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Development of GIS-Based Chemical Distribution Maps from Sprayer Performance Data

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Abstract. *Pesticide application is an essential practice on farms in Kentucky where glyphosate resistant crops and no-till farming strategies are becoming more popular. Off-rate pesticide application errors are the result of incorrect concentrations applied to an area of the field and may result from velocity changes along the spray boom while the sprayer is turning, pressure changes across the width of the spray boom, and changes in effective boom height due to undulating terrain. In an attempt to estimate potential errors resulting from sprayer turning movements, a method was developed to compare the differences in application areas between control sections across the spray boom. The area covered by the two center boom control section positions was considered the "target rate" and the difference in these areas and the remaining control sections were compared to determine errors in coverage areas. The results of the analysis conducted on three irregular shaped fields (containing impassable grassed waterways) indicated that a substantial portion of the fields (14-24%) could have been applied well above or below the target application rate +/- 10%. The* *implication of this is that producers may be under and over applying chemicals to fields where excessive amounts of turning are required during application.*

Keywords. precision spraying, precision agriculture, no-till farming, variable-rate application.

Introduction

Kentucky, being an agricultural state, has approximately 6 M acres of land dedicated to crop production (UKCA, 2007). To counteract the potential for negative environmental impacts and rising input costs of crop production practices, many grain producers in Kentucky have adopted no-till farming practices. No-till soybean production has increased significantly in Kentucky over the past several years. In 1998 for instance, of the approximately 880,000 acres of soybeans planted in Kentucky, 452,000 or 51% were planted using no-till practices (CTIC, 2004). In 2004, no-till soybean acres increased to 930,000 or 70% of the total 1.3 million acres planted (CTIC, 2004). Without the development of pre- and post-emergence herbicides to control weed competition, no-till farming would be impractical. Another major factor affecting increased no-till crop production has been the development of genetically modified (GMO) corn (Zea mays) and soybeans (Glycine max). Glyphosate resistant (GR) corn and soybeans are common GMO crops on Kentucky farms. The use of GR soybeans has increased significantly over the past several years in the U.S., a trend that is expected to continue into the near future (Bonny, 2008). Producers in Kentucky typically apply a burn-down herbicide (such as glyphosate) prior to planting. When weed competition begins to reach an undesirable level, producers then follow up with a second glyphosate application. This magnifies pesticide application errors as GR crops planted using no-till practices are typically sprayed two or more times, doubling the effects of application errors.

Many farmers are utilizing larger equipment to reduce labor costs and time spent in the field. Producers have turned to faster sprayers with boom widths in excess of 30 m. Pesticide application errors, especially those associated with larger equipment; result in a costly and time consuming problem for agricultural producers. Off-target pesticide application errors as defined by Luck et al. (2009) include: skipped-application, multiple-application, or unintentional-application. Previous research indicated that off-target errors may contribute an additional 15-17% of the field area resulting from multiple-application in irregular shaped fields (Luck et al., 2009). Off-rate pesticide application errors are the result of incorrect pesticide rates applied to an area of the field. Off-rate errors may result from pressure changes across the width of the spray boom which affects nozzle patterns and droplet size distributions. Undulating terrain may cause the effective boom height to vary in turn affecting nozzle pattern overlap. Velocity differences across the spray boom also occur while the sprayer is turning which can affect the pesticide rate applied to an area of the field. Problems associated with off-rate application errors are exacerbated with larger equipment as increased boom widths result in greater velocity, pressure, and height differences across the spray boom. Although the effects of increased glyphosate application on soybean yields have not been quantified, studies have shown that over application of glyphosate to GR soybeans can result in reduced plant growth (Reddy et al., 2000; Reddy and Zablotowicz, 2003). Controlling these application errors deserves more attention as pesticides have become one of the most significant costs, being greater than seed cost for the production of soybeans in Kentucky from 1999 to 2003 (Gibson, 2004). Aside from the reduced pesticide efficiency from these errors, eliminating the potential negative effects of off-rate errors on crop growth poses a new challenge to producers.

Although research concerning site specific application of herbicides and pesticides has been conducted (Faechner et al., 2002; Wilkerson et al., 2004), the effects of sprayer turning movements on pesticide application have not yet received much attention. Analyzing spatial data could provide a method for evaluating where and how much pesticide is applied based on machine geometry and geographic position data. Geographic Information System (GIS) is an excellent tool for analyzing spatial data in agricultural environments. Modeling the distribution of dry fertilizer from spreading vehicles has received some attention as researchers have utilized

GIS to verify application distributions in the field (Fulton et al., 2003). Recently, a computer analysis method for evaluating field application variation of dry fertilizer distribution was developed using GIS (Lawrence and Yule, 2007). These results suggest that GIS could be a useful tool for analyzing field data to determine the effects of the sprayer path on off-rate application errors.

The main goal of this study was to estimate potential off-rate pesticide application errors resulting from sprayer turning movements during field application. The specific objectives of this study were: i) to calculate the coverage areas for individual sprayer boom control sections based on the sprayer geometry, geographic coordinates, and the recorded "on" or "off" status of each control section, ii) to estimate the errors in coverage areas for control section positions across the spray boom resulting from velocity variations while turning, and iii) to generate maps indicating the locations of off-rate application errors. Collecting and analyzing actual field data and presenting these findings to producers will be integral in the adoption of new technologies and management strategies.

Materials and Methods

This study was conducted with data collected from a cooperating producer located in Shelby County, Kentucky. This central Kentucky farm consists of numerous irregularly shaped fields, many of which contain grassed waterways that cannot be traversed while spraying. The three study fields selected for this analysis were referred to as Fields 1, 2, and 3 (Fig. 1) and contained 50.7, 34.9, and 15.6 ha, respectively. The study fields were considered "irregularly" shaped in that they all contained unnavigable grassed waterways within the field boundaries. This type of field shape typically creates a situation where a large portion of the field must be sprayed while turning which is believed to contribute to off-rate application errors.

Figure 1. Boundaries of study fields (not to scale): Field 1 (left), Field 2 (center), and Field 3 (right).

A map-based automatic boom section control console (ZYNX X15, KEE Technologies, Sioux Falls, South Dakota) was added to a self-propelled sprayer (RoGator 664, Ag Chem/AGCO, Duluth, Georgia) with 24.76 m boom comprised of 48 nozzles spaced at 51 cm. Along with the control console, the automatic boom section control system used a 30 channel electronic control unit (ECU) (Spray ECU 30S, KEE Technologies, Sioux Falls, South Dakota) connected to individual control sections. The control console and ECU provided 30 separate control channels which activated solenoid valves (TeeJet Nozzle Valves, Capstan Ag Systems, Inc., Topeka, Kansas) connected to each spray nozzle body. As each control section passed over a previously sprayed area, the control system closed the solenoid valves for that respective section, eliminating excess spray overlap. To utilize all 30 control section channels, the six nozzles at the left and right boom ends were controlled with individual channels, while the remaining 36 interior boom nozzles were paired. Effective control section widths were 51 cm for individual nozzles and 102 cm for paired nozzles which provided a relatively high boom control resolution. The control console not only provided map-based automatic boom section control, but also served as a data acquisition system.

As the sprayer covered each field, the control console recorded the geographic coordinates (latitude and longitude in WGS 1984 decimal degrees format) at one second intervals (1 Hz) provided by the DGPS receiver (Ag132, Trimble Navigation, Ltd., Sunnyvale, California). The DGPS receiver used a nearby U.S. Coast Guard radio beacon for differential correction which provided sub-meter accuracy. At each coordinate, the control console also recorded the status ("on" = 1 or "off" = 0) of the 30 ECU control channels. The control console recorded coordinates along with each control section status when a minimum of one control channel was "on" and continued recording this data until all channels were "off."

The General Algebraic Modeling System Data Exchange (GDX) files from the control console were downloaded in ASCII format into ArcMap (ArcGIS v9.3, ESRI, Redlands, California). The ArcMap software was used to transform the coordinates into a Universal Transverse Mercator (UTM) projection from the WGS 1984 format. This allowed the subsequent analyses to be conducted on Cartesian coordinates as opposed to the original latitude-longitude coordinate system. The UTM coordinate pairs were imported into MS Excel® and matched with the corresponding control section status recorded for all 30 ECU channels. The first step in the analysis was to mathematically model boom position with respect to the DGPS receiver on the sprayer using the recorded GPS coordinates (Fig. 2).

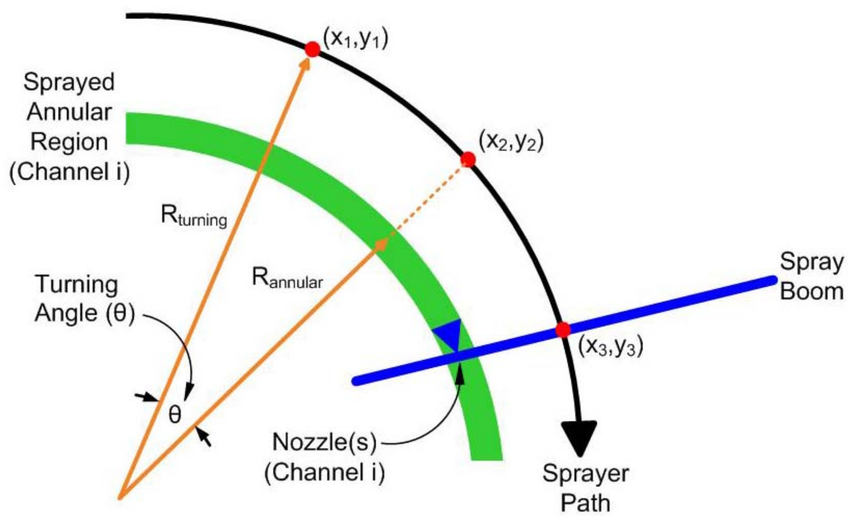

Figure 2. Geometry used to determine treated area for each control section corresponding to the "on" state of the ECU control channel.

A curve was fit between three successive GPS points (x, y coordinates of points 1 to 3) to determine the turning radius of the sprayer ($R_{turning}$). The example in Fig. 2 shows the sprayer turning right. In this case, the corrected turning radius ($R_{annular}$) for control sections on the right side of the boom was less than $R_{turning}$, while control sections on the left side had a greater $R_{annular}$ than $R_{turning}$. The distance from each individual control section was added or subtracted (depending on the turning direction) to $R_{turning}$ to determine $R_{annular}$. For paired nozzles, the center point between the two nozzles was used for determining $R_{annular}$ for that control section. The coordinates for each control section channel were calculated at each GPS coordinate using this information along with the sprayer heading angle. The total coverage area for each control section was calculated by multiplying $R_{annular}$ by the turning angle (from point 1 to 2 shown in fig. 2), the control section coverage width (51 cm for a single nozzles and 102 cm for paired nozzles), and the status of each control section channel ("on" = 1 or "off" = 0). For all control section channels with an "on" status, the result was a coverage area for that control section between consecutive GPS coordinates. Since control section channels in the "off" position have a value of zero, no area was calculated for that control section.

To calculate off-rate errors across the spray boom while turning, the assumption was made that the two center control section channels on the spray boom (in this case the center left and center right are actually paired nozzles) were applying a "target rate" over the calculated coverage area. This assumption was made for two reasons. First, since the sprayer was calibrated by the producer for target rate application at a certain velocity, it was assumed that the center left and center right control sections would deviate least from that velocity during turning. Second, the purpose of this study was to develop a simple method to identify potential off-rate errors resulting from turning movements even though additional errors may result from the operator changing sprayer speed during field application. The areas calculated for the center left and center right control sections were therefore treated as target rate coverage areas between two consecutive GPS coordinates. At each set of GPS coordinates, the target rate coverage area for the center left control section was divided by the coverage area for the remaining control sections along the left side of the spray boom to determine the application error. The same process was carried out for the remaining control sections along the spray boom. The coordinates of each control section were plotted using the ArcMap software with its respective percentage of the target rate for all data records in the three study fields. Between successive GPS coordinates, the coverage area for each control section was known along with the application error. Coverage areas of the field applied above or below the target rate (from 10% to 200%) were summed. This information was plotted to show the trend in application errors as a function of the percent deviation from the target application rate for each field.

Results and Discussion

The line segments perpendicular to the direction of travel in Fig. 3 represent the spray boom at every GPS coordinate recorded for Field 1. All control section positions (30 channels) make up these lines which represent the errors in area applied between two consecutive GPS coordinates. The sprayer path coordinates were converted to a line to better represent the sprayer path and direction traveled through Field 1. Fig. 3 shows areas of Field 1 that were over-applied (in red) and under-applied (in blue) when compared to the target rate +/- 10%. Errors are observable as coverage areas increase along the outside of the turns and decrease along the inside of the turns. The errors appeared to be most concentrated in areas where the operator was forced to make sharp turns to spray around grassed waterways that were impassable. Although the shape of Field 1 was irregular due to grassed waterways, it is possible to see that the errors were greatly reduced in locations where the sprayer was able to travel in straight lines with parallel passes.

Fig. 4 displays a summary of the areas of Fields 1 which were applied above or below the target application rate. The percentage of field coverage is based on the total area covered by the control sections when they were in the "on" position. Field 1 received a total coverage area of 57.3 ha. The coverage area for Field 1 was slightly higher than the actual field area which was believed to be attributed to boom overlap which was built into the system to ensure complete coverage. The trend of the data in Fig. 4 is intuitive in that the coverage area decreases when observing errors above the percentage of target rate and increases when observing errors below the percentage of target rate. Fig. 4 indicates that 8.8% of the field was sprayed at a rate below 90% of the target rate, and approximately 6.1% of the field was sprayed at a rate above 110% of the target rate. Approximately 15% of Field 1 was applied outside the target rate plus or minus 10%.

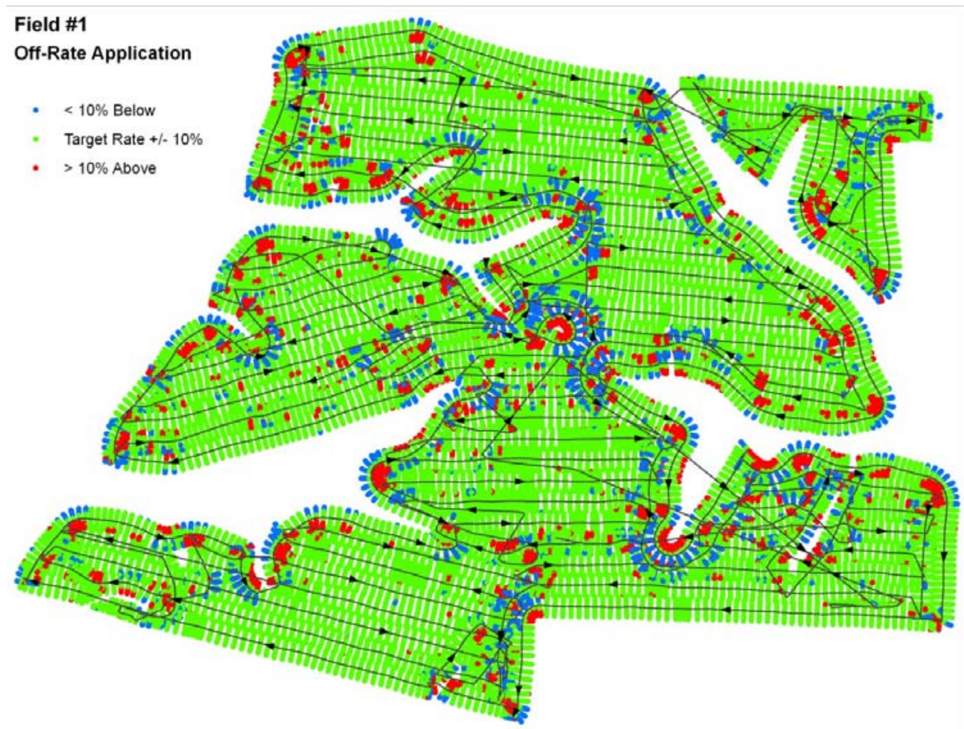

Figure 3. Areas of Field 1 deviating by more than 10% (above or below) of the target application rate.

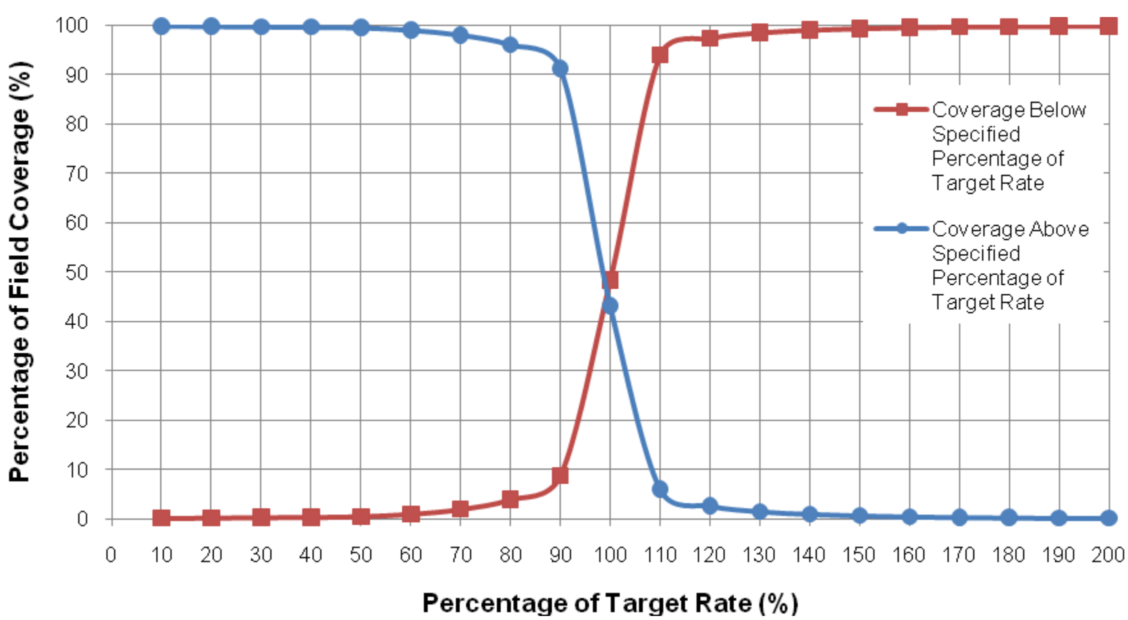

Figure 4. Percent of Field 1 area covered within specified percentage of target application rate.

Fig. 5 shows areas of Field 2 that were over-applied (in red) and under-applied (in blue) when compared to the target rate +/- 10%. Due to the unique shape of Field 2, it appeared that a majority of it was sprayed while turning. Fig. 5 shows that errors again appeared to be most concentrated in areas around grassed waterways; however, because of the boundary of Field 2, it was necessary to spray a significant portion of the field while turning. Based on the sprayer path generated from the data file, the operator was only able to spray a small portion of the field with straight, parallel passes. Fig. 6 displays a summary of the areas of Field 2 which were applied above or below the target application rate. The percentage of field coverage is based on the total area of Field 2 covered by the control sections when they were in the "on" position, or 35.0 ha.

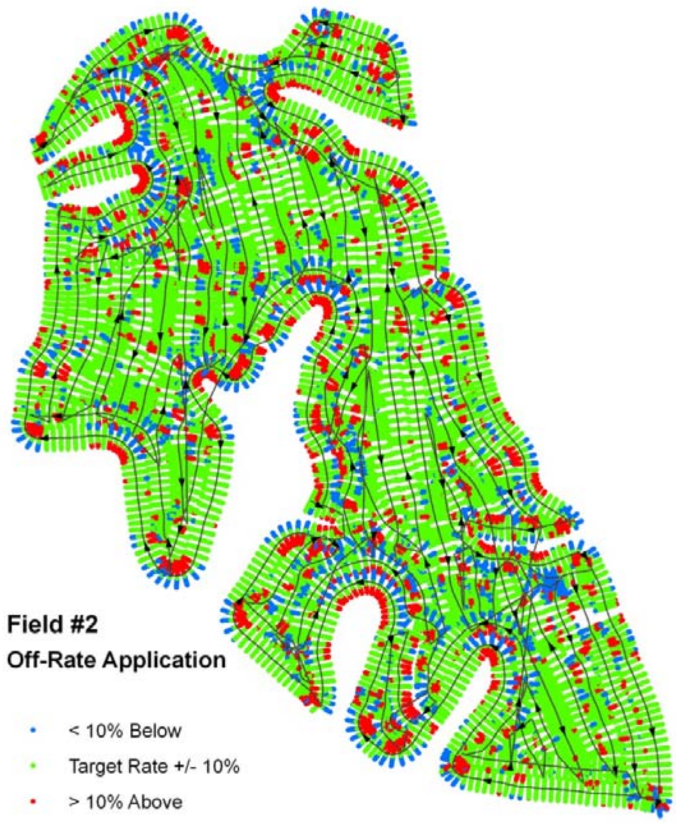

Figure 5. Areas of Field 2 deviating by more than 10% (above or below) of the target application rate.

The trend of the data in Fig. 6 is similar to that noted in Fig. 4. The coverage area decreases when observing errors above the percentage of target rate and increases when observing errors below the percentage of target rate. The off-rate errors were worse in Field 2 as indicated by Fig. 6 where 13.6% of the field was sprayed below 90% of the target rate and 10.3% of the field was sprayed above 110% of the target rate. The result was more severe for Field 2 being that approximately 24% of the field was covered outside of target rate plus or minus 10%.

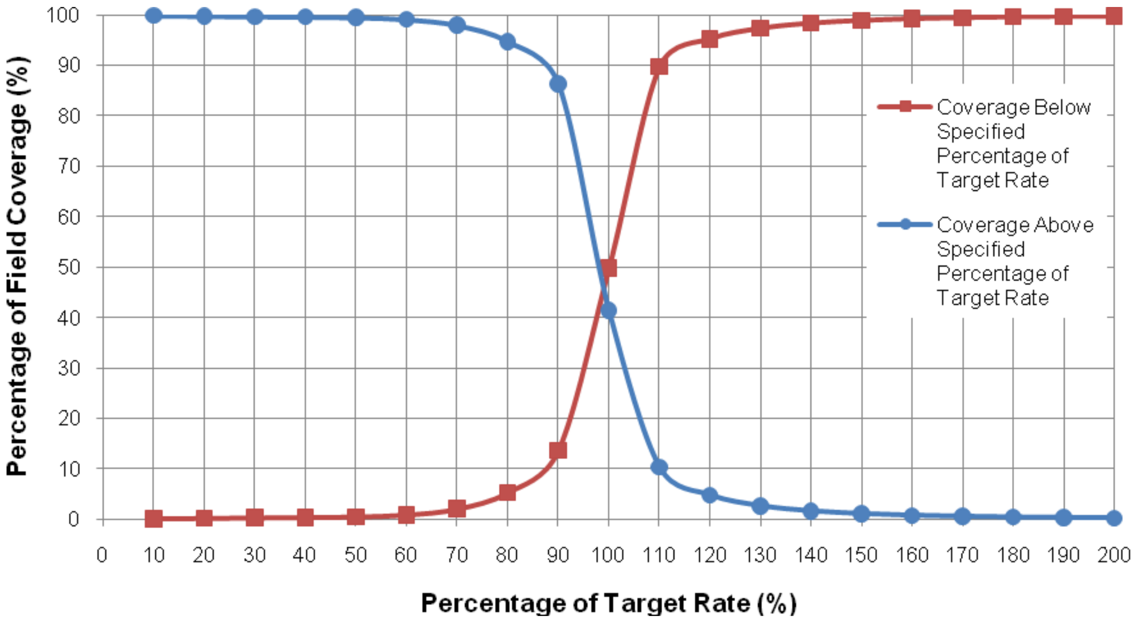

Figure 6. Percent of Field 2 area covered within specified percentage of target application rate.

Fig. 7 shows areas of Field 3 that were over-applied (in red) and under-applied (in blue) when compared to the target rate +/-10%. Fig. 7 shows that errors were most concentrated around grassed waterways along with some portions around the field boundary itself. Based on the sprayer path generated from the data file, it appears the operator was able to spray more of Field 3 using straight, parallel passes which may have contributed to the reduction of off-rate errors compared to Fields 1 and 2. Fig. 8 displays a summary of the areas of Field 3 which were applied above or below the target application rate. The percentage of field coverage is based on the total area of Field 3 covered by control sections when they were “on” or 15.7 ha.

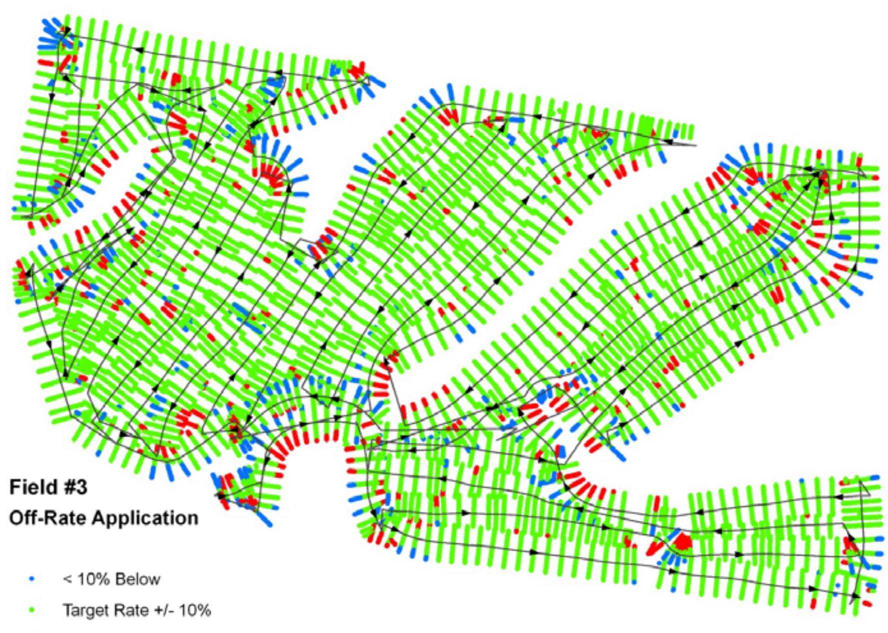

Figure 7. Areas of Field 3 deviating by more than 10% (above or below) of the target application rate.

The trend of the data in Fig. 8 is again similar to that noted in Figs. 4 and 6. The off-rate errors were less severe in Field 3 than in Field 2 as indicated in Fig. 8 where 8.2% of the field was sprayed below 90% of the target rate and 5.8% of the field was sprayed above 110% of the target rate. The result for Field 3 was that approximately 14% of the field was covered outside of target rate plus or minus 10%.

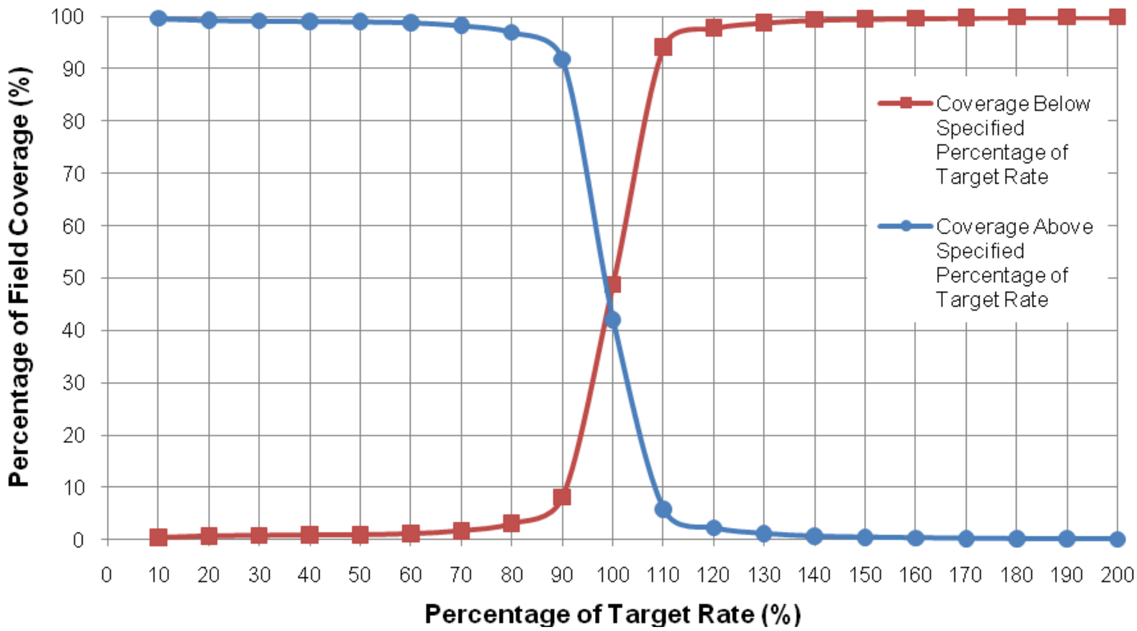

Figure 8. Percent of Field 3 area covered within specified percentage of target application rate.

Table 1 summarizes the information from Figs. 3, 5, and 7, and contains the area and percentage of each field covered at less than 10% below target rate and greater than 10% above target rate. The analysis indicated that Field 2 exhibited the most significant accumulation of off-rate areas of all three fields when observing areas less than 10% below and greater than 10% above the target rate. The data contained in Table 1 indicate that substantial portions of the study fields received application rates that exceeded plus or minus 10% above and below the target rate.

Table 1. Summary of off-rate application errors exceeding +/- 10% of the target rate.

	Field 1		Field 2		Field 3	
Application rate	Area (ha)	Percent (%)	Area (ha)	Percent (%)	Area (ha)	Percent (%)
< 90% Target rate	5.05	8.8	4.78	13.6	1.28	8.2
Target rate +/- 10%	48.74	85.1	26.65	76.1	13.5	86.0
> 110% Target rate	3.50	6.1	3.61	10.3	0.91	5.8
Total field area	57.29		35.04		15.69	

Although the effects of off-rate application are relatively unknown in terms of crop yield, over application of herbicides such as glyphosate have been shown to reduce plant growth in soybeans (Reddy et al., 2000; Reddy and Zablotowicz, 2003). However, wasted materials from over application of pesticides can be easily quantified as they are proportional to the areas covered during application. Similarly, pesticides applied below the target rate usually does not result in crop damage; however, yield loss may occur due to weed competition when application rates fall below prescribed levels, which has been shown in corn (Cox et al., 2006) and soybeans (Shafagh-Kolvanagh et al., 2008).

This study presents what might be considered a worst-case scenario off-rate application errors resulting from sprayer turning movements. The reason for this is that the study fields were highly irregular in shape as they contained multiple unnavigable grassed waterways within the field boundaries. Spraying these fields was accomplished with a substantial number of turns while navigating around grassed waterways and field boundaries, which also contained many curves. Off-rate errors would have been reduced if the producer could have utilized more parallel passes with less turning to complete the fields. While this may have led to higher off-rate errors, small, irregular shaped fields are very common to central Kentucky. Also not considered in this study would have been additional errors resulting from spray boom overlap. The sprayer was equipped with map-based automatic boom section control; however, the control console setup ensured total coverage of the field, which would have resulted in additional overlapped areas. More specifically, areas where point rows may have been encountered or overlaps made during parallel field passes. This study focused solely on application errors resulting from turning movements. Had errors resulting from spraying previously treated areas, total application errors in the study fields may have been higher

Although beyond the scope of this introductory study into the subject off-rate errors, collecting more field data for an analysis of this type may reveal more about how field shape and size can affect these types of errors. Another factor that could have an effect on off-rate errors is the amount of turning required to spray a field. An analysis of changes in sprayer heading angles or turning radius may provide indicators on the magnitude of application errors due to turning movements. Based on this type of information, producers could potentially utilize tools such as path planning to reduce or eliminate these errors.

Conclusions

Turning movements affected estimated off-rate application errors based on the maps generated from the sprayer paths for Fields 1, 2, and 3. Areas where off-rate errors seemed to be the worst included spraying around grassed waterways and field boundaries while turning. In cases where the sprayer operator could cover the field with straight, parallel passes, errors seemed to be well within 10% of the target rate. By observing the cumulative areas where application errors were occurring, it was possible to identify how much of the field was being sprayed within a specified percentage of the target rate. This analysis estimated that approximately 15%, 24%, and 14% of Fields 1, 2, and 3, respectively, was applied outside the target rate plus or minus 10%. This information indicates that producers may be over-applying chemicals to fields where excessive amounts of turning are required at application. Off-rate errors will continue to be a problem until variable-rate application techniques are developed and successfully implemented for precision spraying.

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