The Society for engineering in agricultural, food, and biological systems

Paper Number: 021186
An ASAE Meeting Presentation

Simulation of Variable-Rate Application of Granular Materials

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Written for presentation at the
2002 ASAE Annual International Meeting / CIGR XVth World Congress
Sponsored by ASAE and CIGR
Hyatt Regency Chicago
Chicago, Illinois, USA
July 28-July 31, 2002

Abstract. *Fulton et al. (2001) modified ASAE Standard S341.2 to include a 2-D matrix of collection pans to assess fixed and variable-rate deposition of granular fertilizers and agricultural lime from a spinner disc spreader. Fulton et al. (2000) developed a methodology, using GIS functionality, to generate 'as-applied' surfaces by merging this deposition information and a field record of accumulated application volume file into a rate file. Therefore, the intent of this investigation is to validate the 'as-applied' model developed by Fulton et al. (2000). Field studies were conducted by randomly placing collection pans across two fields. Murate of potash was then applied using a variable-rate spinner spreader. Pan locations were marked using DGPS while material collected in each pan was bagged and weighed. The 'as-applied' method was then used to predict the amount of material each pan should have received. Analysis determined that a 5.5 m (field A) and 4.9 m (field B) offset produced the best results. The resulting offset difference was unexplained but determined*

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small. Comparisons were made between the actual and predicted application rates for each field with R^2 values of 0.45 (field A) and 0.58 (field B) calculated. Therefore, the current 'as-applied' model did not perform well but modifications to the current 'as-applied' model should improve its performance. R^2 values of 0.16 (field A) and 0.21 (field B) were calculated when comparing the actual application rates and prescription maps. These low R^2 values indicated poor application by the spinner spreader but demonstrated that the 'as-applied' model did a better job of representing the distribution of potash compared to the prescription maps. This could be indicative of escalated application errors when moving from fixed to variable-rate application using a spinner spreader. In conclusion, 'as-applied' surfaces provide a means for evaluating fixed and variable-rate application of granular products by spinner spreaders plus this new methodology enhances researchers ability to compare management approached variable-rate technology.

Keywords. Precision Agriculture, Modeling, Spinner Disc Spreader, Fertilizer and Lime Application.

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Introduction

Variable-rate technology (VRT) used in conjunction with the global positioning system (GPS) has become a common practice implemented by precision agriculture (PA) practitioners. VRT appears to provide a method for improving input efficacy. This is accomplished by applying only what is needed based on local soil conditions and crop requirements compared to traditional blanket applications. Additionally, reducing over- and under-application of inputs will enhance productivity, profitability, and environmental concerns. However, the evaluation of machinery equipped with VRT is needed. Errors exist with VRT components such as GPS receiver position error and latency along with time requirement for rate adjustments. Additionally, the deposition or application consistency of product(s) across the swath width is unknown for most equipment. Manufacturers and producers have recognized deposition variability but accept it and continue to apply even though the existence of application inaccuracies.

Today, many agricultural software companies are offering two-way communications between software packages and variable-rate controllers. These software packages not only correspond the desired application rate to the variable-rate controller, but also record the application quantity for a product. The documented application represent a spatial ‘as-applied’ application quantity point file describing the location and amount applied over a field. The main drawback to these files is that they do not represent actual product distribution. They do not account for possible spread pattern inaccuracies at various application rates, over- and under- lap on parallel passes, offset distance of the GPS antenna mounting position to the point of application, and system latency.

Fulton et al. (2001) demonstrated distribution variability at different rates from a spinner spreader by performing fixed and variable-rate application of murate of potash. They cited that distribution variability could compound application errors when moving to variable-rate application with spinner spreaders. Additionally, pattern shifts during rate changes (Fulton et al., 2001; Olieslagers et al., 1997) plus the existence of system latency causing delayed rate changes creates another source for application errors under variable-rate application. Most software packages provide a “look-ahead” feature to help account for system latency by shifting rate changes ahead in time. However, an assessment tool or method is required to assess application accuracies of VRT equipment.

Fulton et al. (2000) developed a methodology for generating ‘as-applied’ surfaces for a spinner spreader by merging different distribution patterns (Fulton et al., 2001) and a field recorded application file (AgView, 1999) containing the spatially summed volume of murate of potash applied. ArcView 3.2 by Esri (ArcView, 1999) was used to combine this information and generate the 'as-applied' surfaces. Additionally, an offset was built-in so the user could account for GPS latency and antenna position in relationship to material application point. This ‘as-applied’ methodology provides a better representation about the distribution of material over a field using a spinner spreader which can be used to assess uniform and variable-rate application accuracy. ‘As-applied’ surfaces also presents a basis for economic and agronomic analysis when used in combination with other spatial data collected on fields. However, validation and accuracy of the ‘as-applied’ model is required. Therefore, the objectives of this investigation are

1. To validate the “as-applied” methodology developed by Fulton et al. (2000).
2. To assess the effect of offset distances and receiver latency on model accuracy.

Methodology

Two fields located in Shelby County, Kentucky were selected to apply Murate of potash. Figures 1 and 2 show the two fields and have been labeled A and B. Field A was 9.2 hectares (22.8 ac) while field B was 34.2 hectares (84.7 ac). The fields were subdivided into 0.4 ha (1 ac) square management zones with soil samples collected at the center of each zone. Fields A and B contained 25 and 89 management zones, respectively. The area of some individual management zones was more or less than 0.4 ha due to irregular field shapes. The collected soil samples were sent to the University of Kentucky's Regulatory Services for analysis. The Melich III extraction process was used for soil analysis. These results were used to determine the requisite amount of murate of potash to apply to each zone using the University of Kentucky's Lime and Fertilizer Recommendations publication (AGR-1, 2000). The software package SSToolbox (SST, 1999) was used to generate the application prescription maps presented in figures 1 and 2. Table 1 provides summary statistics for both prescription maps.

Validation of the ‘as-applied’ model consisted of randomly placing collection pans within each field. A total of 29 and 58 pans were placed in fields A and B, respectively to collect applied murate of potash. Fulton et al. (2001) describes collection pan size and pans were constructed in accordance with ASAE standard S341.2 (ASAE Standard, 1997). The prescription maps were uploaded into the control system of the VRT applicator. Fulton et al. (2001) provides a description of the variable-rate disc spinner spreader along with the control system. The applicator operator was instructed to apply as normal, ignoring pans during application. Figures 1 and 2 show the application transverse for each field generated by AgView. Foam marker was used for guidance. The operator did not fully covered management zones requiring zero application since deemed unnecessary to transverse.

Subsequent to application, test pan locations were recorded using a DGPS receiver (figure 1 and 2). The murate of potash collected in each pan was bagged, identified and then weighed. The ratio of sample mass to pan collection area provided the actual application rate.

Each fields' verification points were imported into ArcView 3.2 along with the application field transverse shapefiles. The Avenue script was run to generate the spread pattern polygon layer using the application files and the spread patterns discussed above (Fulton et al., 2000). Figure 3 shows the resulting distribution pattern polygons and application rate assigned to each polygon for field A. The next step consisted of spearing through the polygon layers for each field using the verification points' locations to calculate the predicted application rates. The predicted results were then compared to the actual application rates. The model also generated an ‘as-applied’ surface for each field. Figures 4 and 5 present the 'as-applied' surfaces for fields A and B superimposed on their respective prescription maps. The generated ‘as-applied’ surfaces are a 10 m by 10 m grid of points. Table 1 contains summary statistics for the verification points (actual and predicted) and ‘as-applied’ surfaces.

Finally, the effect of different offsets on the validity of the model was investigated. The Avenue script moves all the points in the ‘as-applied’ field transverse file by shifting them back in time based on each point’s current position and heading.

Results and Discussion

The results of this investigation are focused on the validation or predictability of the ‘as-applied’ model and not on comparing the ‘as-applied’ surfaces to the application prescriptions. Figures 4 and 5 indicate that variability exists from the desired application prescriptions. The legends for each layer are the same; therefore, the appearance of a point illustrates deviation from the desired application. The same variability is also present for the overlay of these two layers for

field B. Both 'as-applied' surfaces indicate a lot of deviation from the prescription maps for variable-rate application of murate of potash.

Various offset distances were used in the model to determine the influence on the 'as-applied' surfaces. The user inputted offset distance serves to compensate for GPS latency and antenna position in relation to application. Several different offsets were used with the application rates predicted for each of the verification points. The predicted application rates for each offset were then compared to the actual application data. An offset of 5.5 m (18 ft) produced the highest R-value of 0.67 for field A, with 5.8 m (19 ft) and 6.1 m (20 ft) offsets resulting in R-values of 0.66 (figure 6). However, the highest correlation (0.76) was found for an offset of 4.9 m (16 ft) for field B (figure 7). A polynomial regression line was fit to each of the offset data. The polynomial fit for field A (figure 6) indicates that the appropriate offset exists somewhere around 5.5 m. However, a poor polynomial fit for field B (figure 7) was found which suggested an offset around the polynomial's local maximum of 3.5 m (11.5 ft). Therefore, an offset of 5.5 m for field A and 4.9 m for field B were chosen as the appropriate offsets for analyzing the validity of the model. These were the highest correlation coefficients computed for each field. Thus, these offsets were inputted into the model for predicting the application rate at each verification point.

The reason for the different offsets for each field is not understood. It would be expected that the same offset distance would generate the highest correlation coefficient for predicting the application rates on each field. However, only a 0.6 m (2 ft) variation existed which is not that much of a difference. The same spreader setup was used on each field, but the potential difference could be that application occurred on different days with different loads of murate of potash. Possibly, a density and particle size difference existed with the different loads. However, this explanation for the different offsets needs further investigation and could just be inherent to the variability that exist when spreading granular materials with spinners spreaders.

The actual and predicted application rates for the verification points were plotted versus one another to determine the performance of the ‘as-applied’ model (figures 8 and 9). As can be observed, the model did not perform well in predicting the application rates for the 29 verification points. A linear regression was fitted to the data (figures 8 and 9) confirming this observation. A coefficient of determination (R^2) equal to 0.45 (field A) and 0.58 (field B) along with slopes around 0.66 were computed indicating the poor linear relationship. The model performed better on field B but the performance was lower than expected for both fields.

Additional comparisons were made between the actual application rates and prescription maps. Table 2 provides the R^2 values for these comparisons. The interesting point is the low R^2 values of 0.16 and 0.21 for field A and B, respectively. These low values are much lower than those discussed above when comparing the actual and predicted application rates. This indicates poor performance by the variable-rate spinner spreader for these fields. The VRT spinner spreader was unable to apply what the prescription required. There could exist many explanations for the high deviation from the required amount such as VRT hardware and software latency, operator error or spreader setup and calibration issues. This issue needs to be examined further to understand why the actual and desired application differed so much. The low correlation observed also shows that the 'as-applied' model estimates actual application rates compared to the prescription map. Application errors exist for both uniform and variable-rate application and assuming that the application prescription map somewhat depicts actual application is misleading. Further, these low correlations demonstrate that using prescription maps for analysis purposes is not appropriate. While the 'as-applied' surfaces do not accurately predict actual application rates, they appear to be a better representation for actual application rather than the prescription map. Modifications to the current model could improve its accuracy to represent actual distribution of granular materials over a field.

These results indicate the need for improvements to the model. They also illustrate how tough it maybe to model application of granular materials using a spinner spreader. Additionally, these results suggest potential errors with variable-rate application of granular products. Just as Fulton et al. (2001) discovered, variability exists with uniform application of granular products so the addition of VRT to spinner spreaders potentially could increase application errors. Therefore, modifications to the model are in the works to improve its performance for generating accurate ‘as-applied’ surfaces.

Several modifications to the model are recognized and may explain some of the variability between the actual and predicted application rates. First is the modeling of curvilinear travel. The current model uses only rectangular polygons for representing the area of application. Using rectangular polygons does not accurately represent the application area when traveling in a curvilinear path. This results in open areas on the spread pattern polygon layer (figure 3) which tends to over- and under-apply application rates to particular polygons due to an incorrect area definition. Another modification consists of using a simulation technique to account for spread pattern variability observed by Fulton et al. (2001). Figure 10 shows the mean high (168.1 kg/ha) transverse distribution pattern used by the model. The existence of such variation in this distribution pattern advocates using a simulation technique to account for distribution variation. Finally, modeling the distribution pattern two-dimensionally rather than one-dimensional. Fulton et al. (2001) performed static tests indicating that a 2-D distribution pattern might be necessary to correctly modeling the application of granular materials from a spinner spreader. The addition of these modifications should improve the low correlation found in this investigation.

Conclusion

The results of this investigation determined that an ‘as-applied’ surface was unable to accurately model the actual field application of murate of potash. Low R^2 values (0.45 and 0.58) were calculated between the predicted and actual application rates for each field. Improvements are needed to the current model for it to better represent actual distribution of granular products from a spinner spreader. However, a poor correlation existed (R^2 values of 0.16 and 0.21) when comparing the actual application rates and prescription maps. The 'as-applied' model better predicted the actual application of murate of potash rather than the prescription maps. These results showed undesirable performance of the VRT applicator but also demonstrated the lack of prescription maps to depict actual application of products. Ultimately, this could be indicative of escalated application errors when moving from fixed to variable-rate application.

Offsets of 5.5 m (field A) and 4.9 m (field B) were determined to produce the best results for generating the ‘as-applied’ surfaces. The reason for this offset difference is unknown. The effect of offset on the 'as-applied' model needs further investigation to determine if different offsets are needed on a field by field basis. However, the difference (0.6 m) for these results is small when considering the application area of granular products.

Several modifications to the ‘as-applied’ model are warranted to increase the low correlation found. The first is to model curvilinear travel with annular or trapezoidal polygons. Secondly, incorporating a simulation technique to account for distribution pattern variability is needed. Finally, the last modification consists of possibly modeling the distribution pattern as two-dimensional rather the one-dimensional.

Future work consists of making the above modifications to the ‘as-applied’ model. In return, the actual verification data used in this investigation will be rerun to assess potential improvements to predicting actual application rates. Additional validation data is required for ensuring the efficacy of the model. Different field sizes and shapes will be selected to perform these tests.

Once a good ‘as-applied’ model is established, other spinner spreaders and granular products (phosphate and agricultural lime) will be investigated.

The important aspect of this ‘as-applied' research is to develop a post-processing method for taking field application files and converting them into 'as-applied' surfaces. The 'as-applied' surface will better represent the distribution of products under uniform and variable-rate application. Many times the assumption is made that material is applied as depicted by the application prescription map. However, this study demonstrates prescription maps do not potentially represent actual field application. The use of prescription maps for economic and agronomical analysis may generate misleading results. It is imperative to determine whether variable-rate application with spinner spreaders is advantageous when considering the sources of application error. Therefore, 'as-applied' surfaces provide a technique for assessing variable-rate application.

Acknowledgements

The authors would like to thank Worth and Dee Ellis Farms for allowing us the opportunity to perform this research. Thanks are also extended to all the technical support from the shop crew for their assistance and dedicated work.

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Table 1. Statistics for the various layers.

Prescription Map		**Field A**	**Field B**
Field Area		9.2 ha	34.3 ha
Number of Zones		25	89
Min Application Rate		0.0 kg/ha	0.0 kg/ha
Max Application Rate		145.3 kg/ha	211.5 kg/ha
Verification Points			
Number of Points		29	58
Predicted	Min Application Rate	0.0 kg/ha	0.0 kg/ha
	Max Application Rate	141.1 kg/ha	233.5 kg/ha
Actual	Min Application Rate	0.0 kg/ha	0.0 kg/ha
	Max Application Rate	133.3 kg/ha	292.6 kg/ha
As-Applied Surface			
Number of Points		909	3420
Min Application Rate		0.0 kg/ha	0.0 kg/ha
Max Application Rate		218.7 kg/ha	803.5 kg/ha

Table 2. Comparison of various layers.

	R^2	
Comparison	**Field A**	**Field B**
Actual versus Predicted	0.45	0.58
Actual versus Prescription Map	0.16	0.21

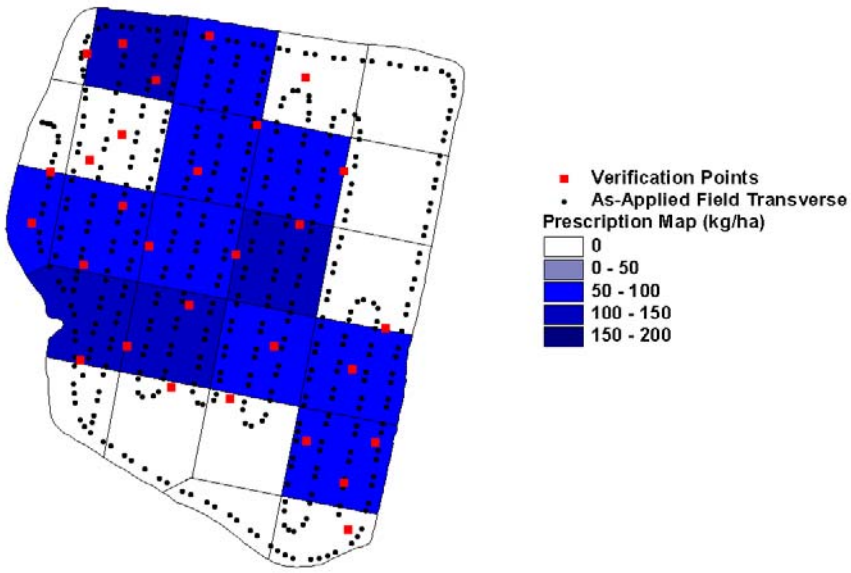

Figure 1. Plot of the application prescription map, as-applied field transverse, and verification points for field A.

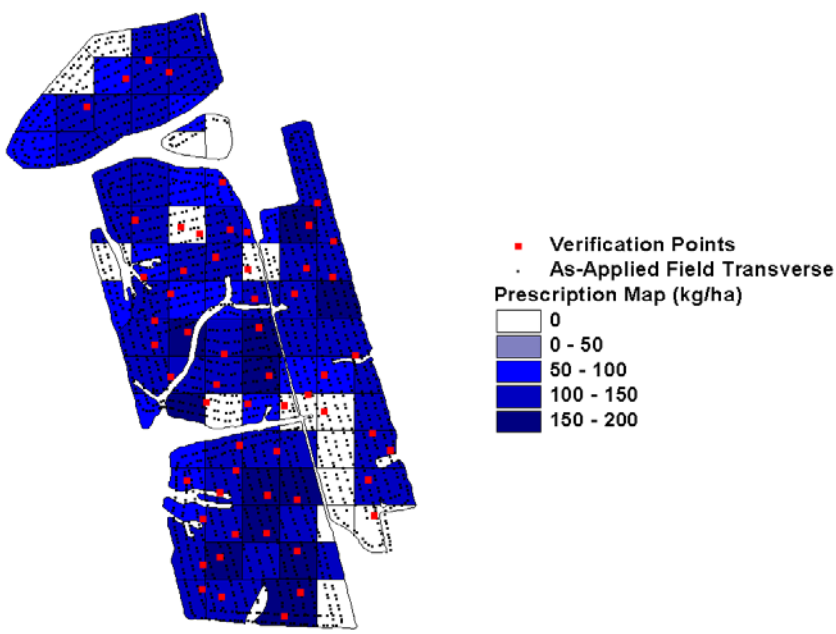

Figure 2. The application prescription map with the as-applied field transverse and verification points for field B.

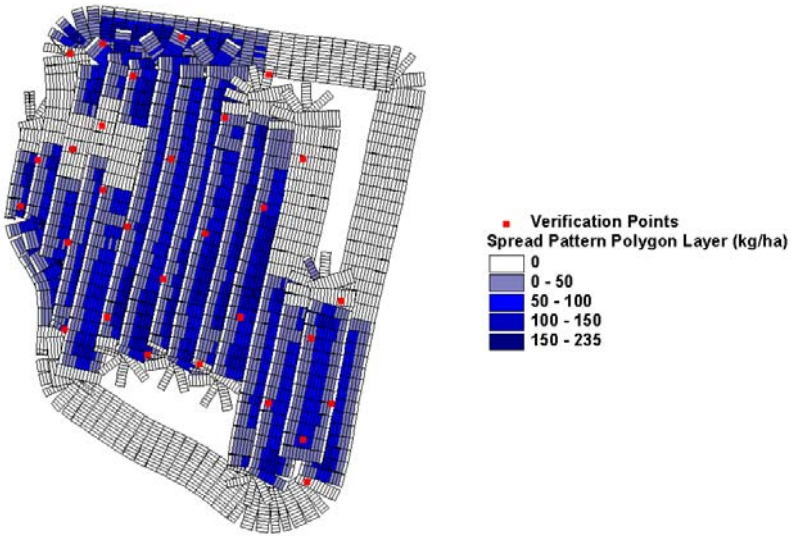

Figure 3. Resulting distribution pattern polygon layer for field A.

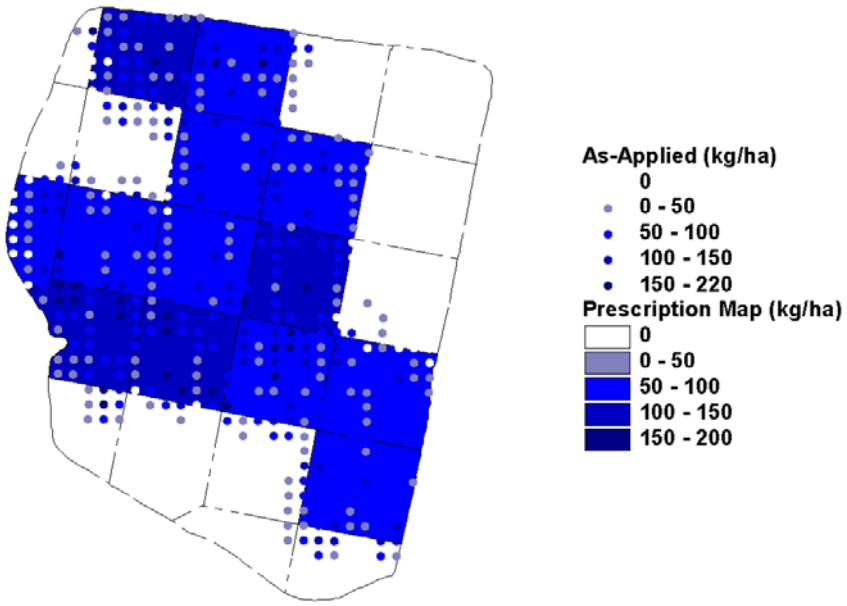

Figure 4. The 'as-applied' surface superimposed on the application prescription for field A.

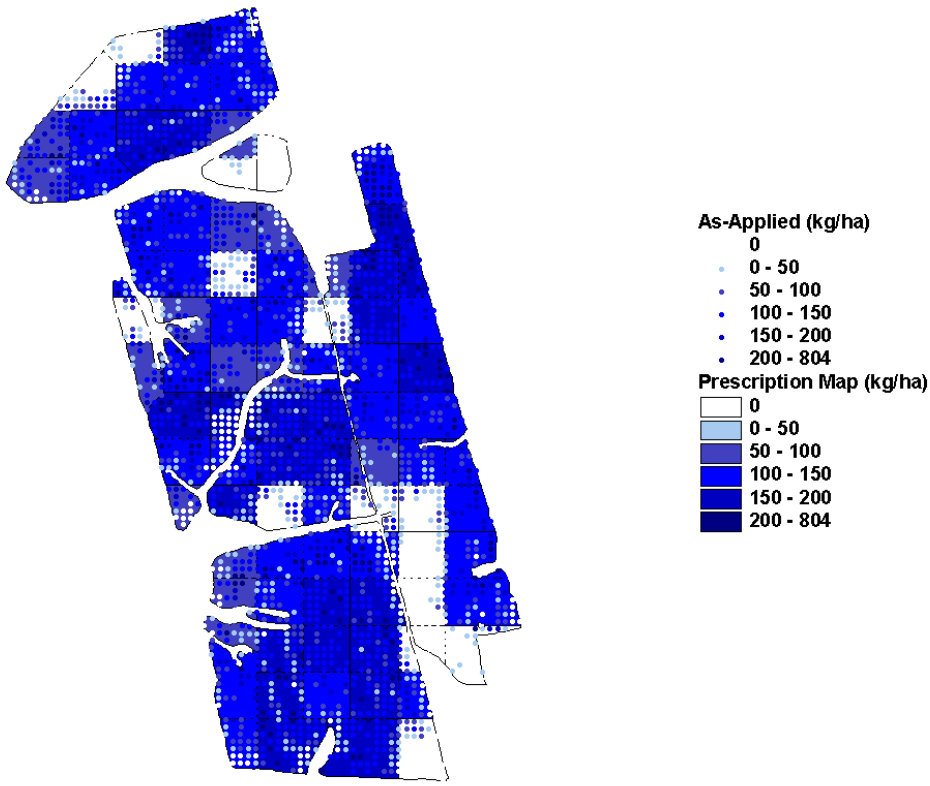

Figure 5. The 'as-applied' surface superimposed on the application prescription for field B.

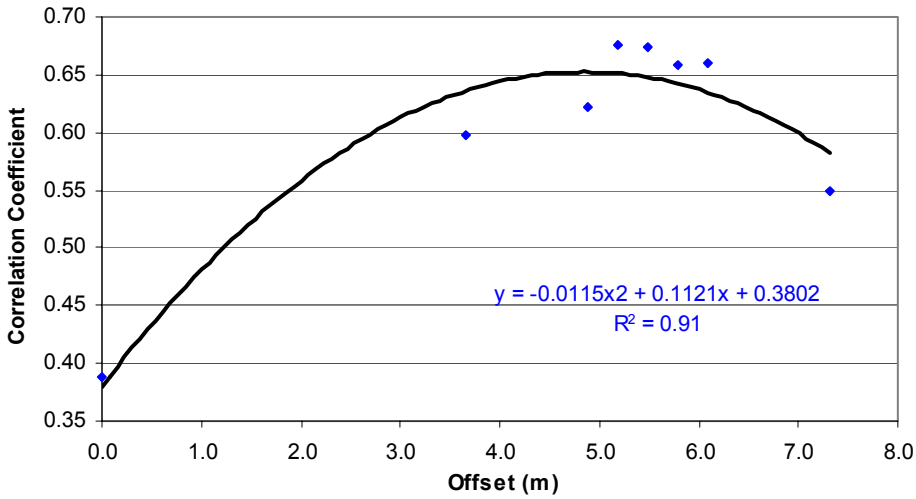

Figure 6. Plot of the correlation coefficient versus offset distance for field A.

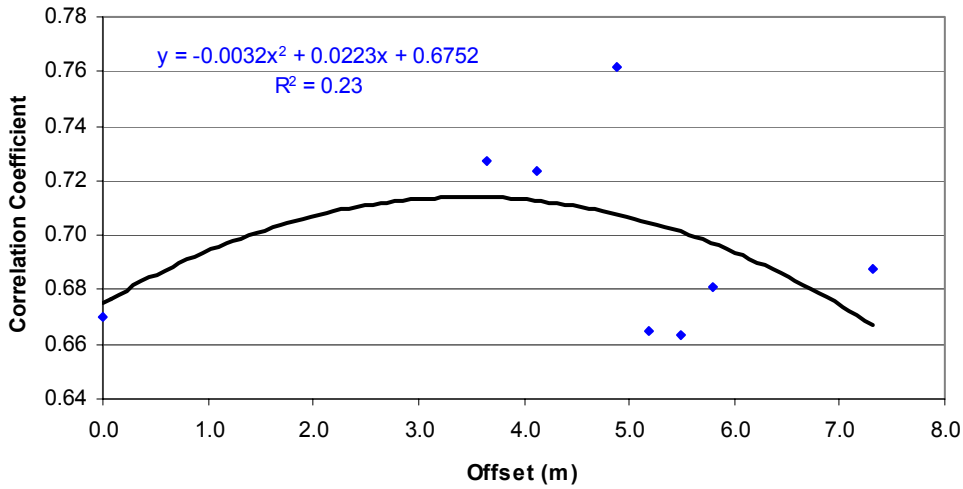

Figure 7. Plot of the correlation coefficient versus offset distance for field B.

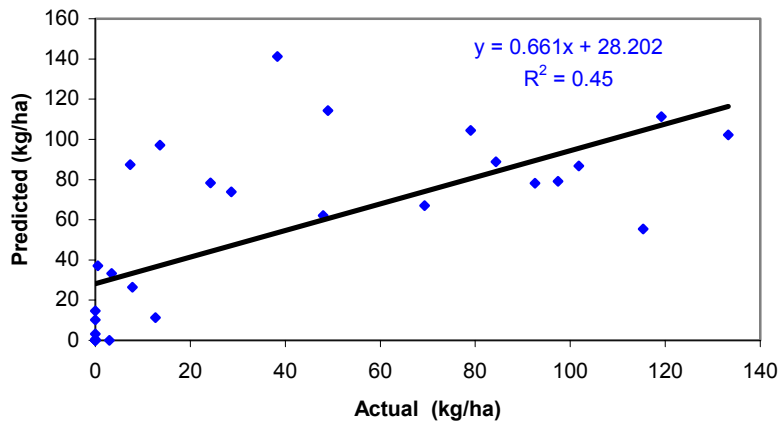

Figure 8. Plot of predicted versus actual application rates for field A.

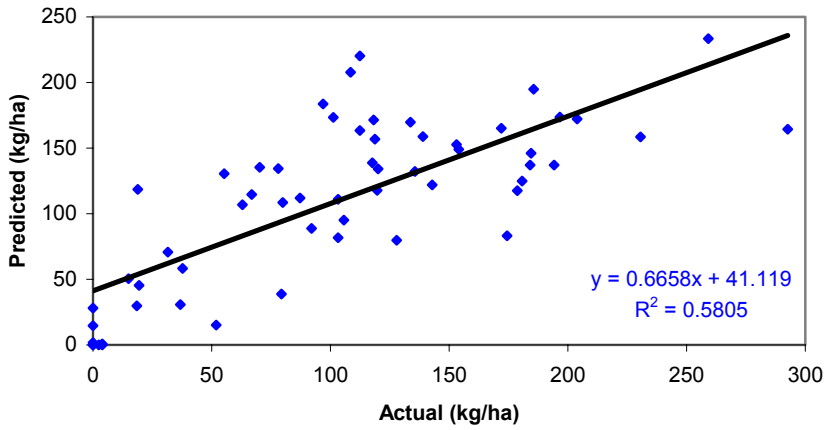

Figure 9. Plot of predicted versus actual application rates for field B.

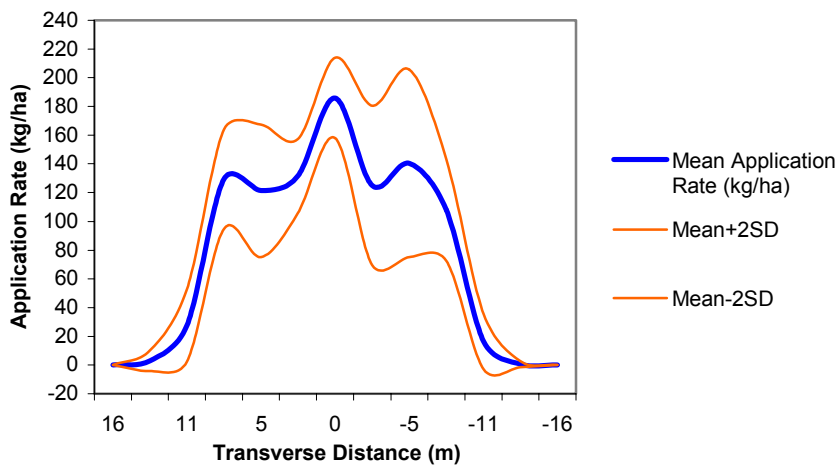

Figure 10. Mean low (168.1 kg/ha) distribution pattern.