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Pattern Assessment of a Spinner Disc Variable-Rate Fertilizer Applicator

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Abstract. *Previous work by Fulton et al. (2000) showed the development of a program for generating an "As Applied" map to assess uniform and variable-rate application of potash. The "As Applied" map was created using an "As Applied" file generated during field operation in conjunction with different application patterns determined by Fulton et al. (1999). While modifications are required to improve the program, a rapid method for determining distribution patterns from granular applicators is desired to help limit the test area, keep the material being tested confined to a smaller area, and have the ability to test several spreaders within a days time at different application rates. Therefore, the focus of this investigation is to determine whether static testing of spinner spreaders equipped with variable-rate technology can be performed rather than the dynamic testing outlined in ASAE standard S341.2 or the procedure used by Fulton et al. (1999). Both static and dynamic tests were conducted at application rates of 2241 kg/ha, 4481 kg/ha, and 6722 kg/ha. The distribution patterns at these different rates were determined and then normalized to generate an effective distribution application pattern*

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using the progressive method outlined in S341.2. To compare the static dynamic testing methods, correlation coefficients of 0.39, 0.58, and 0.33 were calculated for the 2241 kg/ha, 4481 kg/ha, and 6722 kg/ha tests, respectively. The low correlation coefficients along with the variability in the distribution patterns concluded that static testing is unable to replicate the dynamic testing and should not be used to assess distribution patterns. Finally, the variation in the effective distribution patterns (CV's from 20% to 28%), nonuniform flow of lime onto the spinners, and lime missing the spinners at the high application rate indicated that adjustments and possible modifications are required to produce a more uniform spread pattern.

Keywords. Precision Agriculture, Distribution, Variable-Rate Technology, and Pattern Assessment.

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Pattern Assessment of a Spinner Disc Variable-Rate Fertilizer Applicator

J.P. Fulton, S.A. Shearer, T.S. Stombaugh and S.F Higgins

Introduction

Variable-rate technology (VRT) used in conjunction with the global positioning system (GPS) has become a common application on many farms allowing producers to vary the application rates of various inputs such as fertilizers, herbicides, and plant populations. The belief is that products are being metered and delivered accurately as the VRT equipment traverses the field. In most cases, a prescription map has been developed before applying the product of interest using an agricultural software package. The map indicates where and the quantity of material to be applied at particular areas of the field based on soil fertility tests, field history, and/or other field information. In return, the prescription map is then read by a computer, which then controls the metering unit on the machine, applying the prescribed amount to that area. The assumption made by those using VRT is that the product was accurately metered and applied as defined by the prescription map. However, systematic errors such as GPS and control latency along with machine setup can introduce applications errors thereby skewing the desired application of products.

One of the areas that VRT has found wide acceptance has been on spinner disc spreaders. These types of spreaders are the most common means for applying granular fertilizers and lime. Most of these spreaders utilize duel spinner discs to distribute a product or products. Inherent to spinner spreaders is distribution variability when applying products. Most of the time, the application variability is acceptable during uniform application of products. However, varying the application rate has made many skeptical by possibly increasing the spread variability thereby deteriorating the application accuracy of products. VRT introduces more possible sources of errors with the introduction of GPS, a controller, computer, and hydraulic valves. As a result, the application and distribution accuracy of a spinner spreader system utilizing VRT is important to ensure proper and accurate application during field operation.

The American Society of Agricultural Engineers (ASAE) developed a standard to measure distribution uniformity of granular broadcast spreaders (ASAE S341.2, 1997). The standard outlines a methodology by which to assess the distribution pattern of a broadcast spinner using a 1-D row of trays. Similarly, Fulton et al. (1999) modified the plot layout of ASAE S341.2 to include a 2-D array of pans to assess variable-rate application of granular products, to determine distribution patterns at different application rates and evaluate possible spread pattern changes during rate changes. The value of determining distributions patterns using these methods provides a means by which an “As Applied” map can be generated to assess the accuracy of variable-rate application of granular products. Fulton et al. (2000) were able to create an “As Applied” potash surface using the distribution patterns determine by Fulton et al. (1999) and the “As Applied” file generated during field operation of a spinner spreader. In return, comparison of the “As Applied” map to the prescription map can determine distribution accuracy of granular products.

An “As Applied” map serves many benefits for assessment of application errors. However, a rapid distribution pattern assessment of granular applicators at different applications rates is desired; a technique which limits the required testing area, thereby keeping the product

of interest confined, and permits rapid testing of several applicators within a short time period. The procedures outlined by ASAE S341.2 and Fulton et al. (1999) require a large area for allowing the applicator to reach operating speed and the control system to stabilize before traversing the test area. If the test space was limited to a small area such as parking lot or field, the applied product could be cleaned up after the completion of testing. Therefore, static testing of granular applicators might be a viable alternative procedure for determining distribution patterns. Therefore, the objectives of this investigation are

1. To perform static agricultural lime distribution pattern assessments at a low, medium and high rate using a spinner spreader.
2. To perform dynamic agricultural lime distribution pattern assessments at the same three application rates.
3. To compare and contrast the dynamic and static tests to determine whether static testing provides an adequate means for determining distribution patterns.
4. To compare and contrast the applicability of static and dynamic spread pattern distribution test methods for generation of 'As Applied' field coverages.

Background

Precision agriculture (PA) has a brought a new technique for managing agricultural land. Many believe that the use of PA practices allows for better nutrient management by applying only what is required for crop growth thereby possibly providing agronomic, economic and environmental advantages over the traditional approach of treating a field as a single unit. While VRT has become a widely accepted method in the agricultural community for vary the application rate of various inputs, potential errors with this technology along with proper calibration and operation is critical to ensure accurate application of inputs.

One of the means to measure and characterize application accuracy is computing the coefficient of variation (CV). The coefficient of variation provides a quantification of spread variation and accuracy. Low CV's indicate a more uniform spread distribution with 5% to 10% being a desired range for spinner disc spreaders. However, Sogaard and Kierkegaard (1994) reported that CV's could be more in the range of 15% to 20% under field-testing. These higher CV's are probably due to rougher surfaces experienced under field conditions. Parish (1991) reported CV's in the upper 20's to the lower 30's in some test cases with these high variations resulting from terrain irregularities.

ASAE standard S341.2, Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders (ASAE S341.2, 1997), provides a uniform procedure for testing, assessing the performance, and reporting the results of broadcast spreaders. It specifies test setup, collection devices, test procedures, effective swath width, and determination of the proper testing application rates. When using the outlined procedure, the results provide a quantification of application accuracy and possible spread pattern deviations. However, this standard does not cover the testing of broadcast spreaders with VRT.

Fulton et al. (1999) outlined a procedure for testing a variable-rate spinner disc applicator. They modified ASAE S341.2 to include a 2-D array of collection pans so to assess uniform and variable-rate application of potash. Their results indicated the occurrence of pattern shifts as observed in both the uniform and variable-rate tests. Most noticeably, at the high testing rate of 168.1 kg/ha, a very distinct W-shaped pattern resulted with a slight M-shape pattern occurring at the low rate of 56.0 kg/ha. These tests indicted application errors

associated with both uniform and variable-rate application of potash. Olieslagers et al. (1997) also observed pattern shifts during rate changes and suggested that continuous changes to various spreader adjustments might be required to maintain a uniform distribution pattern during rate changes. Though the 2-D array of collection pans used by Fulton et al. (1999) provides a viable means for assessing variable-rate application of granular products, it requires a large area in order to capture rate changes and becomes time consuming to collect and bag samples due to the large number of collection pans.

Methodology

Dynamic and stationary deposition tests were conducted to evaluate the application distribution of a variable-rate spinner disc spreader spreading agricultural lime. ASAE Standard S341.2 (ASAE S341.2, 1997) was modified to include a two-dimensional array of collection pans for performing these tests. Modifications to the outlined procedure by S341.2 were required since both dynamic and static were conducted and equivalent transverse pan spacing for each of the plot layouts was desired to compare the static and dynamic tests. Agricultural lime was selected as the test material. Test cases to investigate the application of agricultural lime included fixed-rate application at a low, medium and high rate with replication for each test. The results from the stationary and dynamic tests were then compared to determine if static testing of spinner spreaders provided an acceptable method for determining distribution patterns.

Tests were conducted on days when sustained wind speeds were less than 8 kilometers per hour at a height of 2.5 m (5 ft) above the ground and the slope of the testing site was less than 2 % (ASAE S341.2, 1997). All tests were run with the hopper filled to approximately 40 to 50% capacity as defined as ASAE S341.2. Aluminum collection pans were fabricated as outlined in ASAE S341.2. The pans measured 40.6 cm (16 in.) wide, 50.8 cm (20 in.) long and 10.2 cm (4 in.) in height. An aluminum divider with a 10.2 cm by 10.2cm (5.1 cm (2 in.) height) grid was also fabricated to place inside each tray to reduce material from ricocheting out of the tray.

The low, medium and high application rates were selected for this investigation based on ASAE 341.2. ASAE outlines that tests should be conducted at 25%, 50% and 75% of the maximum application rate as recommended by the University of Kentucky's Lime and Fertilizer Recommendations for agricultural lime (AGR-1, 1998). For no-till corn production, AGR-1 recommends a maximum application rate of 8963.0 kg/ha (4 ton/ac). Based on this maximum rate, the low, medium and high test application rates for this investigation were calculated as 2241 kg/ha (2000 lb/ac), 4481 kg/ha (4000 lb/ac) and 6722 kg/ha (6000 lb/ac), respectively.

The variable-rate spinner disc spreader used for this investigation is maintained within the Biosystems and Agricultural Engineering Department. The spreader has a custom built spreader bed containing two separate compartments for the application of multiple granular products. However, only the rear compartment was used for this investigation. Fulton et al. (1999) contains a detailed description of the spreader and control system. However, current system differences include using the software package AgView by GIS Solutions (AgView, 1999) instead of Agris's FieldLink and using a Trimble 132 DGPS receiver.

The spreader had been previously calibrated for lime application. Before performing any tests, the settings for the spreader and control system were checked to adhere to those determined at calibration. These are the same settings used during field application of lime with

this spreader. The spinner speed was set at a nominal speed of 550 rpm producing a 15.0 m (49.2 ft) effective spread width with the rear gate fully opened. It should be noted that for lime application with this particular spreader, the rear divider must be positioned all the way forward. Field operation with this spreader consists of running in 1st gear with the engine running at 1900 rpm resulting in a speed of 12.2 km/hr (7.5 mph), which must be entered into the MidTech controller for static operation of the spreader.

Stationary testing was conducted first. The size of the test area had to be established by determining the maximum, static throw distance of agricultural lime by this particular spreader. The spreader was parked in a level, open field. The hydraulic control system was engaged to operate the spinners and apron chain for spreading and metering out lime. The rate of lime deposition was set at 6722 kg/ha since this represented the maximum test rate. As lime was spread, flags were used to mark the maximum distance lime reached in all directions. Figure 1 presents the general shape of the application area. The area was circular in nature with some material distributed in front of the spinners or towards the front of the spreader. An additional 5 m was added to the maximum distance to ensure all material distributed by the spreader would be captured within the test area. Test area symmetry was maintained from side to side. The overall dimensions for the test area are shown in Figure 1.

With the static application area known, a uniform pan matrix was applied to the test area for collecting lime. A uniform spacing was used since it provided a simple approach for laying out the test plot. Pan spacing was determined by limiting the number of pans to under 169 (number of fabricated pans) and keeping it to 0.5 meter increments. A constraint for the static testing was keeping a row of pans directly behind the spreader. Different pan spacings were applied to the test area with 2.5 m generating the best coverage. Figure 2 presents the final pan locations in relation to the center of the spinners with a total of 157 pans used. While the number of pans used of this investigation is not much less than the 169 pans used by Fulton et al. (1999), the objective is to first see if static testing could replace dynamic testing. If so, the next step would include determining the minimum number of pans required to capture distribution patterns under static testing.

A preliminary test for agricultural lime was performed at the 2241 kg/ha rate to determine the appropriate test time for each of the three different rates. The goal was to collect the same amount of material for each of the different rate tests without lime building up in any pan and spilling over the side. The preliminary test showed that 1 minute and 30 seconds was an appropriate tests time for the 2241 kg/ha rate. Based on this time, the 4481 kg/ha tests was performed for 45 seconds (twice the application rate) and the 6722 kg/ha test for 30 seconds (three times the application rate). A stopwatch was used for maintaining the correct test time.

Once the spreader and pans were properly positioned, the static tests were performed. The three different application rate tests were conducted with replication, for a total of six static tests. Upon completion of each test, the lime collected in each pan was placed in individual plastic bags, sealed and labeled. All sample weights were determined back in the lab with the weights recorded to generate distribution and surface plots for all test cases. Random lime samples were collected from the spreader bin before testing to determine the density and moisture content of the lime.

Dynamic tests consisted of making a single pass over a comparable 2-D array of pans as used for the static tests. The pan layout for these tests is similar to the outlined procedures from S341.2 except modifications to the transverse pan spacing. The same 2.5 m transverse spacing was used for comparison purposes between the static and dynamic tests. Figure 3

shows the plot layout with a total transverse width equal to 40 m (131.2 ft), which is over twice the effective swath width (15.0 m) for this spreader (ASAE S341.2, 1997). Five rows of pans were selected to provide five replications while only traversing the pans once with the spreader at each of the three application rates. Therefore, a total of three dynamic tests were conducted.

The MidTech controller was set to the appropriate test rate for each dynamic test. Before entering the pans, the spreader was brought up to operating speed (12.2 km/hr) and the control system (MidTech controller and hydraulic system) allowed to reach its operating status thereby stabilizing the output flow from the spreader when traversing the test area. Just as with the static tests, the lime accumulated in each pan for each test was bagged, labeled, and then weighed to generate distribution patterns for each test rate.

Results and Discussion

Random lime samples had been collected during all testing to compute moisture content and density. Before conducting tests, the spreader was unloaded and then refilled (ASAE S341.2, 1997). The moisture content of the lime ranged between 3.0 and 4.0% (wet basis) with the density ranging from 1280 kg/m^3 (79.8 lb/ft^3) up to 1475 kg/m^3 (92.0 lb/ft^3).

Figure 4 shows the mean transverse distribution patterns determined by the dynamic tests. Taking the amount of lime accumulated in each pan and dividing it by the pan's bottom surface area calculated the application rate for each pan. The mean was then computed for the five pans at each transverse location. There were five rows of pans (figure 3), thus five replications. The shape of each pattern is different with the 6722 kg/ha pattern illustrating a distinct W-shaped to it. The 2241 kg/ha pattern shows a slight M-shape with the 4481 kg/ha looking more like a M-pattern than a W-pattern. The results do indicate slightly more lime being deposited to the left of the spreader. This can be seen when comparing the curves at the $\pm$ 5 m transverse distances. Overall, the shape of these distribution patterns deviate from the desired Gaussian or oval pattern indicating a poor distribution pattern for lime at all three rates using this spreader.

Summing the application rates across the distribution patterns found in figure 4 and dividing the summed rate into each data point on the pattern normalized these distribution patterns. Therefore, the sum of the normalized mean applications rates across the pattern now equals 1. The spread patterns are now unit-less, providing a means to compare the dynamic distribution patterns to those determine in the static tests. Figure 5 presents the resulting normalized mean application rates based on the dynamic tests along with $\pm$ 2 standard deviation curves. This figure again demonstrates distribution unevenness along with the 2 standard deviation curves showing the variability between the five replications. The variability and non-desirable patterns indicate application errors with this spreader. The results also suggest that changes are required to the spreader setup to produce a more uniform distribution.

A typical lime distribution surface for one of the 2241 kg/ha static tests is presented in Figure 6. This figure just presents a visual representation of lime accumulation in the pans during the static tests. The surface plot was generated using Surfer (Surfer, 1996). The black cross designates the center location between the two spinners during testing. The top view of the test area in Figure 2 better shows the position of the spreader during testing. Figure 6 shows that a high percentage of lime was deposited near the spinners. However, the amount of lime collected in the pans quickly diminishes when moving away from this area and towards the

outer edges of the test plot. It also illustrates how some lime is thrown forward, towards the front of the spreader.

Spread patterns for the static tests were determined by summing pans at each of the transverse distances giving a total of 17 data points across the spread pattern with the same 2.5 m spacing used in the dynamic tests. For example, nine pans exist longitudinally at transverse distance 0.0 m (figure 2) with the summed material collected in these pans representing the center data point of the spread pattern. The static distribution pattern for the test illustrated in figure 6 is shown in figure 7. Normalized spread patterns for each test were calculated by dividing the total material across the spread pattern into each data point. The normalized static distribution patterns are presented in figure 8 with replication 1 in figure 8a representing the normalized spread pattern depicted in figure 7. All three plots in figure 8 show a resulting M-shape pattern, which indicates deviation from a desired Gaussian distribution. The curves in each plot show similar trends between replications with figure 8a demonstrating similar shaped patterns. The patterns in figures 8b and 8c slightly deviate from one another by not having the same shape. Of interesting note, the W-shaped pattern found during the 6722 kg/ha (figure 4 and 5c) dynamic testing does not appear in the 6722 kg/ha static tests. It was observed during the 6722 kg/ha static testing, that lime was flowing over the rear edge of the spinners and onto the ground thereby, missing the spinners and not being distributed. This was primarily due to the high outflow rate and speed of the apron chain. Again, as observed in the dynamic testing, the static results tend to indicate application variability and problems with the spreader setup for applying lime. Consequently, changes are needed to ensure all material is placed on the spinners during high application rates.

Another issue observed during the static tests was nonuniform flow of lime off the apron chain and onto the spinners. Lime seemed to pack together and then break off in clumps. This produced uneven or cyclic flow onto the spinners whereby possibly influencing the distribution of lime. A device or mechanism to help smooth the flow might be needed. Future research might be required to investigate smoothing the flow of lime off the apron chain and onto the spinners.

The replicated spread patterns at each application rate in figure 8 were averaged to create a single normalized spread pattern for each application rate. The normalized distribution patterns for the static and dynamic tests were overlaid and shown in figure 9. Figure 9 provides visual differences between the spread patterns determined under the two different testing methods. Differences are seen in all three plots between the spread patterns. None of the static patterns follow the shape found in the dynamic patterns. The static pattern in figure 9a shows more of a W-shape pattern than the dynamic pattern. The left sides of the patterns in figure 9a (–5 to –20 m) do overlap. Conversely, the right sides of the patterns in figure 9b (0 to 20 m) closely overlap with left side showing different shapes. The patterns in figure 9c show totaling different trends with the dynamic test producing a W-shape while the static test produced a M-shape. The difference in shapes in figure 9b can be contributed to the dynamic test collecting the material missing the spinners, as observed during the 6722 kg/ha static testing, and not being captured during the static test. A pan was not positioned under the center or slightly behind the spinners (location 0, 22.5 m in figure 2) during the static tests. Therefore, the differences occurring at the center locations of the patterns in figure 9c. This issue with lime missing the spinners at the 6722 kg/ha application rate needs to be addressed and corrected. Overall, figure 9 tends to show differences in spread patterns between static and dynamic testing.

The uncertainty and variability between the static and dynamic distribution patterns can be seen in figure 10. Figure 10 is similar to figure 9 but with the addition of the $\pm$ 2 standard

deviation curves for the dynamic normalized patterns. The static patterns in each of the plots at some point lie outside the ± 2 standard deviation curves. This variation beyond the ±2 standard deviation curves occurs for the most part at the center of the patterns between the –7.5 and 7.5 m transverse positions. These plots tend to indicate that the results from the static testing differ from those determined by the dynamic tests.

Simulated overlap spread patterns for the static and dynamic tests were constructed in order to compare the different testing methods and conclude whether static testing could produce an alternative method for determining granular applicator spread patterns. Each spread pattern was selected individually and an overlap distribution line generated using the 'progressive application method' outlined by S341.2 (ASAE S341.2, 1997). S341.2 defines progressive application as, "An application method where the spreader applies adjacent swaths in alternative directions (back and forth application). This method produces a right-on-right pattern overlap alternatively with a left-on-left pattern overlap." The progressive method was chosen since it represents the most prevalent spreading method when using this spreader. In return, the effective application line for the static and dynamic patterns for each of the three different rates was generated. Figure 11 shows an example overlay for the normalized dynamic 2241 kg/ha distribution pattern. The first and third passes are would be made in the same direction with pass 2 made in the opposite direction; thereby, creating the right-on-right and left-on-left pattern overlap. The effective application rate line is just the addition of the patterns and overlap, which simulates the effective distribution of material under field application. In theory, this line should be a constant horizontal line.

Figure 12 shows the calculated effective dynamic and static distribution lines for each of the three different rates. The resulting distribution lines seem to deviate from one another in all the tests. Similar trends appear in each plot with the lines overlapping in a few locations. As would be expected, a difference occurs in figure 12c between the 6722 kg/ha two lines due primarily to the differences mentioned above during collection between the two testing methods. The results shown in these plots seem to indicate that static testing is not a viable option compared to dynamic testing.

Table 1 presents the statistical results for the progressive application patterns for each test. Surprisingly, the effective application pattern means are equivalent (0.17) except for the 2241 kg/ha static test, which was calculated at 0.16. However, the CV's for all tests were above 20% with a few around 28%. The dynamic tests produced CV's of 28.0%, 20.6%, and 27.9% for the 2241 kg/ha, 4481kg/ha, and 6722 kg/ha, respectively. The high CV's are expected observing the application variation in figure 12. These high CV's for applying agricultural lime again suggest changes to the spreader setup to help even out the distribution to produce a more uniform spread.

Table 2 contains the correlation coefficients for comparing the resulting effective application patterns in figure 12. The correlation coefficients indicate a low correlation between the effective static and dynamic patterns. The 4481 kg/ha tests produced the best correlation at 0.58 with the 6722 kg/ha having the lowest at 0.33. Once would expect the 6722 kg/ha correlation coefficient to be higher if the lime missing the spinners could have been captured during the static test. Regardless, these low correlation coefficients prove that static testing was unable to produce equivalent results as found in the dynamic testing. Therefore, static testing of a spinner spreader does not provide an alternative method for determining distribution patterns for a spinner spread.

Conclusion

The aim of this investigation was to determine whether using a static test could be used to collect distribution patterns from a spinner spreader. The underlying idea for using static testing to assess distribution patterns was to minimize the required testing space and keep the product of interest confined. The thought is to produce a quick and easy method for determining spread patterns at different rate for granular applicators, especially those equipped with VRT. Normalized distributions patterns were generated for each of the three application rates for both the dynamic and static tests. In return, these normalized distribution patterns were used to create an effective application rate pattern using the progressive application method outlined by ASAE standard S341.2. The resultant effective application rate patterns were compared producing low correlation coefficients. The highest correlation coefficient was 0.58 for the 4481 kg/ha application rate with the 2241 kg/ha and 6722 kg/ha producing 0.39 and 0.33 correlation coefficients, respectively. Therefore, this study showed no correlation between static and dynamic testing which indicates static tests distribution patterns cannot be used to generate 'As Applied' maps

These tests also showed variation in the spread patterns at the three application rates. Both M- and W-shaped patterns were observed for the dynamic test. Calculated CV's for these tests were 28.2%, 20.6% and 27.9 % for the 2241 kg/ha, 4481 kg/ha, and 6722 kg/ha, respectively. The deviation of the patterns from a desired Gaussian shape indicates changes are needed to the spreader to improve the application performance of it. Further, the static tests performed demonstrated some problems with the applicator especially at the high application rate (6722 kg/ha). It was observed that lime was flowing over the rear of the spinners at this high flow rate. Similarly, the flow of lime was not uniform off the apron chain. The lime seemed to pack together and then shear off in sections before dropping down onto the spinners, thereby creating more of a cyclic flow. This could explain some of the variations in the distribution patterns. Nevertheless, these observations along with the resulting distribution patterns seems to require modifications to the delivery system and possibly the spinners to help maintain a more uniform flow onto the spinners and ensure all material reaches the spinners. This could include redesigning the location of the spinners and rear divider in relation to the apron chain in hopes of producing a more uniform spread pattern. Variable positioning fins may also be needed to help maintain a uniform pattern at different rates. In conclusion, future research is required to investigate issues and errors associated with lime application found in this investigation.

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Table 1. Statistical results for the normalized effective spread patterns (progressive application method).

Application Rate	Test	Normalized Effective Application Pattern Mean	CV (%)
2241 kg/ha	Dynamic	0.17	22.0
	Static	0.16	28.2
4481 kg/ha	Dynamic	0.17	22.7
	Static	0.17	20.6
6722 kg/ha	Dynamic	0.17	27.0
	Static	0.17	27.9

Table 2. Correlation coefficients comparing the normalized effective static and dynamic application lines.

Test	Correlation Coefficient
2241 kg/ha	0.39
4481 kg/ha	0.58
6722 kg/ha	0.33

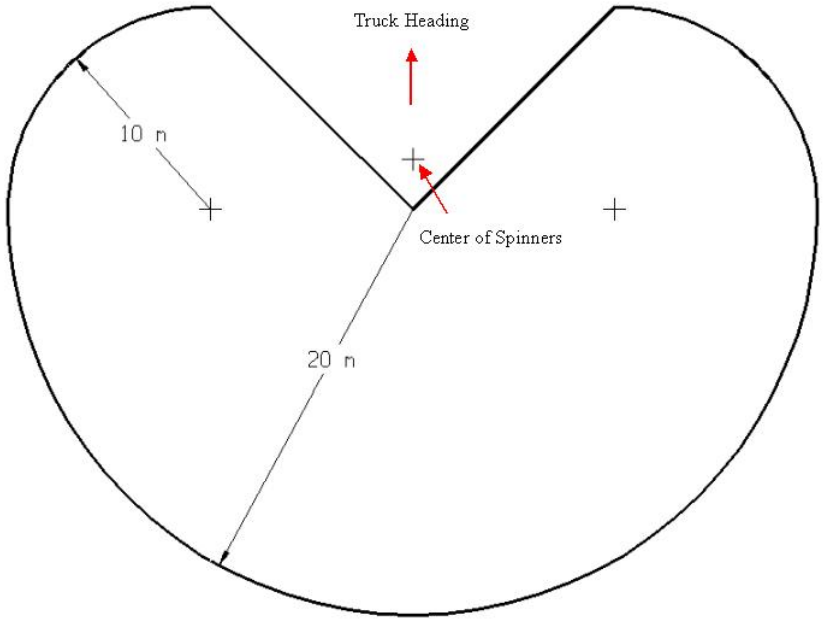


Figure 1. Test area.

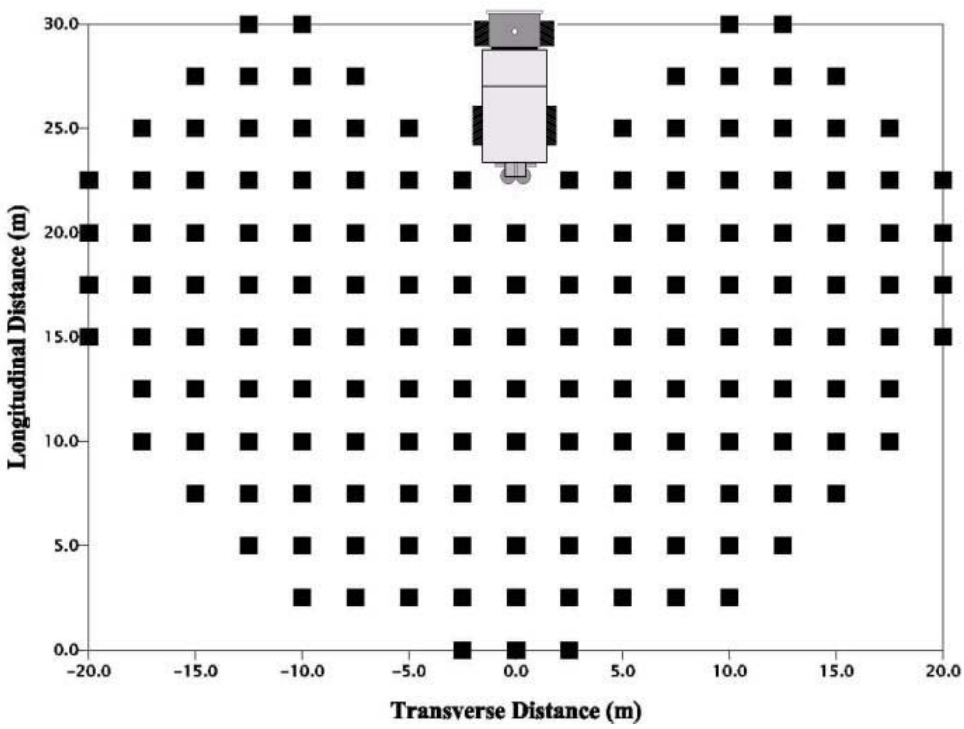


Figure 2. Collection pan matrix and dimensions for static tests.

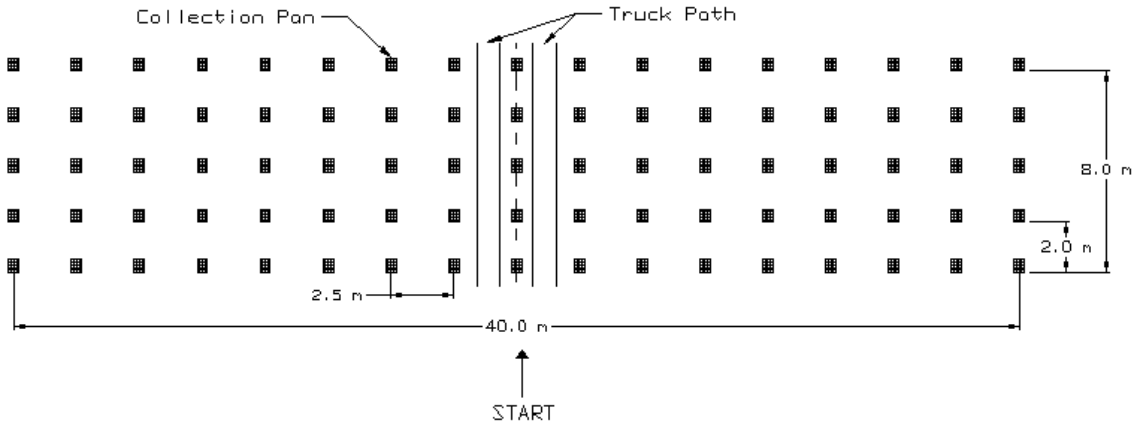


Figure 3. Pan matrix for dynamic tests.

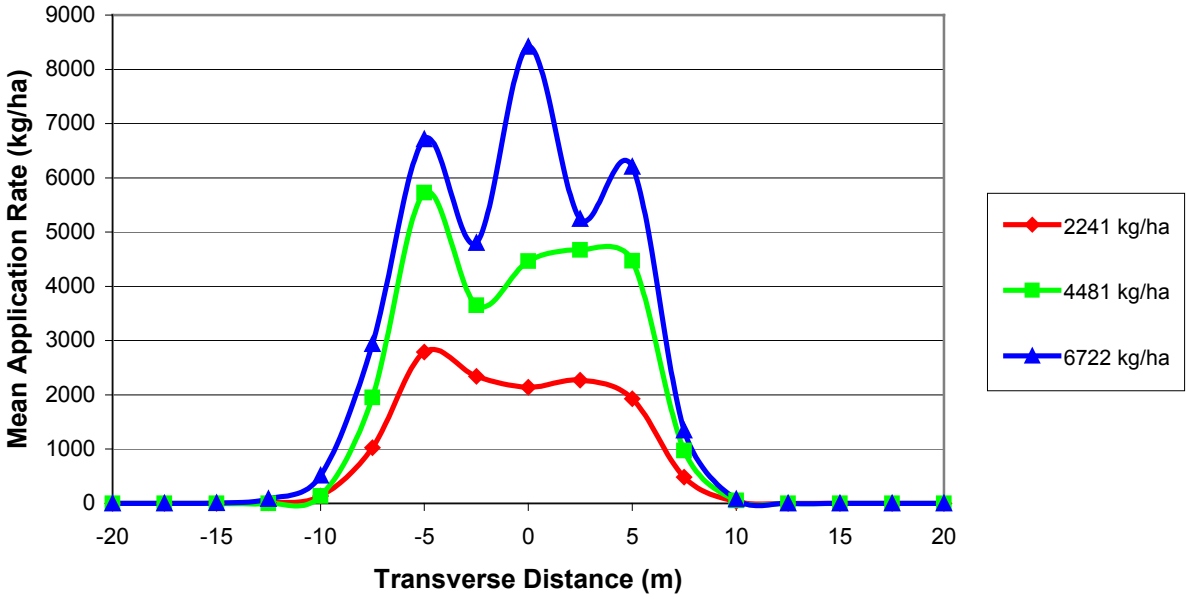
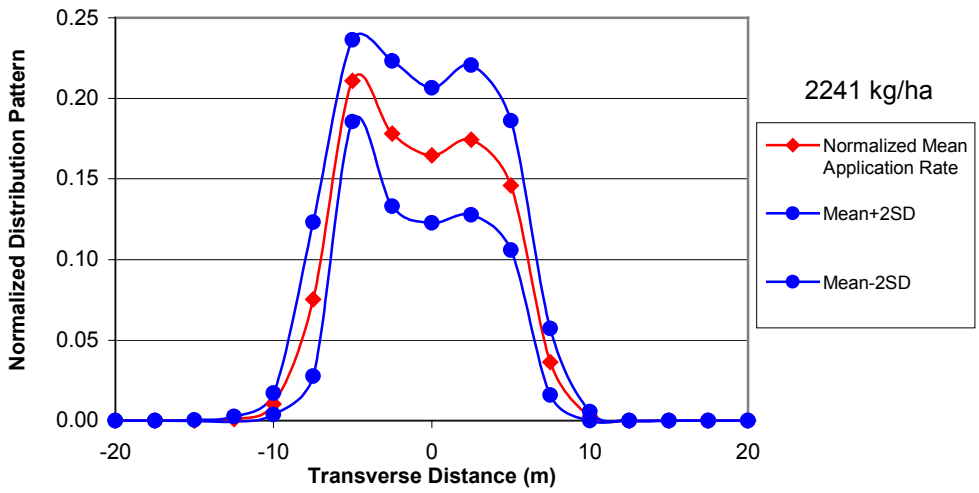
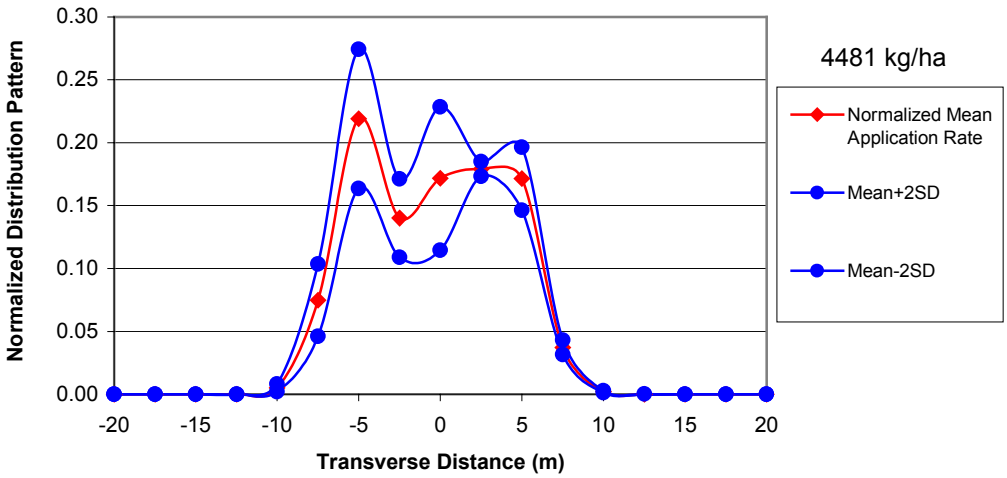


Figure 4. Mean dynamic transverse distribution patterns.

a)



b)



c)

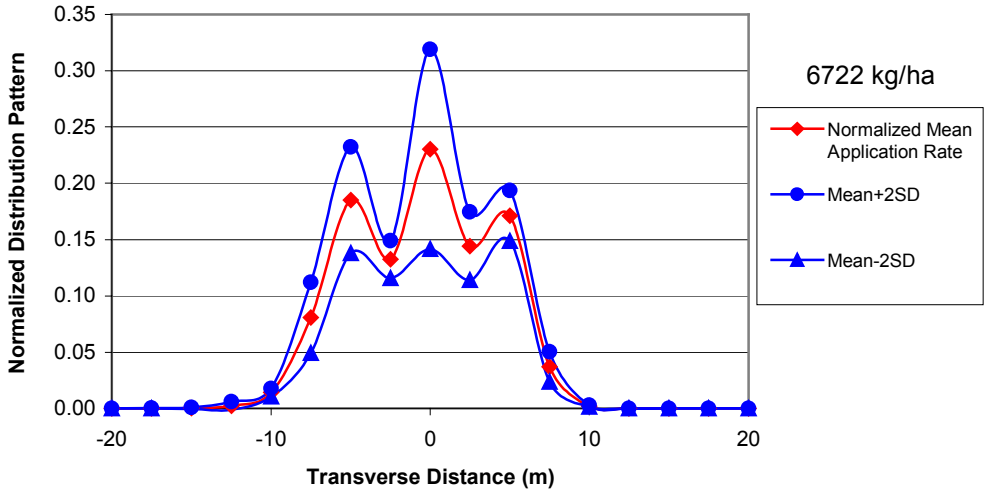


Figure 5. Normalized dynamic, mean distribution patterns.

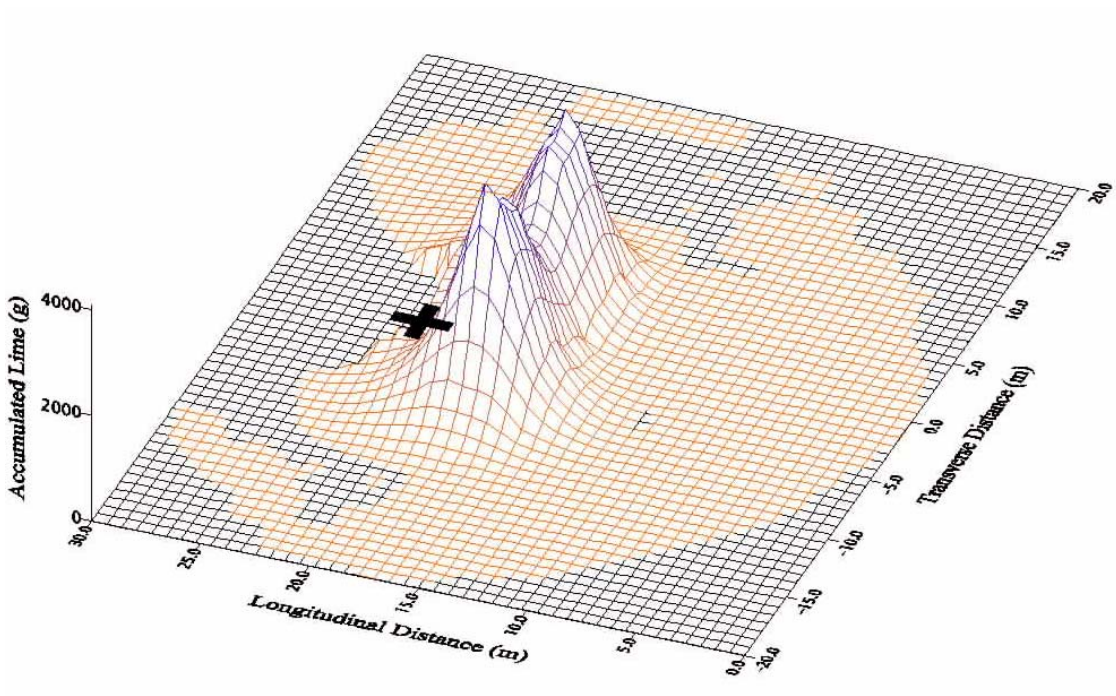


Figure 6. Lime distribution surface plot for one of the 2241 kg/ha static tests (black mark indicates the center location of the spinners).

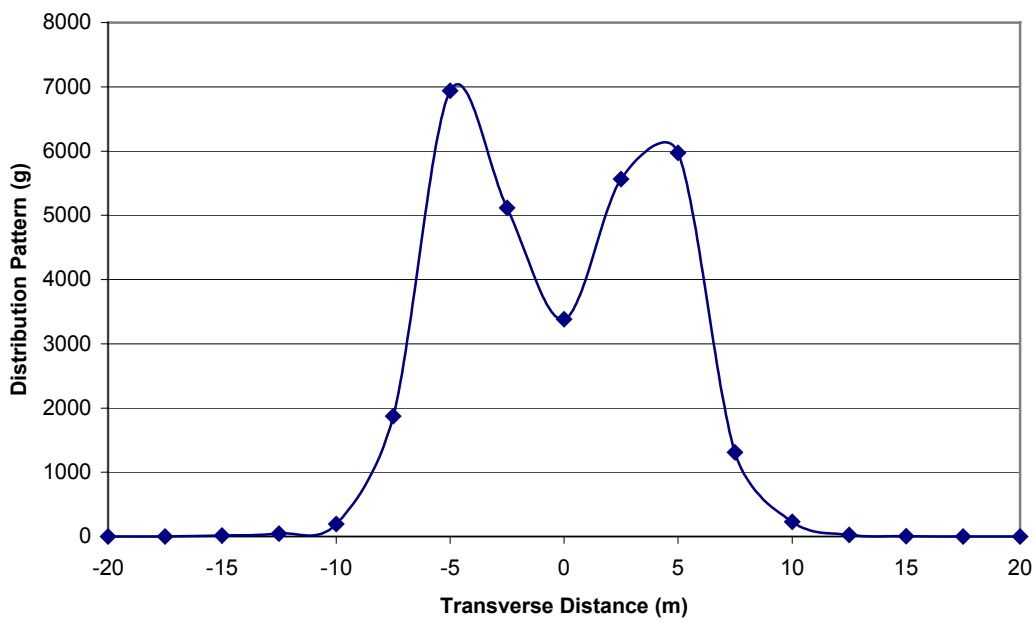
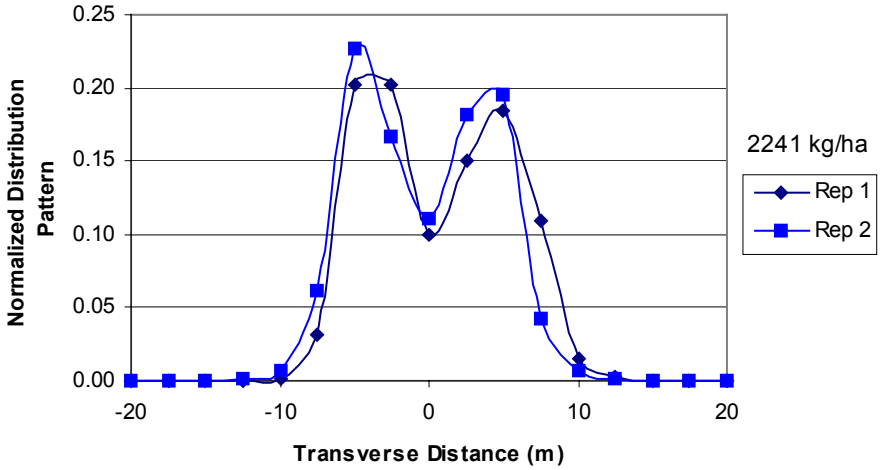
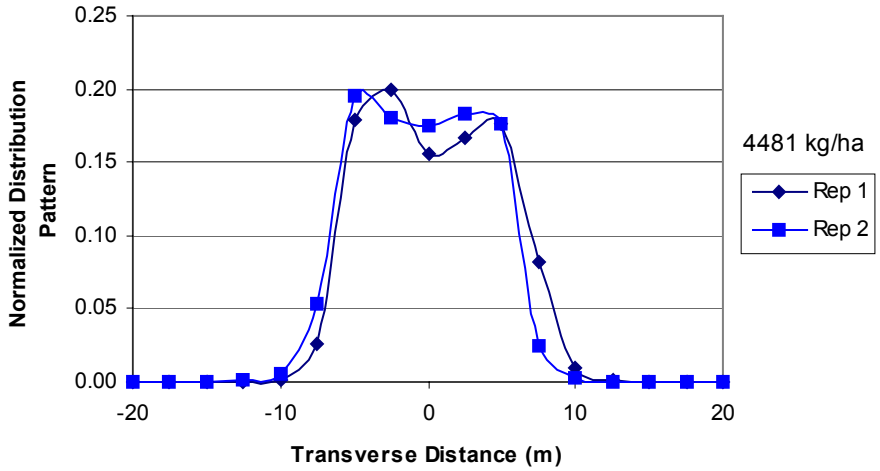


Figure 7. Resulting static distribution pattern from the same 2241 kg/ha test as shown in figure 6.

a)



b)



c)

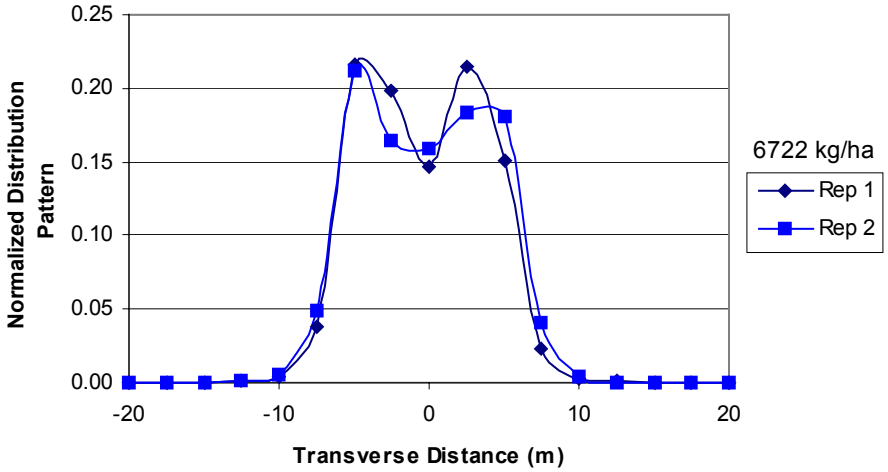
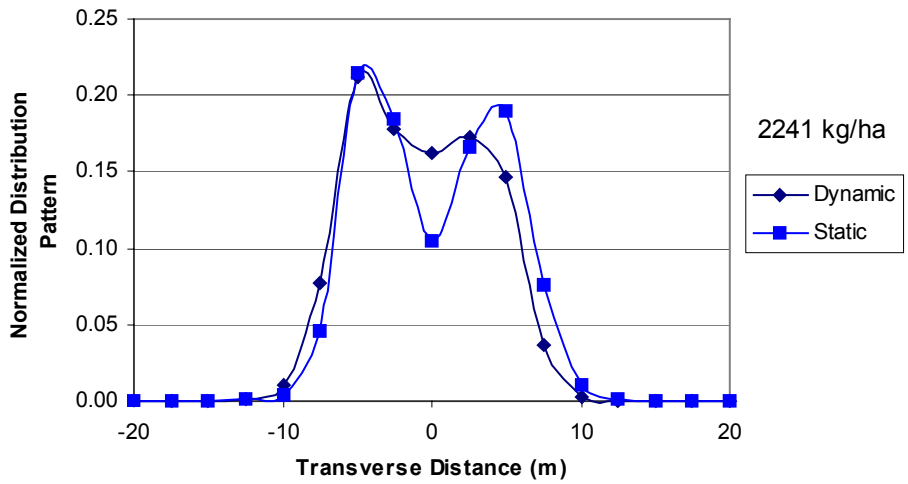
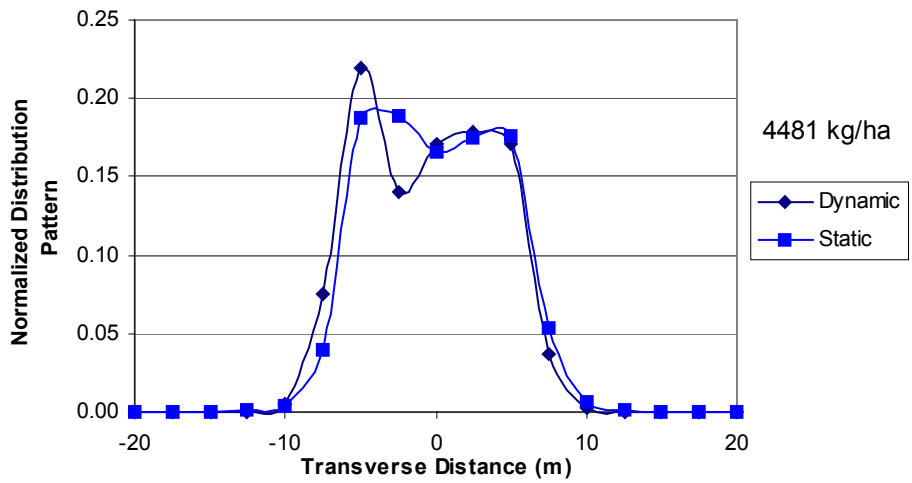


Figure 8. Normalized static distribution patterns.

a)



b)



c)

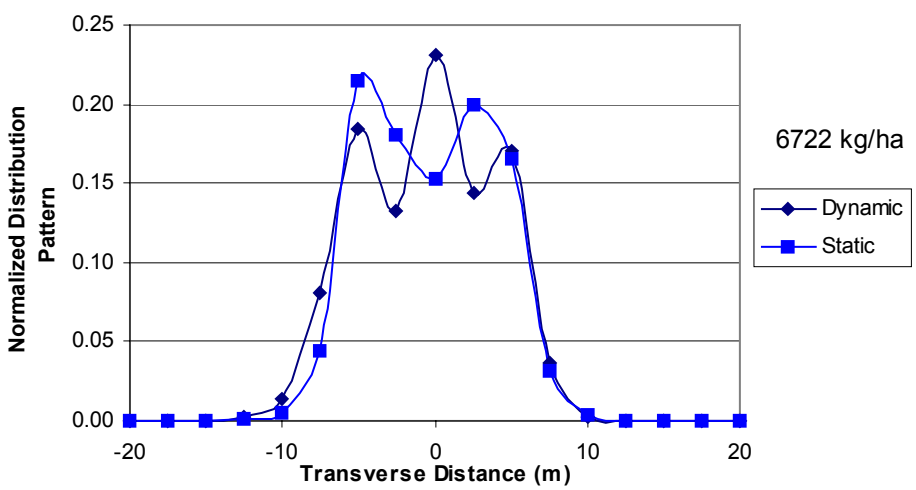
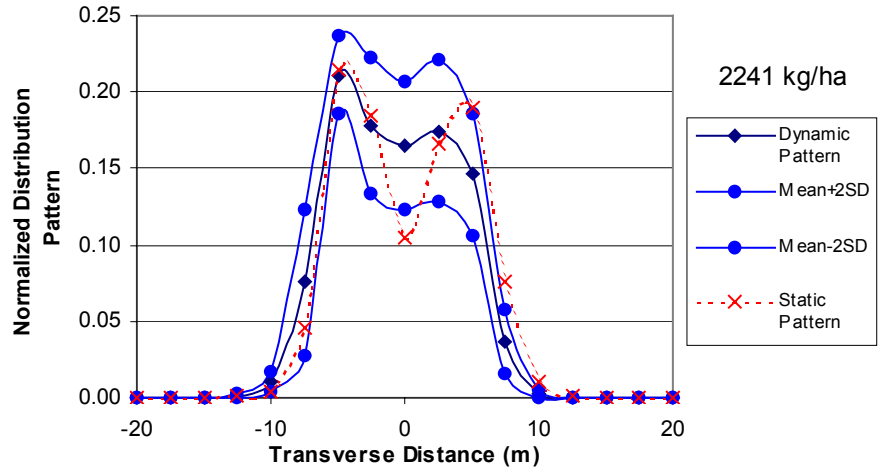
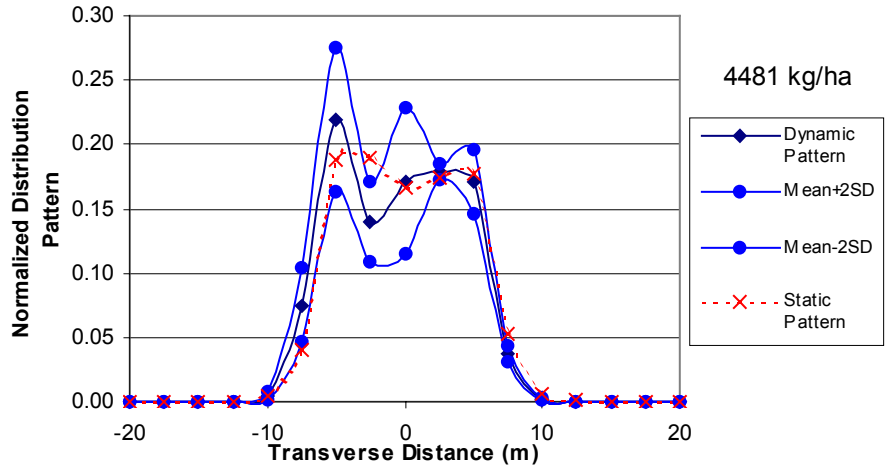


Figure 9. Comparison of normalized distribution patterns for the static and dynamic tests.

a)



b)



c)

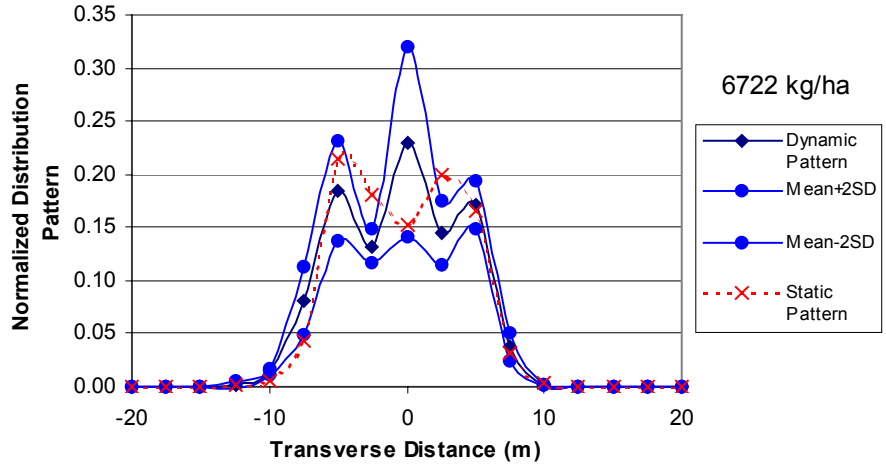


Figure 10. Static normalized distribution pattern superimposed onto the dynamic normalized pattern with ± 2 standard deviations curves.

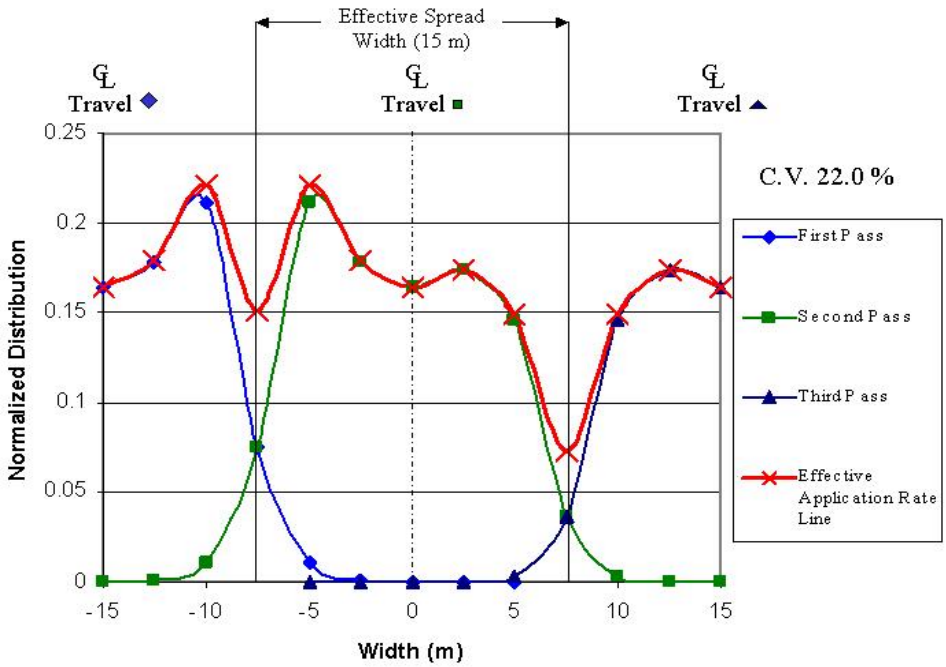
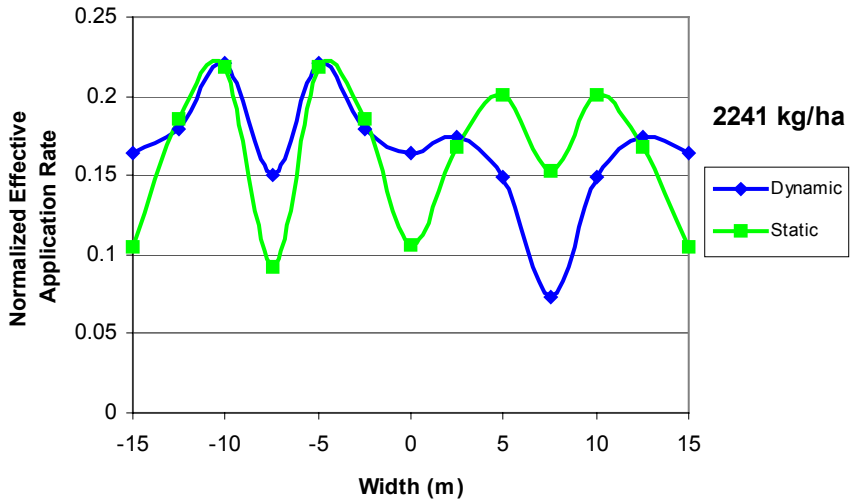
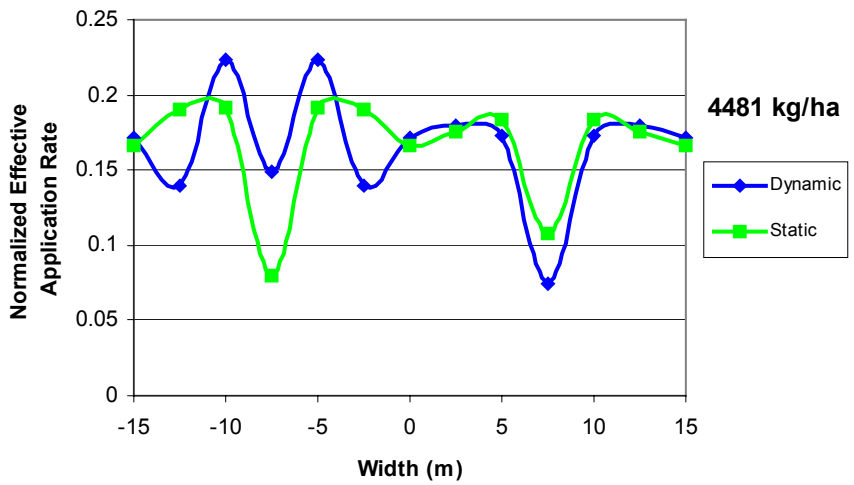


Figure 11. Graphical representation of the simulated overlap spread pattern (progressive application method) based on the normalized distribution pattern from the dynamic 2241 kg/ha test.

a)



b)



c)

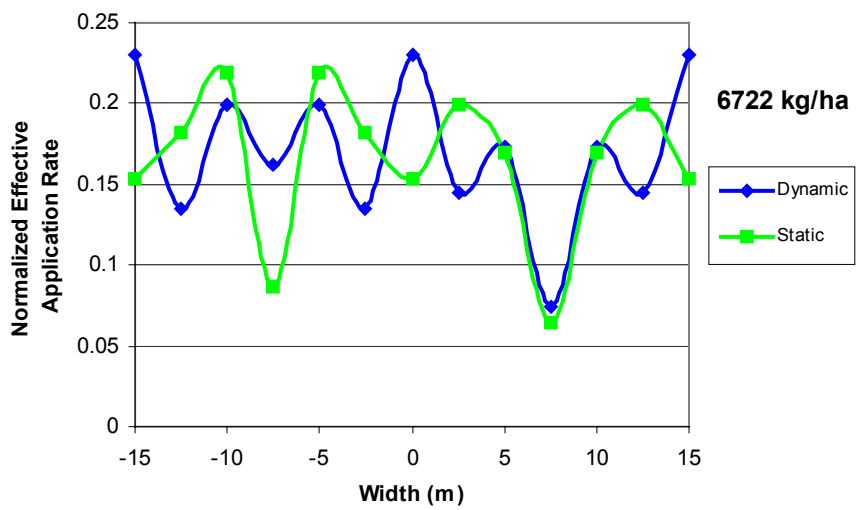


Figure 12. Overlay of dynamic and static overlap data.