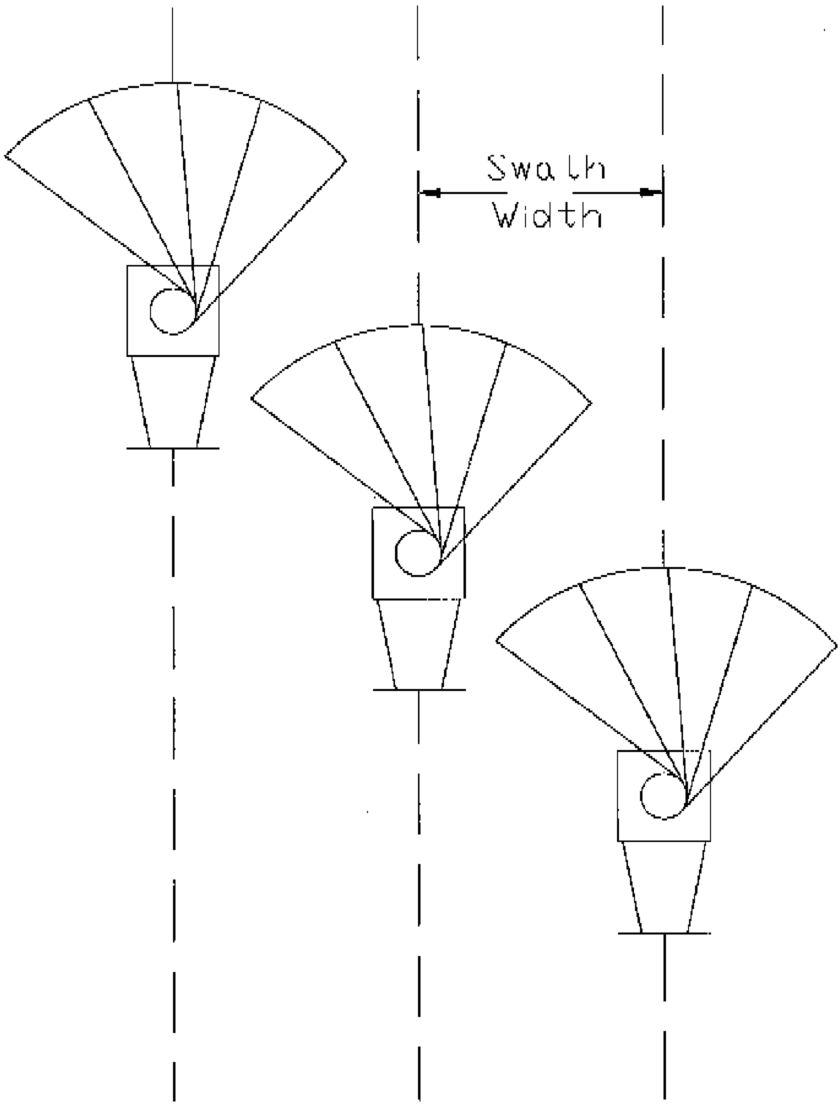

Figure 21. Right-on-left, left-on-right overlapping with circuitous mode of operation.

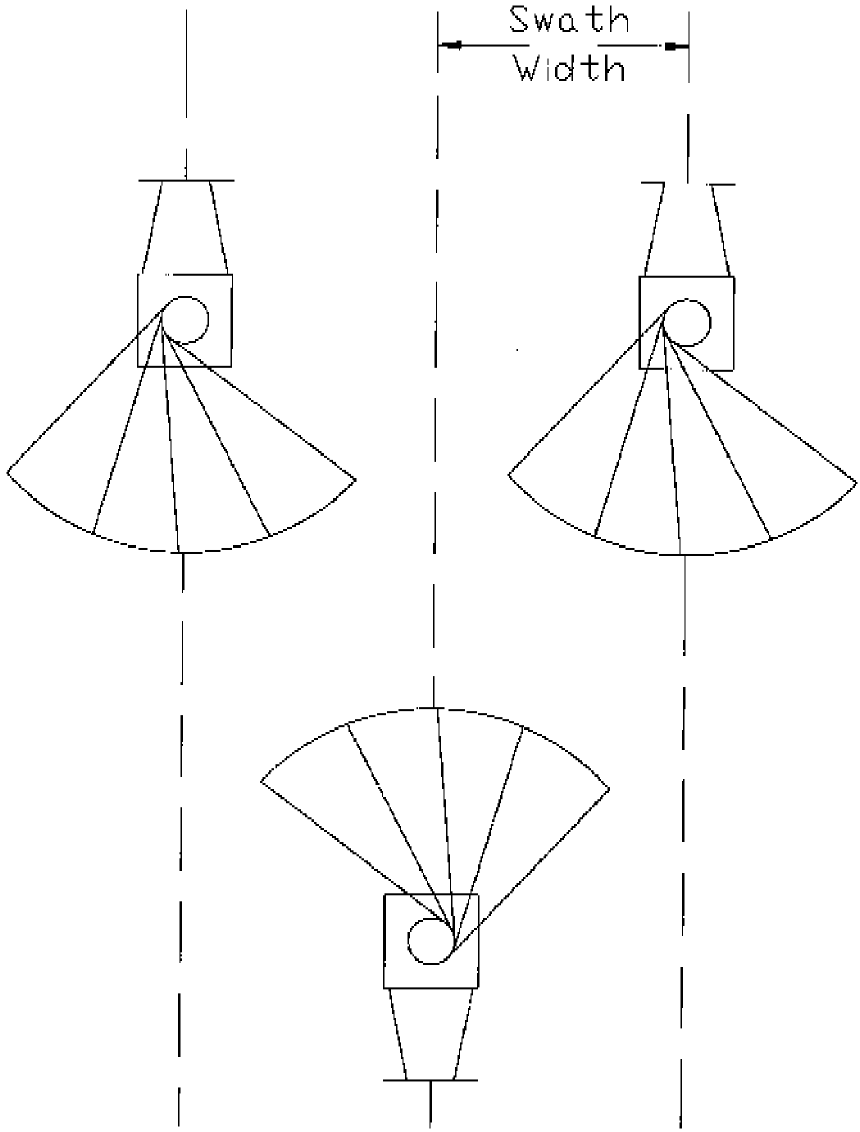

Figure 22. Right-on-right, left-on-left overlapping with back-and-forth mode of operation.

Half-Width vs. Right-Angle

In some cases, the distribution pattern from a broadcast spreader is not uniform enough, even after all spreader adjustments available have been tried. A common recommendation in such cases is to cut the rate of application in half and cover the field twice at right angles (56, 73) (Figure 23). Although this method is recommended in many books and and technical articles, it is not the best way to address this problem.

A much more effective way to improve a spreader pattern is to cut the delivery rate in half and also cut the swath width in half while maintaining parallel swaths (Figure 24). Patterns from 87 spreader tests were compared using computer simulations of

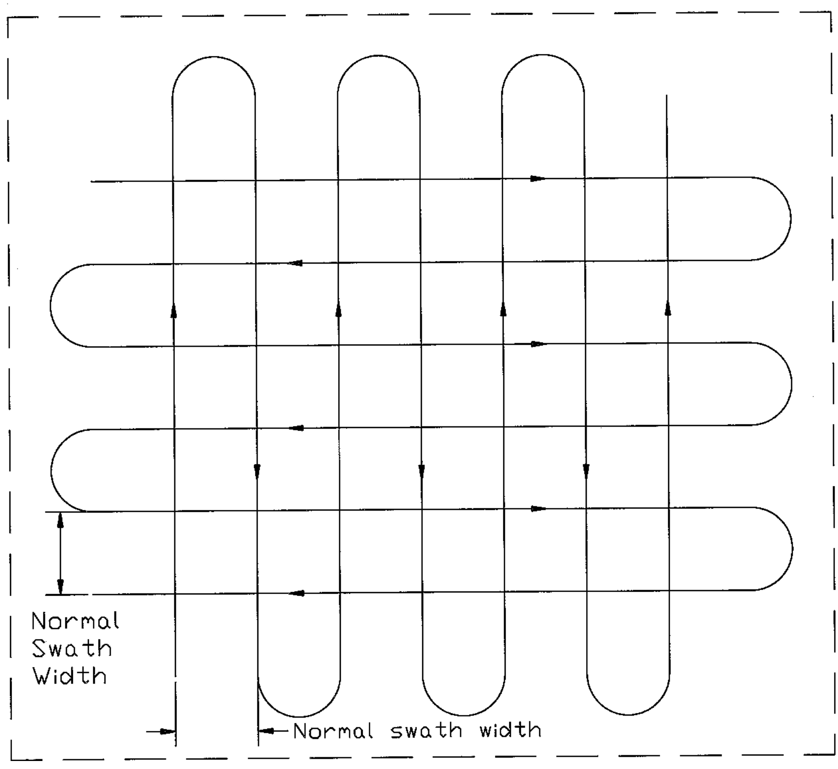

Figure 23. Right-angle method of spreader pattern correction.

both operating modes (8). Four spreaders, five products, and a wide range of pattern adjustments were included. The mean CV for a normal pattern width was 44%. The right-angle method improved the mean CV to 31%, while the half-width method improved the mean CV to 25%. Out of the 87 test patterns, the half-width method provided improvement in 98% of them. The half-width method was more effective than the right-angle method in 75% of the cases.

The reason that the half-width method works is illustrated by Figure 15. The shape of this graph is typical for many broadcast spreader patterns. Note that there are two dips in the graph indicating lower CV values. The dip on the right occurs at the normal effective swath width. As discussed previously, the operator would normally select that point as the effective swath width

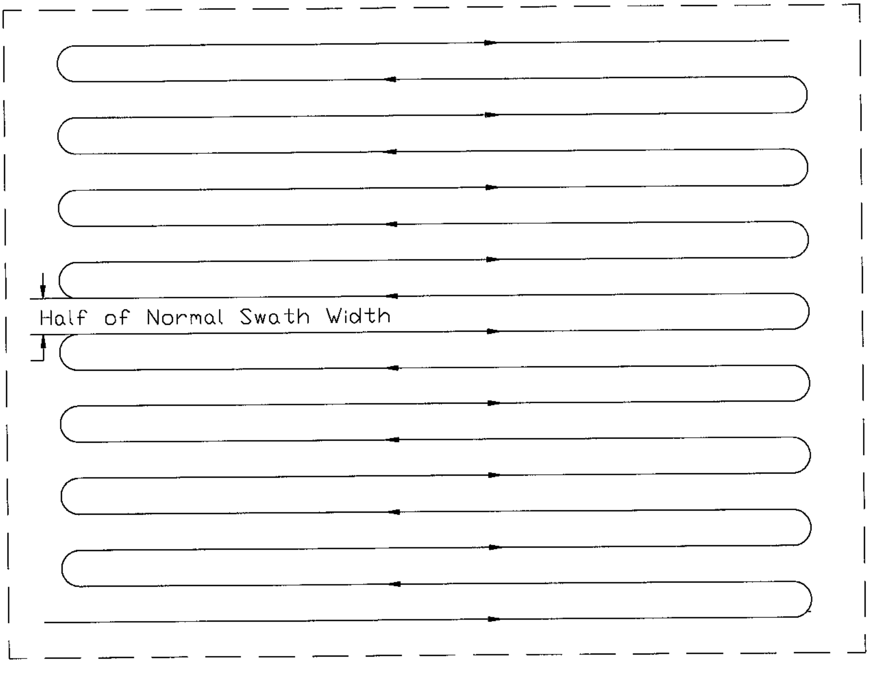

Figure 24. Half-width method of spreader pattern correction.

since it represents a lower CV than narrower or wider widths. The other dip in CV occurs at a width approximately half the normal width, and the CV at this point is somewhat lower than the CV at the normal width. Figure 14 shows another facet of this issue. Not only is the CV reduced at the half-width, but the minimum and maximum points are improved also. Since the difference between the minimum and maximum points is what causes striping, reducing this variation will reduce striping.

The right-angle method will generally reduce the CV but will not change the minimum and maximum points in the pattern. When the right-angle method is used, the extremes in the pattern (i.e. minimum and maximum) will remain exactly the same, but less of the total pattern *area* will experience those extremes. The effect of using the right-angle method is to change from striping to a diagonal checkerboard pattern, but there will still be the same minimum and maximum points. Therefore, although the CV will be reduced somewhat, the potential for variation in greening ***is not*** reduced. With the half-width method, the potential for variation in greening ***is*** reduced.

The half-width method is not routinely needed with good spreaders. If the spreader can be adjusted to give an acceptable pattern with a normal swath width, then the normal swath width should be used since it will be much faster. If the overlapped pattern is not good enough even after all feasible adjustments have been made, then the half-width method can be used to further improve the pattern. The half-width method is also useful when the operator wants extra “insurance” of good uniformity. An example would be fertilizing golf greens before a major tournament. In such a case, the need to avoid fertilizer striping at all costs might justify the extra time involved to use the half-width method.

With some low-quality homeowner and semi-professional spreaders, the half-width method is needed routinely since the spreaders will not deliver adequate uniformity at a normal swath width with most materials. These spreaders tend to have a pattern that is triangular rather than trapezoidal and is heavily skewed with most products (30). Figure 25 shows a typical pattern for this type of spreader. Since these spreaders have no means of pattern adjustment, it is necessary to use the half-width method to obtain reasonable uniformity. The widths typically recommended for these spreaders by their manufacturers must be ignored and a half-width used. In summary, *at no time is the right-angle method recommended for any spreader* (8).

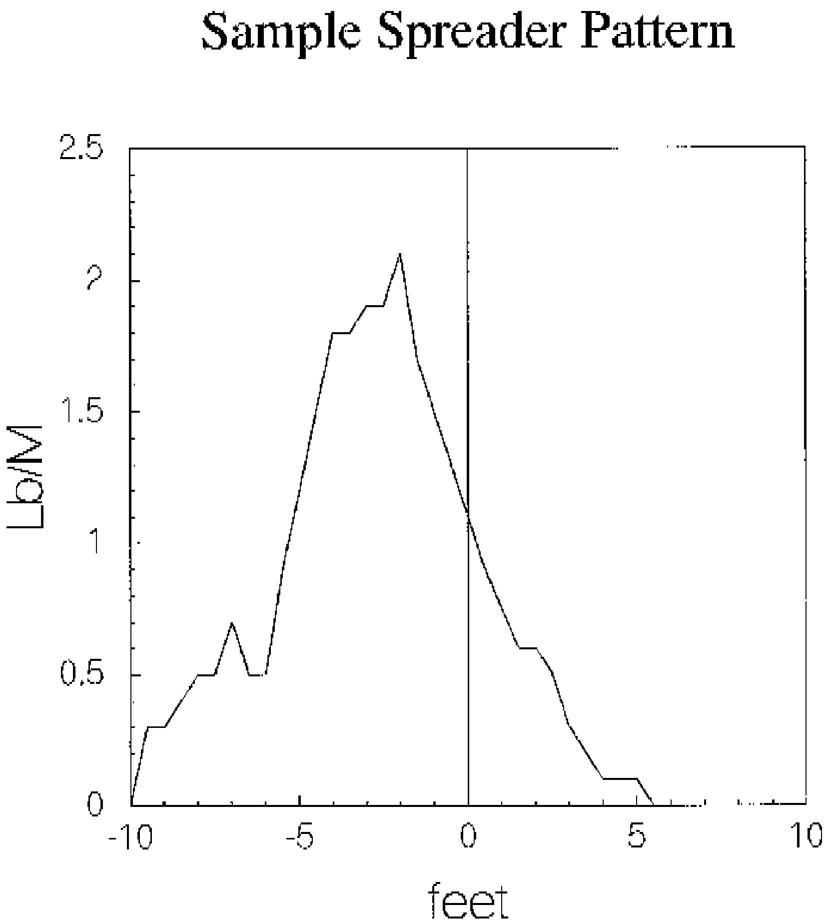

Figure 25. Typical skewed triangular pattern from some homeowner and semi-professional rotary spreaders.

Header Strips

Standard broadcast spreader pattern tests evaluate the steady-state patterns as the spreader is operated back-and-forth across a field but do not consider the transient patterns at the ends of the field. When the typical back-and-forth pattern is used, header strips are needed along each end of the field. The header strips are usually single spreader passes along each end of the field in a direction perpendicular to the main spreader operation. The header strips provide a place to turn off the spreader, turn it around, and turn it back on. The spreader should not be turned on or off while standing still; it should be moving when turned on or off to avoid excessive application.

The use of header strips can result in very uniform application with drop-type spreaders if the spreader is turned off and on at exactly the edge of the header strip. With broadcast spreaders, the application rate in and near the header strips is seldom uniform. Since the header strip generally consists of a single spreader pass, there is no overlap in the header strip itself, and the pattern tapers to both sides. When the regular passes enter and leave the header strip, they will be rounded. The beginning of a pass will be concave, and the end of a pass will be convex as shown in Figure 26. When these rounded passes cross the tapered header strip, unpredictable patterns of high and low rate result. This can be demonstrated for any given spreader pattern data, and examples have been studied, but no consistent general pattern prediction is possible. Suffice it to say that the pattern in the header strips will be erratic. The operator can only do his best to turn the spreader off and on consistently and thus try to minimize the inherent variability (42).

Some small homeowner spreaders do not have a means of shutting off the flow while turning at the ends of the field (or lawn). Consumer research showed that many homeowners did not use the on-off lever anyway; they just left the spreader on while making turns. Based on this research, a rotary spreader was designed that had no remote on-off linkage (6, 44). It did, however, have a small ring molded around the impeller that stopped the product flow after a small amount of product built up on the impeller - if the impeller was not rotating. This prevented material being discharged when the operator stopped, but allowed normal flow when the spreader was moving. The spreader thus had "automatic" operation without the need for or expense of a remote shut-off linkage.

Speed

The effects of speed on rate and pattern have been discussed. It is important that the operator run the spreader at the speed at which the pattern tests and rate calibration were done. Generally, the manufacturer's recommended speed should be used, but it is most important that the testing and calibration speed match the operating speed.

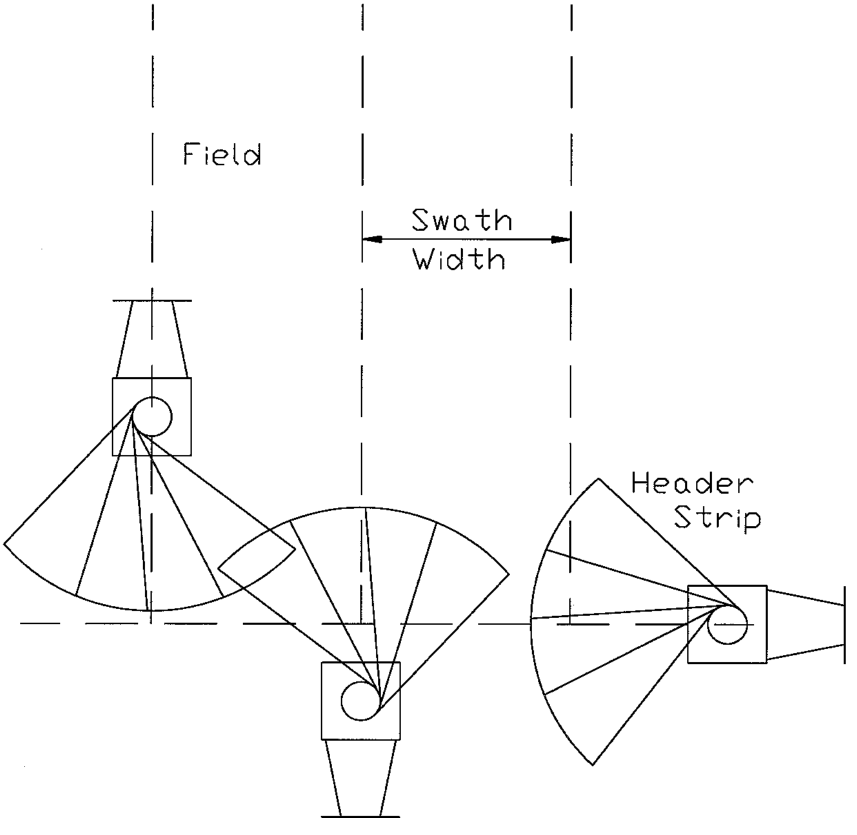

Figure 26. The effect of regular passes entering and leaving a header strip.

Level

Most spreaders are designed to be level while operating. With broadcast spreaders, that means that the impeller or spout should be in a horizontal plane. For a drop spreader, it generally means that the hopper should be level. With tractor- or vehicle-mounted spreaders, the spreader should be leveled when hitched. With walk-behind spreaders, the operator must hold the spreader level. There is a tendency for operators to change the handle height and thus the angle of the spreader when pushing hard (uphill, full spreader, etc.). Operators need to be warned of the implications of this and be cautioned to hold the spreader level.

Care and Maintenance of Spreaders

Cleaning

The single most important step in maintaining a fertilizer spreader is to clean it thoroughly after each use (2, 4, 5, 41). That doesn't mean after each season's use or even every week; it means *every day*. The spreader should be emptied and thoroughly washed every day it is used. Cold water is normally adequate unless there is a buildup of cold-water-insoluble fertilizer. With some urea formaldehyde and methylene urea fertilizers, it is difficult to remove deposits with cold water unless the buildup is scrubbed. Hot water will often loosen the buildup and allow it to be rinsed off. If the buildup is in the hopper, it often helps to close the spreader and fill the hopper. By the time the water has all drained out, the material will usually be loosened.

Some encapsulated slow-release fertilizers present a special problem since the sulfur, wax, or polymer coating may build up and be water-insoluble. Either abrasion or a solvent will be needed to remove these materials. Either way, care must be taken to avoid damaging the spreader.

Once the spreader has been washed clean, it should be allowed to dry before storage. Parking the spreader in the sunshine for a hour or so is an excellent way to promote drying. If water is trapped in pockets anywhere in or on the spreader, the spreader may have to be tipped or inverted before it will dry.

Lubrication and Protection

Properly lubricating a spreader is important. Lubricating the wrong parts or using the wrong lubricant can do more damage than not lubricating at all. The best guide in determining how to lubricate a spreader is the operator's manual furnished by the manufacturer. Because of different designs and the use of different materials, lubrication recommendations will vary.

Damage From Solvents

Some common lubricants are solvents for some of the materials commonly used in spreader construction. An example is WD-40® which dissolves ABS plastic, a material commonly used for knobs and other parts on homeowner spreaders. If some spreaders are lubricated indiscriminately with WD-40®, the ABS parts will begin to soften, weaken, or even dissolve.

Other solvents can damage the finish on spreaders. Many metal spreaders now use a powder-coated finish (3). Common powder coatings such as epoxy, polyurethane, and polyester are thermoset plastics and tend to be unaffected by most solvents. Other coatings may be more easily damaged. Plastic hoppers and impellers can also be damaged. Fiberglass-reinforced hoppers are generally made with thermoset materials such as polyester and may be less damaged by solvents than parts made of thermoplastic materials such as polystyrene or ABS. Thermoplastic parts made of polyolefins such as polyethylene and polypropylene are relatively immune to many solvents.

The general rule for lubrication remains: follow the manufacturer's instructions.

Damage From Too Much Grease

More walk-behind rotary spreader gears have been damaged from over-lubrication than from under-lubrication. The gears on many spreaders should not be greased at all. Gears that are made of nylon impregnated with molybdenum disulfide are self-lubricating. Greasing any gear set increases the risk of dirt buildup and thus abrasion damage to the gears. Keeping the cover on the gear set will help prevent dirt buildup. If the manufacturer recommends grease, then grease in moderation; if the manufacturer does not recommend grease, don't grease it. In general, open gears are better off without grease.

Excessive lubrication of other parts, too, can lead to dirt buildup and abrasive wear. Lubricate in moderation, and only when recommended.

Storage

Most important, fertilizer spreaders should be completely clean with no remaining fertilizer residue when stored. Store spreaders inside away from sunlight, heat, and moisture. Nothing should be piled on or in spreaders during storage; this could deform the hopper and / or wheels and could also accelerate corrosion. Spreaders should be lubricated per the operating instructions before storage.

Spreaders should be stored with the mechanism open or "on." This relieves the load on the operating spring and also prevents material or moisture being trapped in the hopper. The rate setting should be moved to the largest setting prior to opening the mechanism and storing the spreader.

Misuse

A fertilizer spreader is neither a lawn cart nor a wheelbarrow. It should not be used as such. A spreader contains delicate metering components that can be damaged by rough handling. It is particularly important to avoid impact or damage to the rate metering components when handling or storing spreaders. The shut-off bar on drop spreaders and the shut-off plate on broadcast spreaders are especially delicate and subject to damage from rough handling.

For Additional Information

Standards

The following ASAE standards relate to fertilizer spreaders and may be of interest to readers.

ASAE S327.2. 1998. Terminology and Definitions for Agricultural Chemical Application. American Society of Agricultural Engineers, Niles, MI.

ASAE S341.2. 1998. Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders. American Society of Agricultural Engineers, Niles, MI.

ASAE EP371.1. 1998. Procedure for Calibrating Granular Applicators. American Society of Agricultural Engineers, Niles, MI.

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