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Procedures for Evaluating Variable-Rate Granular Material Application Accuracy

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Procedures for Evaluating Variable-Rate Granular Material Application Accuracy of Broadcast Spreaders

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1 Purpose and scope

1.1 The purpose of this Standard is to provide a method to evaluate application accuracy of granular materials applied using variable-rate application systems including spinner-disc broadcast spreaders or similar equipment that distribute fertilizers. Specifically, this standard will facilitate the collection and reporting of map-based application accuracy of both single and multiple granular products.

1.2 Testing of equipment commonly used to support site-specific management, machinery guidance, and other precision agriculture practices forms the basic scope of this Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies unless noted. For undated references, the latest approved edition of the referenced document (including any amendments) applies.

ASAE S341, Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders

ASAE EP371, Procedure for Calibrating Granular Applicators

ASAE S327, Terminology and Definitions for Chemical Application

ANSI/ASABE AD3600:2016 MAY2016, Tractors, machinery for agriculture and forestry, powered lawn and garden equipment — Operator's manuals — Content and format

3 Definitions

3.1 Global positioning system (GPS) or global navigation satellite system (GNSS) receiver: an instrument capable of determining the position of its antenna in geographic coordinates and in near real-time

3.2 Variable-rate technology (VRT): a system of controls, positioning device, and a task computer integrated into application equipment capable of varying inputs to crop production systems based on a predetermined prescription map or sensor (individual or array) evaluating crop, soil or other in-field variability. This control system details how the inputs are to be varied across the soil landscape to include at a minimum, an application rate tied to geographic entities in either raster or vector format.

3.3 Prescription (Rx) map: a map with spatial features such as polygons called zones that spatially describe unique application rates of various soil amendment and other inputs to crop product systems. A single layer prescription map includes information for an individual product or input whereas a multiple layer prescription represents information for varying multiple products. For a single layer prescription map, for each zone there exists one unique application rate for the soil amendment or crop production input.

3.4 Look-ahead time: a feed-forward time period that is specified with the specific purpose of alternating the initiation of an application rate change or response in time to where the change or response shall occur to make up for system response lag or latency that arises from external influences or is inherent to system components, configuration, or control algorithm.

3.5 Collection pan matrix: an array of collection pans designed to obtain the spatial distribution mass or volumetric discharge from granular application equipment.

3.6 Rate delay time: elapsed time between when control commands are sent to the rate controller, and the overall VRT system response necessary to affect a 5% change in the actual application rate. ISO11783-11 outlines a similar parameter that should be noted, referred to as DDI 142 “Physical Setpoint Time Latency”, which is used on VRT capable equipment to communicate the rate delay time between system components.

3.7 Rate transition time: elapsed time required to affect 90% of a rate change. Determined by transition between the point at 5% of the total change (in the proper direction whether increasing or decreasing the rate) from initial rate and the point at 95% of the final rate.

4 Background

4.1 Variable-rate technology (VRT) has become an accepted method for spatially varying inputs within production agriculture. Elimination of application errors through proper calibration and operation is critical to ensure accurate VRT performance.

4.2 ASABE Standard S341, *Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders*, provides a uniform method for assessing and reporting the performance of broadcast granular spreaders. This standard focuses on uniform-rate (UR) application and does not contain considerations for testing VRT equipment. No standard or defined test protocol has been published to evaluate VRT. Standard test and reporting procedures are needed to assess VRT equipment since traditional UR application errors might not be indicative of VRT application inaccuracies.

4.3 With VRT application of granular materials, application rates change dynamically based on spatial location. A typical VRT applicator system integrates components such as a GPS receiver, rate controller, task computer with appropriate software or firmware and product delivery system. Each component produces some level of error which in turn contributes to the overall system error. The overall error is a summation of individual component errors with the understanding that interactions between these components can also affect overall VRT system errors.

4.4 The addition of VRT components to traditional application equipment may require unique calibration and operating procedures to minimize application errors when contrasted with traditional practices.

4.5 Most, if not all, VRT systems control the volumetric flow of granular materials. However, if satisfactory pattern uniformity cannot be maintained during flow rate adjustments with a VRT system, then speed adjustments or a combination of speed and mass flow may be an option for achieving acceptable distribution.

4.6 The “look-ahead” feature provided in most software packages may reduce application errors providing VRT system latency or delay time can be quantified, and there is a similar system response for increasing and decreasing rate changes. These delay times produce application errors by having the rate transition occur after or before the desired time. Considerable improvement in VRT performance can be achieved through feed forward control. However, distribution pattern errors may be introduced with the existence of substantial lag times at application points across the spread width.

4.7 Accurate spatial application of granular materials requires instantaneous flow and distribution control. Currently, no commercially available spreaders possess both features. Reported rate response time for VRT granular applicators can be up to 10 s. The variation in rate response times from an individual system may require different “look ahead” times for increasing versus decreasing rate changes. Software supporting VRT can provide the ability to set an individual or “look-ahead” time for some systems multiple “look-ahead” times can be set. These “look-ahead” times are an important setup feature for VRT.

5 Collection pan matrix layout

5.1 Deposition tests shall be performed in keeping with ASABE Standard S341, using defined pans and test protocols. In particular pan size, layout and summary.

5.2 The collection pan matrix will consist of at least 12 rows of pans containing the corresponding pans within each row to capture material spread to each side of applicator or spreader. Row-to-row pan spacing shall be adjusted so that the complete rate transition event is captured, and that at least three rows of pans at the beginning and end of the matrix of the matrix contain the initial and final nominal application rates. Considerations should be given to the radial pattern plus the expected time to make a rate change. As an example, a spinner spreader has a distribution pattern of 24 m. Due to its radial pattern, the spreader shall travel 12 m into the test area to capture the original spread rate in the first row of pans in order to capture the pattern inside the test area. Then, we need 3 rows before the rate change, and 10 rows after the rate change, making a 144 m long test length for the pans, plus speed up before and slow down after the run.

5.3 Pan spacing within each row should be adjusted to permit the applicator to track within the collection pan matrix plus capture the full-width of spread. Further, the pans shall be spaced uniformly across the entire application width as outlined in ASABE Standard S341. Sufficient space should be provided for application equipment to navigate the test pan matrix by straddling the center of the collection pan matrix. The test site shall be laid out with a suitable measuring device

5.4 A typical pan collection matrix used for assessing the rate transition times for VRT application of granular materials is presented in Figure 1.

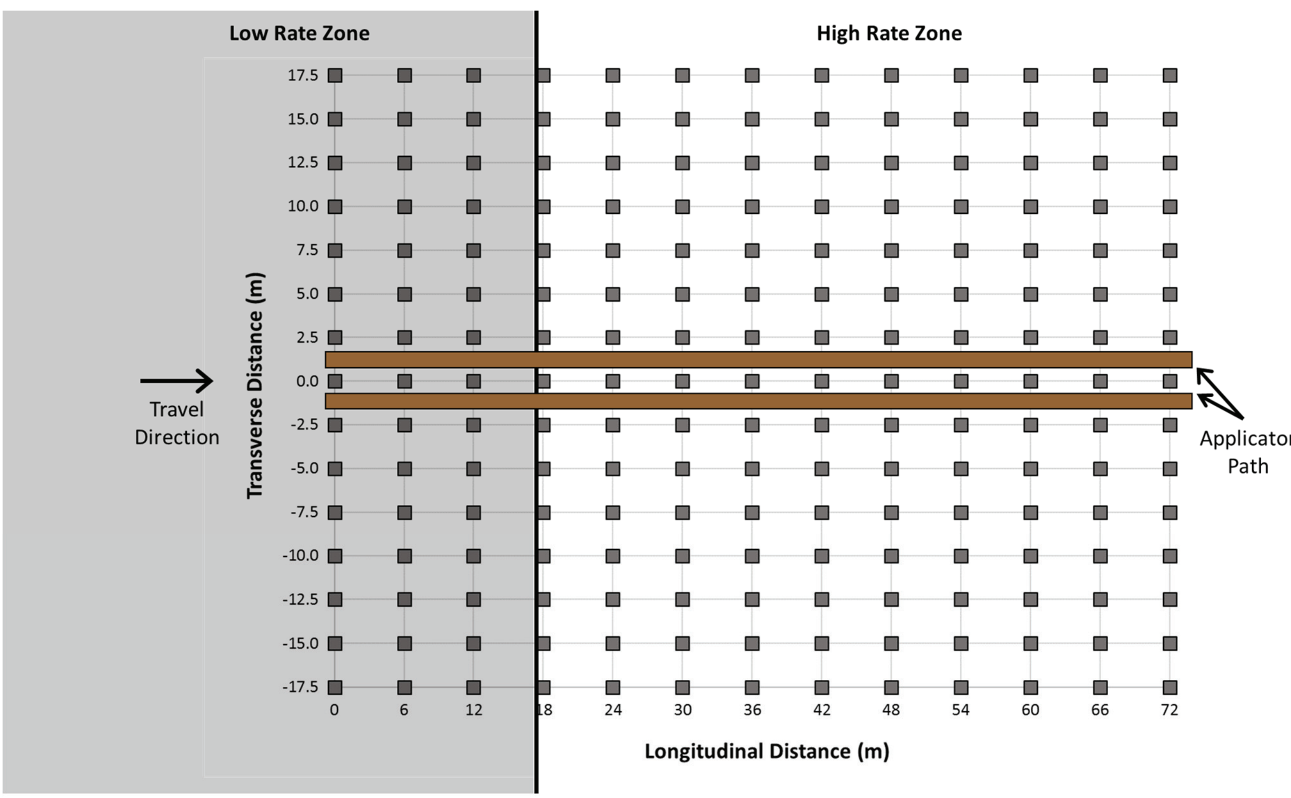

Figure 1 – Example collection pan matrix for rate transition tests (low-to-high test illustrated). In this example, pans were not removed to allow applicator to pass over pan matrix.

5.5 At either end of the collection pan matrix sufficient space shall be made available to allow the applicator to accelerate and reach a steady state ground speed consistent with test requirements. A similar region at the end of the collection matrix is required to insure safe de-acceleration of the applicator without affecting the application pattern within the collection pan matrix.

6 Single product pattern uniformity

6.1 Select low and high applications rates that are representative of the capabilities of the applicator to be evaluated. For example, if typical ground speed for the applicator, under normal field conditions is 25 km/h, and the maximum application rate of granular material at this ground speed is 500 kg/ha, then it would be appropriate to evaluate the fixed-rate application patterns at 25% (low) and 75% (high) of the maximum expected application rate as required by ASABE Standard S341. For the applicator in this example the low application rate would be established at 125 kg/ha and the high rate would be 375 kg/ha. Of importance, the established rates in this section will be utilized for determining rate transition times in Section 7. The applicator can be tested at additional application rates over these defined rates.

6.2 Calibrate the applicator in accordance with ASABE Standard 341, and make any equipment adjustments in accordance with manufacturer's literature or other recommended practices. Be certain to consider distribution patterns at both low and high test rates. Any and all pattern adjustments shall be made prior to the start of testing.

6.3 Select the ground speed for the applicators identified in section 6.1. Be careful to consider overall applicator performance for the range of application rates to be used when testing.

6.4 Check the application pan matrix to be certain all of the collection pans are empty, free of any foreign matter, and as close to level as practical. Further, pan alignment with the matrix layout should also be checked.

6.5 Begin the pattern assessment test by first operating the applicator at the low application rate while traversing the collection pan matrix. When possible select granular materials (e.g. fertilizers or lime) and pan matrix locations so as to minimize the environmental impact (e.g., use muriate of potash as a test material on a test site with low soil test K levels).

6.6 Note any deviations/changes in weather or operating conditions for the test run. Also, note anything that might have altered the spread patterns (e.g., wind, driver error, or terrain irregularities).

6.7 Carefully collect and weigh the material accumulated in each collection pan from the test run. When using sample bags to collect and preserve the material deposited in the collection pan matrix, be careful to select samples bags with tare weights within 0.005 g of one and other. When weighing the material accumulated in each pan utilize digital scales with a resolution of at least 0.01 g. Record the weight of each sample to within 0.01 g, being certain to note the corresponding pan matrix location.

6.8 Repeat steps 6.5 through 6.7 for the high application rate.

7 Single product rate response

7.1 Using the high and low application rates from Section 6, generate two prescription maps that coincide with the collection pan matrix. The first prescription map shall feature a low to high rate transition while the second map shall include the high to low rate transition. Please note that it might be necessary to collect some preliminary rate transition data so that the rate transition line within the matrix can be located so that the rate transition takes place within the collection grids and is in keeping with guidelines presented in Section 5.2.

7.2 Check the collection pan matrix as outlined in Section 6.4.

7.3 Begin the rate response test by first using the low to high rate transition prescription for a single product while traversing the collection pan matrix. When possible select granular materials (e.g. fertilizers or lime) and pan matrix locations so as to minimize the environmental impact (e.g., use muriate of potash as a test material on a test site with low soil test K levels).

7.4 See Section 6.6.

7.5 Carefully collect and weigh the material accumulated in each collection pan from the test run in accordance with Section 6.7.

7.6 Repeat steps 7.3 through 7.5 for the high to low rate transition prescription.

8 Multiple product application pattern uniformity

8.1 For multiple product (e.g. blended fertilizer or independently metered products) application pattern uniformity repeat the procedures outlined in Section 6. When repeating these procedures apply the same criteria to both granular products with respect to the rate selection.

8.2 With regard to Section 6.7, an additional analysis will be required to assign the appropriate mass fraction to either of the two products being applied. The analytical test to be utilized shall be consistent with the products being applied (e.g. Mehlich III extraction for identification of P and K mass fractions). This process shall be repeated for each of the collection pan samples.

9 Multiple product rate response

9.1 For multiple product (e.g. blended fertilizer or independently metered products) application pattern uniformity, repeat the procedures outlined in Section 7. When repeating these procedures apply the same criteria to both granular products with respect to rate selection and rate changes.

9.2 With regard to Section 7.5, an additional analysis will be required to assign the appropriate mass fraction to either of the two products being applied. The analytical test to be utilized should be consistent with the products being applied (e.g. Mehlich III extraction for identification of P and K mass fractions). This process shall be repeated for each of the collection pan samples.

10 Overall single product application accuracy

10.1 Select a representative field for variable-rate product application. A prescription map shall be available as input data for control of the VRT application. This map will also serve as the basis for assessing the overall quality and accuracy of the application. The field should be consistent with the applicator capacity. For example, an applicator with an effective spread width of 20 m and a ground speed of 10 km/h will cover approximately 20 ha/h. A reasonable size field in this case would be from 10 to 20 ha.

10.2 The field should be divided into a typical number of zones. In the case of regularly aligned grids a typical management zone might be 1 ha. The management zones should cover a broad range of application rates. For example 25% of the field should receive application rates at or below 33.3% of the maximum application rate as identified in Section 6.1. Similarly, approximately 25% of the field should receive an application rate of greater than 66.7% of the maximum application rate. The size or resolution of zones should be considered when testing as size can influence results. It is recommended that no zones less than 0.4 ha be used unless otherwise justified and noted in summary report.

10.3 Using the geographic coordinates of the boundary as the extents, utilize a random number generator to produce coordinate pairs describing random points located within the field boundary. A total of 35 random points within the field boundary shall be identified (Figure 2).

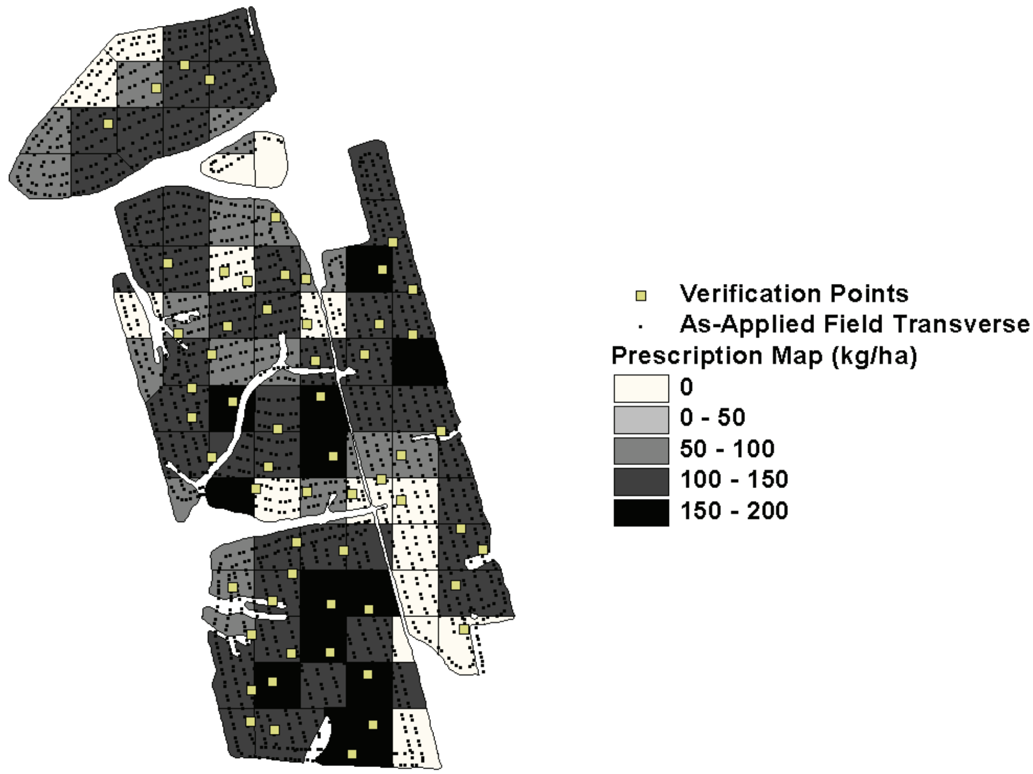

Figure 2 – Example prescription map with the as-applied field transverse and assessment points.

10.4 Once the random points have been identified within the field where the single product is to be applied, navigate to those locations within the field and locate sample collection pans. The pans should be centered about the points identified in Section 10.3. Orient the pans in a random fashion so that roughly 7 to 8 pans are aligned: N-S, NE-SW, E-W, and SE-NW, respectively.

10.5 Prior to the application pass, test pan locations shall be surveyed using a suitable DGPS receiver with a horizontal static error of better than 1 m.

10.6 After placing the collection pans at the random locations, operate the applicator to apply the single product in accordance with the prescription map. Minor course deviations to miss collected pans should be noted and accounted for appropriately within the final analysis or the collection pan omitted from final analysis if impacting results.

10.7 Carefully collect and weigh the material accumulated in each collection pan from the test run in accordance with Section 6.7.

11 Overall multiple product application accuracy

11.1 For multiple product application pattern uniformity, repeat the procedures outlined in Section 10. When repeating these procedures apply the same criteria to both products with respect to rate selection, rate changes, and field selection.

11.2 With regard to Section 10.7 an additional analysis will be required to assign the appropriate mass fraction to either of the two products being applied. The analytical test to be utilized should be consistent with the products being applied (e.g., Mehlich III extraction for identification of P and K mass fractions). This process shall be repeated for each of the collection pan samples.

12 Data analysis and visualization

12.1 Effective application rate

12.1.1 Collection pan mass, by nutrient, shall be converted to an effective application rate. This is accomplished by dividing the accumulated mass, or total mass, by the area of the collection pan. The final rate should be reported in typical units such as kg/ha. Conversion of pan mass to application rate should be completed for all collection pan data prior to performing the remainder of the analyses.

12.2 Pattern uniformity — This portion of the analysis will be used to produce two visual plots, or more, if additional application tests were conducted, of distribution pattern uniformity parallel to the direction of travel. The first plot will describe uniformity of single pass applicator operation while the second plot will approximate the uniformity of overlapping passes. Both relative and absolute measures of uniformity will be computed to describe the application uniformity of the simulated overlap case.

12.2.1 A plot of the mean application rate as a function of boom position or spread width shall be generated. A 95% confidence interval shall be added to this plot (Figure 3).

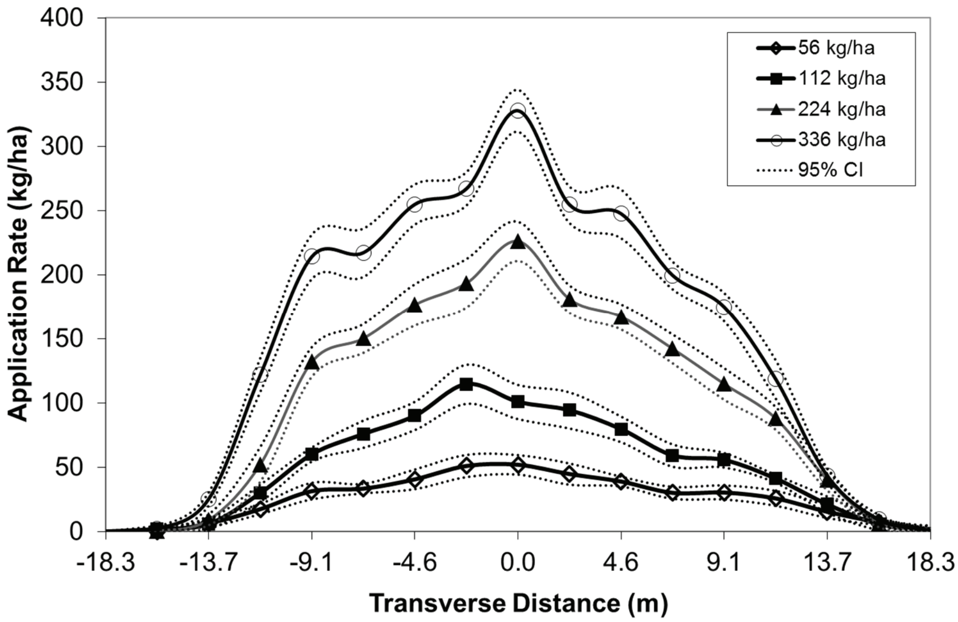

Figure 3 – Mean, single-pass, application patterns for 4 different rates with 95% confidence intervals.

12.2.2 Following ASABE S341, single distribution application plots shall be overlapped and summed for the desired pass-to-pass applicator spacing. From the summed patterns, two CVs (e.g. uniformity of distribution) shall be determined (See ASABE S341 Section 5.5.4.1).

— The "relative" CV will be determined using the mean application rate based on the overlap analysis.

— The "absolute" CV will be determined using the prescribed or desired application rate for the test.

12.3 Optimal swath spacing — This analysis will be conducted to determine the optimal swath spacing for an applicator at each tested application rate.

12.3.1 A plot of computed CVs versus swath spacing and driving direction shall be developed (See ASABE S341 Section 5.5.5.2) as depicted in Figure 4.

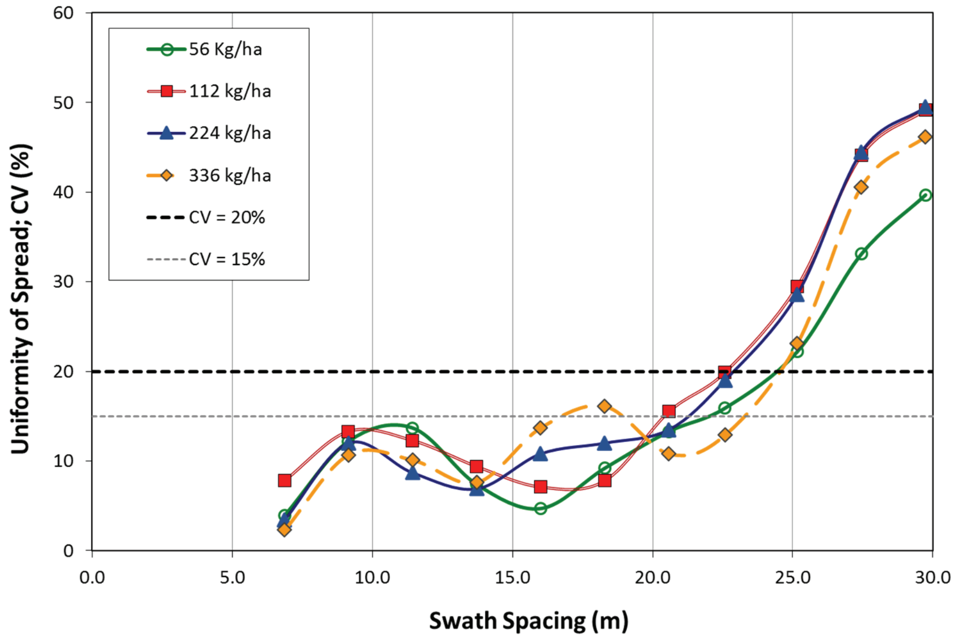

Figure 4 – Example plot of CV versus swath spacing for determination of the optimal swath width.

12.3.2 The appropriate swath spacing for an applicator shall be selected in accordance with Section 5.5.5.2, ASAE S341. When the optimal swath spacing varies between the tested application rates, then the effective swath spacing shall be selected associated with the largest swath spacing providing the lowest CVs for all rates.

12.4 Rate response — The analysis for this portion of the data is intended to produce lag or lead times for the corresponding low-high and high-low rate changes.

12.4.1 Surface plots shall be generated using a suitable software package for each set of collection pan test data. This plot (Figure 5) provides a visual rendering of application variability and rate transition dynamics.

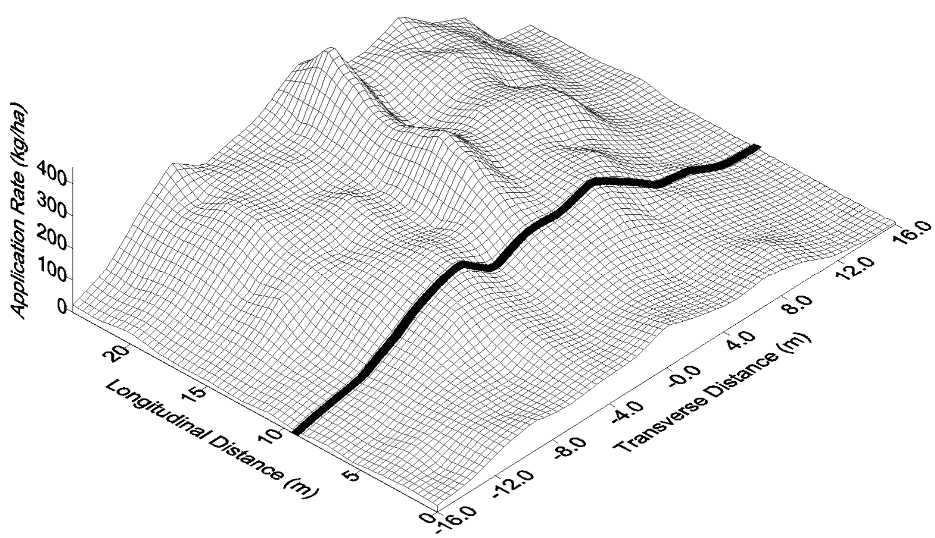

Figure 5 – Example rate transition surface with black line representing border between zones.

12.4.2 Rate transition parameters, *transition time* and *delay time,* shall be determined for each data set. Transition time is defined as the elapsed time from the actual start to finish of the rate change. The delay time characterizes the time difference from when the rate change actually commenced to the desired start time.

12.4.3 Start and end distances for the rate transitions are established by using a four-parameter, sigmoidal regression function to model rate changes. The sigmoidal fit best describes both increasing and decreasing rate transitions for most commercially available applicators.

— Figure 6 illustrates the procedure for defining the start and end distance for the rate transitions. The start and end points were defined using a 5% settling time. This corresponds to a 5% and 95% change in the overall rate transition defined by the resulting sigmoidal regression minimum and maximum rates on the asymptotic tails.

— The "delay distance" is determined as the difference between the location of the initiation of rate change (e.g. 5% change in the initial application rate) and location of desired change line (e.g. zone boundary). The rate change is determined using the sigmoidal curve that was fit to the pan data for each row of pans parallel to the direction of travel. These distance values are averaged for all rows to establish the overall "delay" distance for either rate change scenario. By assuming a constant ground speed, the "delay" distance is converted to a "delay" time.

— The "rate transition" distance is determined as the distance between the 5% and 95% rate change locations. The 5% and 95% rate change locations are determined using the sigmoidal curve that was fit to the pan data for each row of pans parallel to the direction of travel. These distance values are averaged for all rows to establish the overall "delay" distance for either rate change scenario. By assuming a constant ground speed, the "rate change" distance is converted to a "rate change" time.

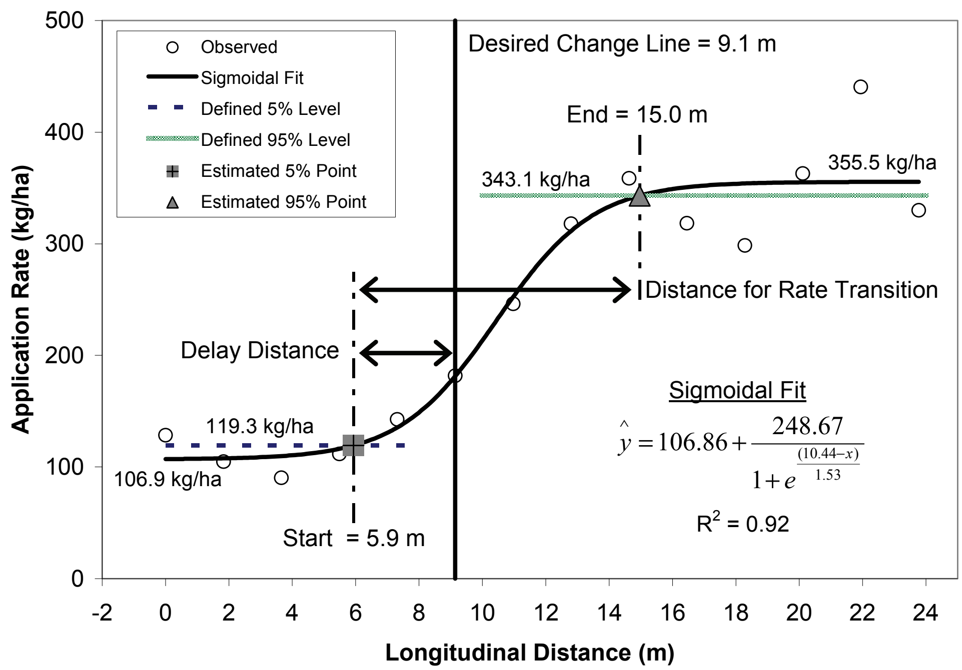

Figure 6 – Example characterization of rate change dynamics with desired rate change line indicating border between zones.

12.4.4 This process is repeated for each nutrient or soil amendment for which collection pan data is available, and for each rate change scenario.

12.5 Whole field application accuracy — While pattern uniformity and rate change response are important factors when it comes to assessing application rate accuracy for VRT equipment, the true measure is to assess application accuracy under actual field conditions. The analytical techniques presented in this section will produce a single test statistic that describes overall applicator performance.

12.5.1 Using the data collected from the procedures in Sections 10 and 11, plots of actual applications rates (randomly placed collection pans) should be plotted against the prescription or target rates. Regression can be utilized to assess the trend such as linearity, and correlation, of the plot (Figure 7). The correlation of this plot is a measure of overall application accuracy.

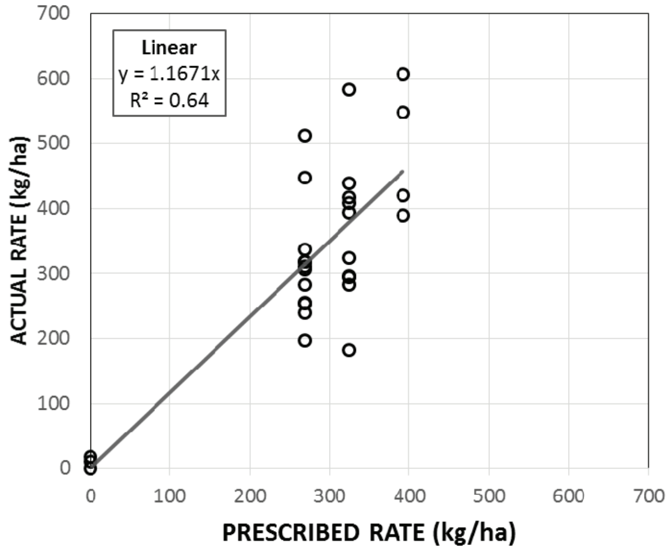

Figure 7 – Example plot of actual versus the prescribed application rates during a field application.

13 Test data reporting requirements

13.1 A detailed report shall be developed that contains a summary of all of the data collected from the pan matrix and the randomly placed pans. Pan and baffle dimensions shall be included. A brief description of the spreader should precede the pan layout description. Where appropriate, summary statistics should be reported. The report should also include the figures developed as part of the analysis in Sections 12.2.2, 12.3.1., and 12.4.2.

13.2 Product density, moisture content, particle size distribution and chemical composition shall be reported for each of the granular materials used in the assessment.

13.2.1 The report should include a complete listing of all of the systems components including the make, model and serial number of the spreader box. In addition, any user adjustment to the applicator, firmware, display, and rate controller, shall be included along with date, time and location. If the spreader is using a rate controller, the calibration number, rate controller model and software version shall be noted.

13.3 The local weather conditions that existed at the time of data collection shall be summarized in the report. A summary of weather conditions should be included, but is not limited to: ambient temperature, humidity, wind speed and direction, and precipitation.

14 Limitations and disclaimers

14.1 These test procedures overview the minimum data collection and analysis guidelines required to assess VRT of single and multiple granular products. This standard is not intended to be an exhaustive assessment of every possible performance trait or characteristic of multiple classes of equipment. Additional test elements may be desirable for particular field operations and applications conditions.

14.2 End users of this information shall be cautioned with regards to its applicability or suitability for representing the performance of similar systems where the equipment set-up is altered (i.e., change of controller gains or feedback control algorithms), or where other components have been integrated into a system (i.e., a different make and model of GPS receiver).

14.3 The test site should provide conditions favorable for the GPS receiver (open sky, negligible vibration, upright position, etc.). If performance estimates in unfavorable conditions are required, any of the listed tests can be replicated with clear specifications of test settings.