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Generating 'As-Applied' Pesticide Distribution Maps from a Self-Propelled Agricultural Sprayer Based on Nozzle Pressure Data

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Abstract. *The application of pre-emergence, post-emergence, and burn-down herbicides (i.e., glyphosate) continues to increase as producers attempt to reduce both negative environmental impacts from tillage and input costs from labor, machinery and materials. The use of precision agriculture technologies such as automatic boom section control allows producers to reduce off-target application when applying herbicides. While automatic boom section control provides benefits, pressure differences across the spray boom resulting from boom section actuation can lead to off-rate application errors. Off-rate errors may also result from spray rate controller compensation for* *ground speed changes and velocity variation across the spray boom during turning movements. This project focuses on quantifying accumulated pesticide application for three fields located in Central Kentucky. GPS coordinates were collected along with nozzle pressure data (at 13 nozzle locations) at one second intervals as the sprayer traversed the study fields. The method previously developed by Luck et al. (2009) was used to calculate coverage areas for the control sections along the spray boom in MS Excel. Nozzle discharge flow rates were estimated from the nozzle pressure data (based on manufacturer calibration information) which was then incorporated into MS Excel to determine the rate of pesticide applied to the fields. Results indicate the majority of each field received application rates at or below the target rate. Only 34.2%, 33.9%, and 22.9% of Fields 1, 2, and 4, respectively, received application rates at the target rate +/- 10% during these post-emergence treatments. The goal of this project was develop distribution maps to better understand the effects of boom section control and turning movements on herbicide accumulation.*

Keywords. precision agriculture, pesticides, variable rate application, spray deposition.

Introduction

The adoption of precision agriculture technologies, including map-based automatic section control, has increased considerably in the past few years, particularly for use on agricultural boom sprayers. The goal of these systems when deployed on sprayers is to reduce pesticide over-application by automatically turning off boom sections as they pass over previously sprayed areas or outside of the field boundary. In central Kentucky, a study was conducted to determine the potential reduction in coverage areas for irregularly shaped fields using an automatic section control system at a resolution of approximately 1.0 m (Luck et al., 2010a). Figure 1 shows the status of the boom control sections where points in green indicate sections turned on, while points in black indicate sections that have been turned off. Areas in black are indicative of locations where savings occur to the producer. For this case, coverage areas were reduced by an average of 16% (Luck et al., 2010a). In another study, an automatic boom section control system with a control resolution of approximately 6.0 m reduced coverage areas by an average of 6.2% compared to manual control for 21 fields of various shapes and sizes (Luck et al., 2010b).

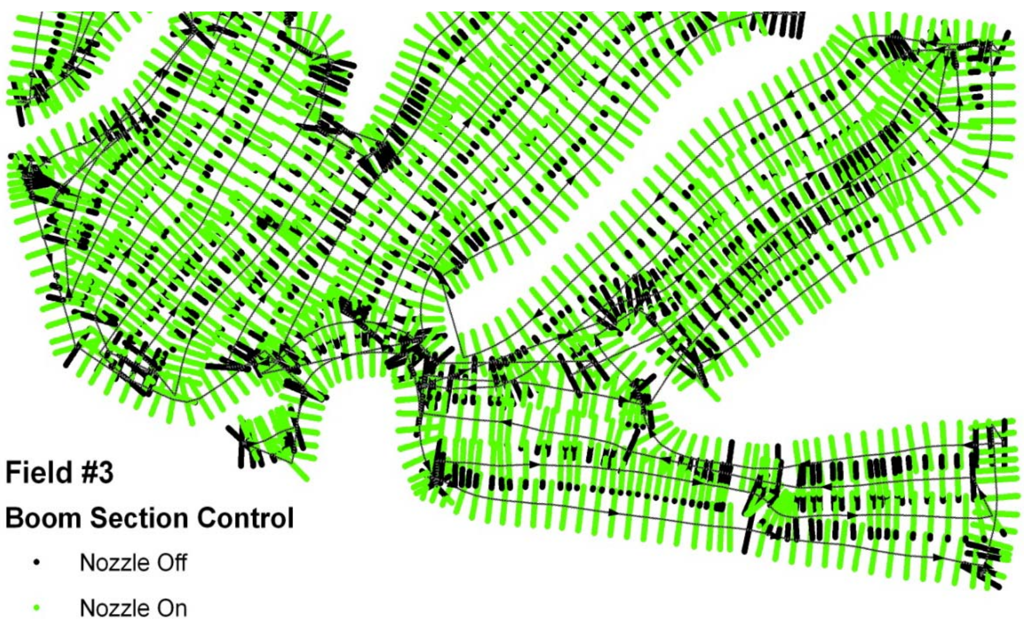

Figure 1. Nozzle control section status from central Kentucky field applied using map-based automatic boom section control system (control section “on” in green, “off” in black).

A recent analysis of sprayer paths found that a sprayer with a 24.8 m boom could under or over apply pesticides to substantial portions of a field when turning (Luck et al., 2009). This study revealed that in one 35 ha field, 23% of the field area may have received greater or less than +/- 10% of the target application rate because of boom velocity variations. While off-rate errors resulting from sprayer turning movements have been estimated, a method for quantifying application rate errors would be helpful in understanding where these errors occur. The goal of this study was to generate pesticide application rate maps by merging nozzle pressure, nozzle control section status, and sprayer GPS coordinates using GIS. The resulting maps would indicate the field application rates with combined errors resulting from pressure variations across the spray boom and sprayer turning movements. These data would provide more information regarding the extent to which boom section actuation, sprayer velocity changes, and boom velocity variations affect application uniformity.

Materials and Methods

This study was conducted with data collected on three fields from a cooperating producer's farm located in central Kentucky. This central Kentucky farm consists of numerous irregularly shaped fields, many of which contain unnavigable grassed waterways. The producer utilized a map-based automatic boom section control system which eliminated application to areas outside the field boundary and within grassed waterways. Each field received a post-emergence treatment of glyphosate to an established soybean crop during the summer of 2009.

The cooperating producer applied glyphosate using a self-propelled sprayer (RoGator 1074, Ag Chem/AGCO, Duluth, Georgia) with 30.48 m wet boom with 60 nozzles spaced at 51 cm. The automatic boom section control system consisted of a console (ZYNX X20, KEE Technologies, Sioux Falls, South Dakota) and a 30 channel electronic control unit (ECU) (Spray ECU 30S, KEE Technologies, Sioux Falls, South Dakota). The control console and ECU provided 30 control channels for actuating solenoid valves (TeeJet Nozzle Valves, Capstan Ag Systems, Inc., Topeka, Kansas) connected to spray nozzle bodies. Spray nozzles were mapped to individual channels as follows: nozzles 1 through 6 at the left and nozzles 55 through 60 at the right boom ends were controlled via individual channels; nozzles 7 through 12 and 49 through 54 were controlled in pairs; the remaining 36 interior boom nozzles were controlled in groups of three (Fig. 2). Effective control section widths were 51 cm for individual nozzles, 102 cm for paired nozzles, and 152 cm for nozzles in groups of three. The control console also served as the data acquisition system by recording the geographic coordinates (NAD 1983 UTM format) at up to 5 Hz as boom control sections were actuated. Reference coordinates were generated using an RTK GPS receiver (StarFire II, Deere & Company, Moline, Illinois). At each coordinate pair, the control console also recorded a time stamp along with the control channel states ("on" = 1 or "off" = 0) as a 30 bit binary number. The control console recorded these data when any channel state was set to "on" and stopped recording data when all channels were set to "off."

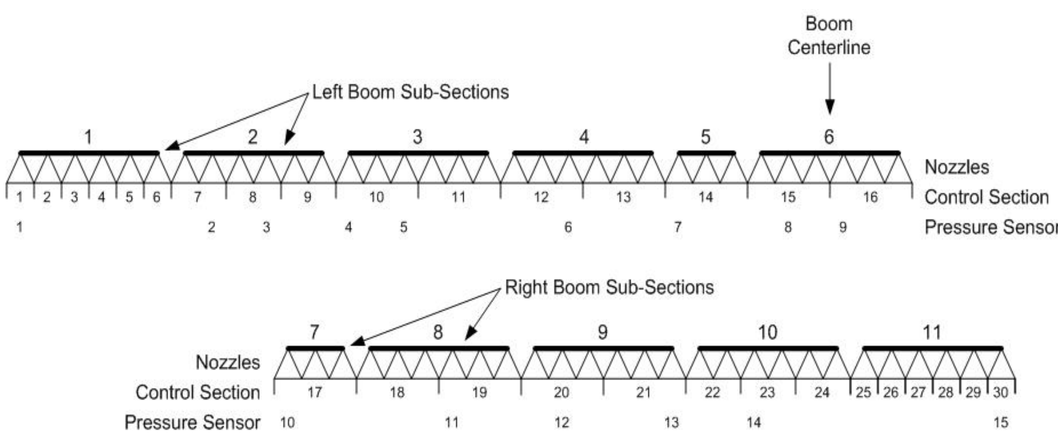

Figure 2. Diagram identifying sprayer wet boom sub-sections (1 to 11), automatic control section nozzle groupings (1 to 30), and pressure sensor locations (1 to 15).

Pressure transducers (Model 1502 B81 EZ 100 PSI G, PCB Piezotronics Inc., Depew, NY, USA) were installed at fifteen nozzles across the spray boom with at least one transducer in each boom sub-section (Fig. 2). The transducers were connected to a data acquisition (DAQ) system for A/D conversion (9221 Analog Module, National Instruments, Austin, Texas, USA) to record the voltage output at a rate of 10 Hz for each pressure transducer. An additional DGPS receiver (Ag132, Trimble Navigation, Ltd., Sunnyvale, California) was used to read the GGA string using a serial module (9870 Serial Input Module, National Instruments, Austin, Texas, USA). The pressure transducer voltage values (14.5 mV/kPa) were converted into pressure readings (kPa) and these data were written to a text (.txt) file using a program written in LabVIEW along with DGPS coordinates and time stamps logged at one second intervals. The DAQ system was connected to an external PC (separate of the control console) to carry out these procedures.

The automatic boom control section actuation states and RTK GPS coordinates from the control console were synchronized with the pressure data recorded by the DAQ system by matching the time stamps from both data sets. The combined data set contained entries that included a GPS time stamp, RTK GPS coordinates, control section status (30 digit binary number), and the pressure values from all transducers. Coverage areas for each control section were calculated between successive GPS coordinates based on methods outlined by Luck et al. (2010a) for individual, paired, and three-nozzle groupings. It was necessary to estimate nozzle flow rates based on the pressure transducer data; therefore, calibration curves were developed from data provided by the manufacturer for the nozzle tips used (TeeJet TT11005, Spraying Systems Co., Wheaton, Illinois). Nozzle flow rate (L s^{-1}) was plotted versus the nozzle pressure (kPa) from manufacturer data (Spraying Systems Co., 2010) are shown in Fig. 3. The calibration curve equation (zero intercept) from these data was used to estimate the nozzle flow rate from the pressure transducer readings for the nearest pressure sensor in each control section. Typically, these calibration curves are plotted without an intercept. However, since many pressure values below 100 kPa were recorded, the decision was made to estimate pressure in this region by forcing the curve through the origin slightly reducing the R^2 value.

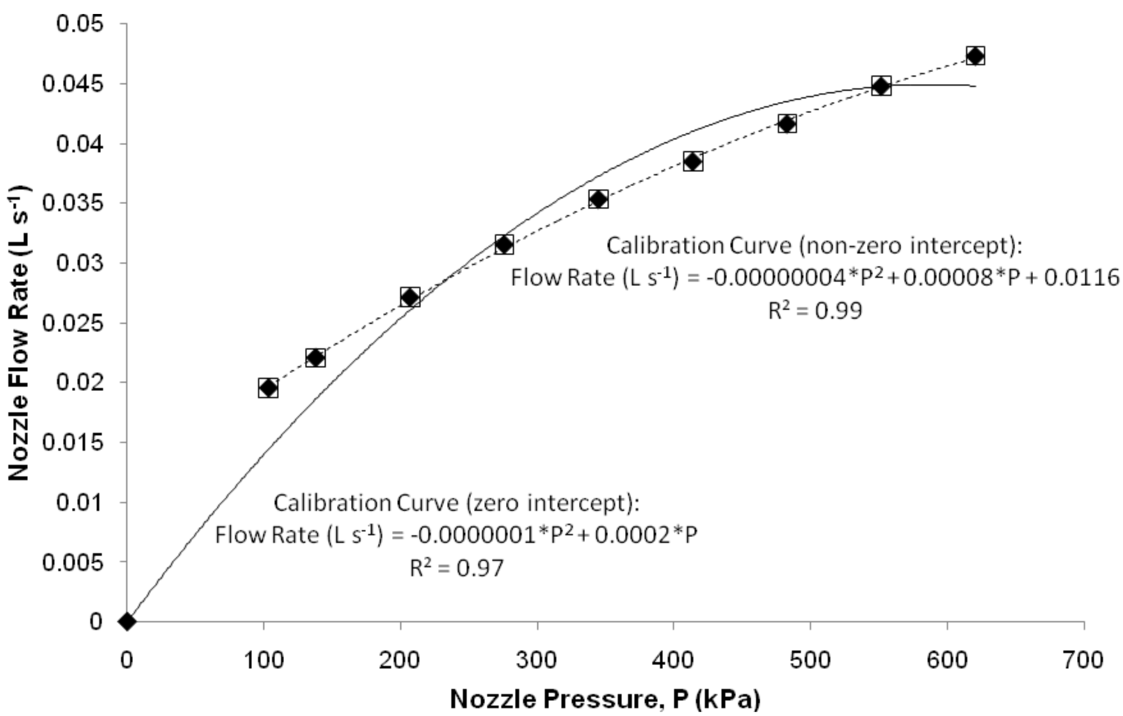

Figure 3. Calibration curve for estimating nozzle flow rates from nozzle pressure sensor data with typical calibration curve (non-zero intercept) from manufacturer data.

Application rates were then calculated between successive GPS coordinates by multiplying the estimated nozzle flow rate (L s^{-1}) with the time between coordinates (s) and dividing this value by the control section coverage area (ha). Resulting application rates were recorded (L ha^{-1}) and plotted with the corresponding control section GPS coordinates in ArcMap using methods outlined by Luck et al. (2009). Application rates were compared to the target rate (93.5 L ha^{-1}) to determine areas of the field applied outside this range +/- 10%.

Results and Discussion

Estimated application rates were divided into five ranges to classify the variation in pesticides applied across each of the study fields. Table 1 summarizes the area of each field along with the percentage of each field that received applications within the specified rate ranges. An important point to note is that the target application rate set by the producers was 93.5 L ha^{-1}, and the range of 84.2 to 102.9 L ha^{-1} represents this target rate +/- 10%. Figure 4 illustrates the distribution of the application rate versus the percent of the field area receiving those rates. From this information it is possible to see that the majority of the field appears to receive treatments at or below the target rate set by the producer.

Table 1. Area and percentage of study fields receiving specified ranges of application rates.

	Field 1		Field 2		Field 4	
Application Rate	Area	Percent	Area	Percent	Area	Percent
(L ha^{-1})	ha	%	ha	%	ha	%
< 37.4	0.402	16.9	2.243	11.2	1.304	19.5
37.4 – 84.2	0.846	35.7	5.819	29.2	2.639	39.4
84.2 – 102.9	0.811	34.2	6.769	33.9	1.535	22.9
102.9 – 149.7	0.297	12.5	4.863	24.4	1.148	17.1
> 149.7	0.016	0.7	0.251	1.3	0.074	1.1

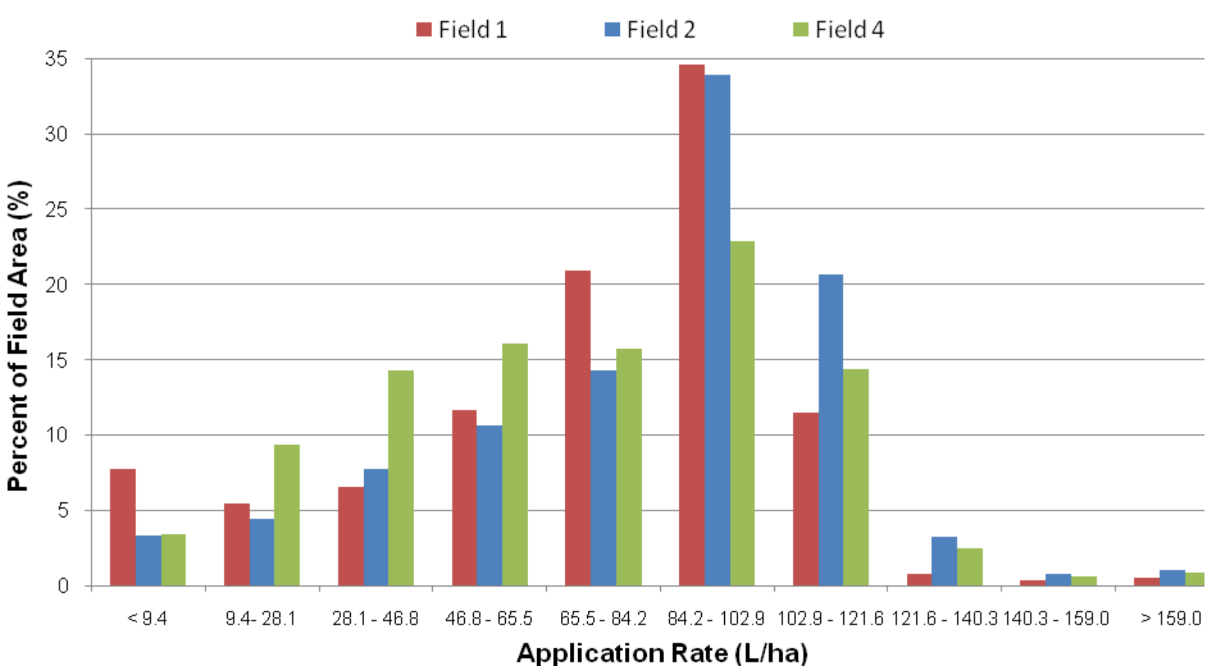

Figure 4. Distribution of percent of field area versus selected ranges of estimated application rates.

The variation in estimated application rates can be seen in Fig. 5 for Fields 1 and 2 where these data were plotted using the previously calculated GPS coordinates. The same application rate ranges outlined in Table 1 were used to plot the data in Fig. 5. The data shown in Fig. 5 highlight the locations where the estimated pesticide application rates may have been affected by factors such as boom section actuation, ground speed changes, and sprayer turning movements.

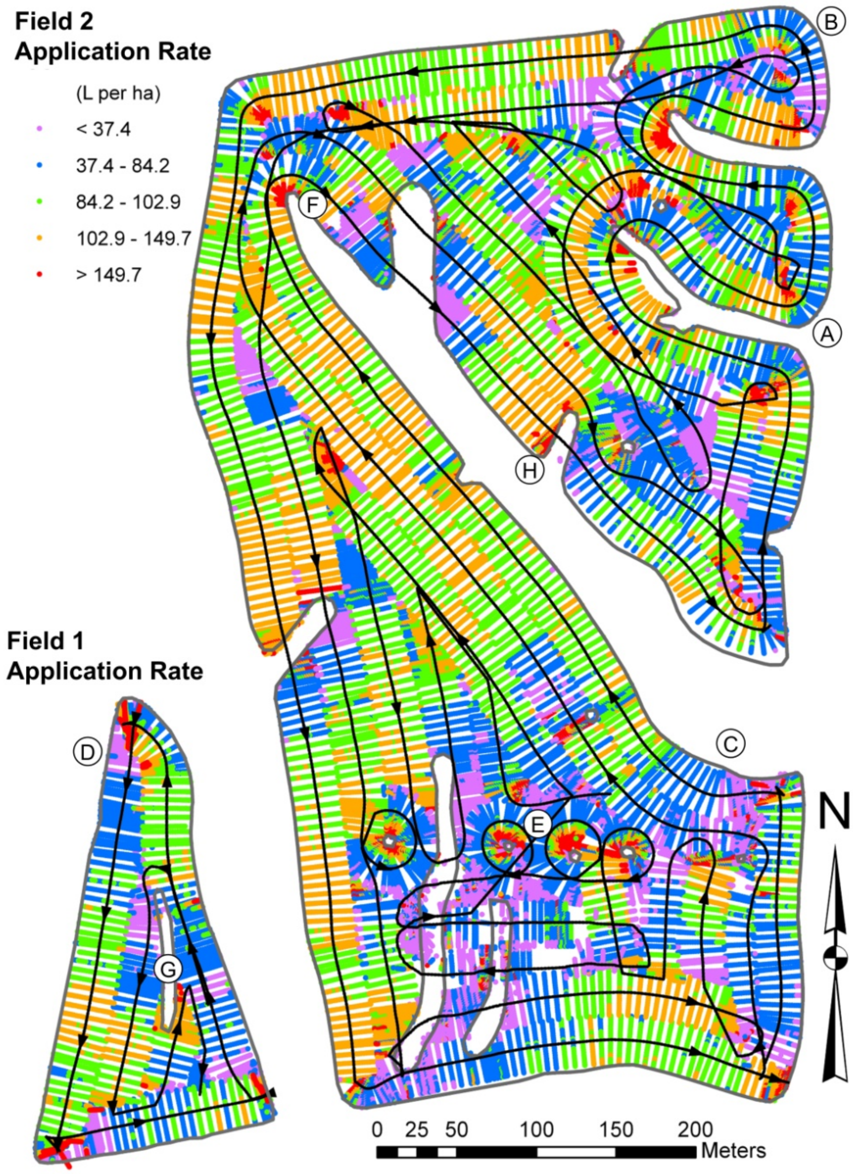

Figure 5. Application rates reflecting boom pressure variation and sprayer turning movements for Fields 1 (left) and 2 (right) with sprayer path and direction.

It is interesting to note that pesticides were applied to the highest percentage of Field 2 (33.9%) at the target rate (+/-) 10%. The bulk of Fields 1 and 4 (35.7% and 39.4%, respectively) received application rates below the target rate (37.4 to 84.2 L ha^{-1}). It is clear from the data in Table 1 and Figure 4 that for all fields, pesticides were typically applied at or below target rates (84.2 to 102.9 L ha^{-1}) as opposed to higher rates. This might be attributed to application while turning as larger portions of the field are covered by the outside of the boom when compared to areas covered by the inside portion of the boom (Fig. 5 locations A and B). Another factor that may have resulted in lower application rates to greater portions of the field may be control section actuation. Sharda et al. (2008) noted that as some control sections were turned on, boom pressure dropped and there was a delay before the nozzle pressures returned to the necessary operating pressure. This may have occurred because of the control system used on the sprayer. Locations are seen in Fig. 5 (C and D) where the boom is turned off, then sections are turned back on and the sprayer travels for some distance before the application rate reaches the target rate. In terms of increased application rates, as the sprayer turns, the interior portion of the boom covers much less area. As noted by Luck et al. (2009), these areas may have received higher application rates compared to the center or exterior sections of the boom. Locations where this occurs may best be seen in Fig. 5 (E and F) where the sprayer travels around utility poles and a grassed waterway. Boom pressure variations can also lead to increased application rates as control sections are turned off and pressure spikes occur in the remaining sections. This was noticed by Sharda et al. (2008) where the control system was able to stabilize pressure in the remaining sections after some period of time. Examples of this can be seen in Fig. 5 (locations G and H) where some control sections are turned off as the sprayer passed into previously treated areas and into a grassed waterway. Another potential cause for application rate variations is controller response to ground speed changes. The sprayer control system was configured to maintain the desired application rate regardless of ground speed variation. While the final effect on application rate is largely unknown, this likely caused some variation depicted in Fig. 5.

Conclusions

The results from this study indicate that substantial portions of the study fields may have received application rates that were much higher and lower than the target application rate due to boom pressure variations and sprayer turning movements. Only 34.2%, 33.9%, and 22.9% of Fields 1, 2, and 4, respectively received application rates at the target rate +/- 10% during these post-emergence treatments. It appeared that the majority of the fields were covered at application rates below 90% of the target rate which likely occurred from turning movements and control system delays in adjusting boom flow to the required level as assessed by measuring nozzle pressures along the boom. Although beyond the scope of this study, this information raises important questions regarding the efficacy of the pesticide in areas where boom pressure variation or turning movements occur. If pesticides applied at lower rates are not effective, then crop yield loss from weed competition could occur. Alternatively, the potential for crop damage due to high pesticide application rates may also be a concern to producers.

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