GENERATING HERBICIDE EFFECTIVE APPLICATION RATE MAPS BASED ON GPS POSITION, NOZZLE PRESSURE, AND BOOM SECTION ACTUATION DATA COLLECTED FROM SPRAYER CONTROL SYSTEMS

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ABSTRACT

The application of pre- and post-emergence 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 has provided benefits, pressure differences across the spray boom resulting from boom section actuation as well as changes in ground speed can lead to off-rate application errors. This investigation focused on quantifying accumulated herbicide application rates for three fields located in central Kentucky. GPS coordinates were collected along with nozzle pressure data (at 15 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 ArcMap. Nozzle flow rates were estimated from the nozzle pressure data which was then incorporated into ArcMap to determine the field application rates. The goal of this project was to develop distribution maps to better understand the effects of nozzle pressure variation from boom section control on herbicide application accuracy. Results indicated that only 22.9 to 34.2% of the fields investigated received application rates at the target rate (93.5 L ha^{-1}) +/- 10%.

Keywords: precision agriculture, pesticide application, spray application uniformity, precision spraying, no-till farming

INTRODUCTION

The adoption of precision agriculture technologies including map-based automatic section control has increased considerably in the past few years. In terms of pesticide application, this technology has been adapted to agricultural boom sprayers. The goal of these systems is to reduce pesticide over-application by automatically turning off boom sections as they pass over previously sprayed areas. 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).

While automatic boom section control systems have obvious benefits, a new problem has been identified with these systems. As sections are turned off, pressure spikes occur in boom sections that remain on (Sharda et al., 2008), resulting in higher nozzle discharge rates, and potentially increased application rates. Additionally, when those sections are turned back on, there is a delay before the system pressure returns to the normal operating range, resulting in decreased nozzle flow rates.

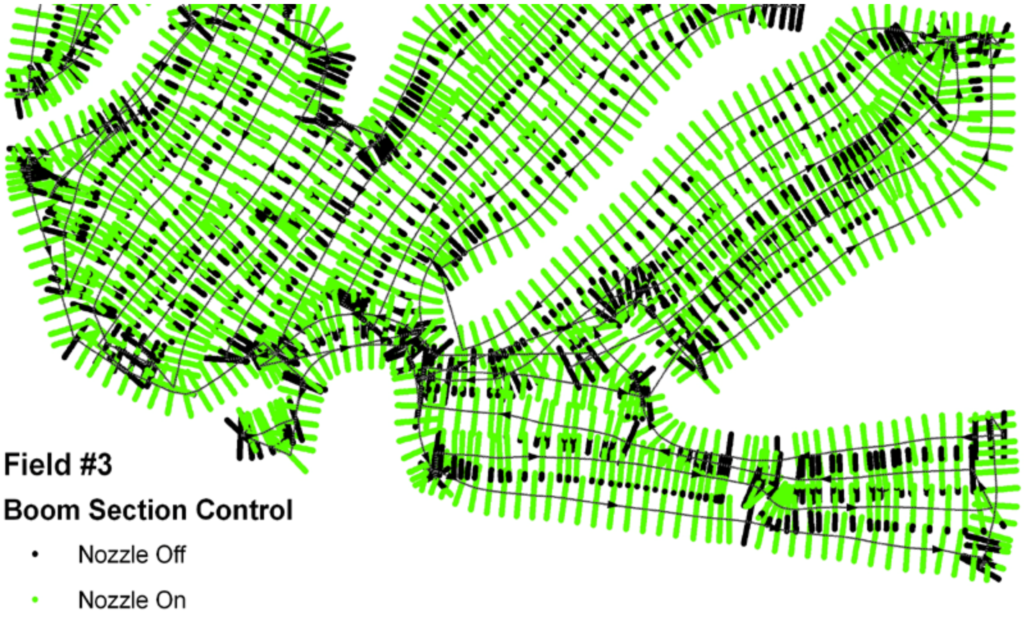

Fig. 1. Nozzle control section status from central Kentucky field applied using map-based automatic boom section control system (control section “on” in green, “off” in black).

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. 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 can affect spray 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. This system eliminated application to areas outside the field boundary and within grassed waterways. Each field received a post-emergence treatment of glyphosate to soybeans 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.”

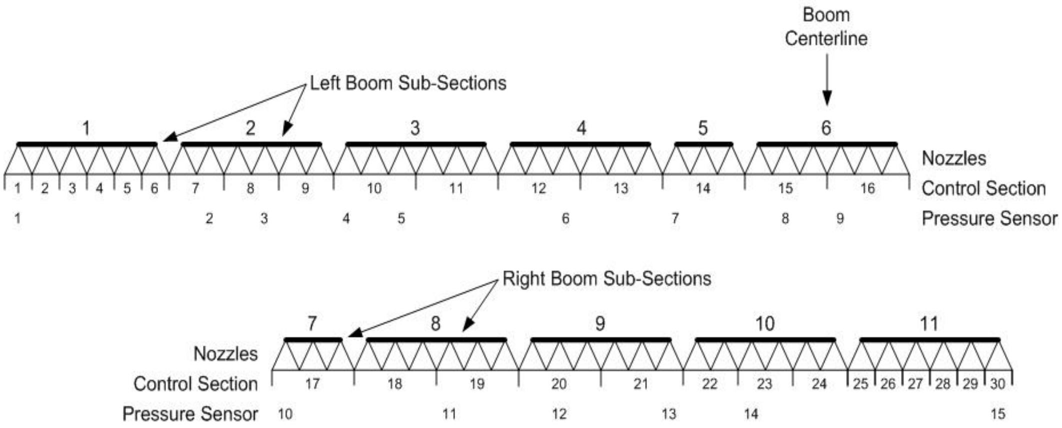

Fig. 2. Diagram identifying sprayer wet boom sub-sections (1 to 11), automatic control section nozzle groupings (1 to 30), and pressure sensor locations (1 to 15).

Pressure transducers (PCB Piezotronics Inc. Depew, NY, USA, Model 1502 B81 EZ 100 PSI G) 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 using national instruments (NI) 9221 analog modules to record the voltage output at 10 Hz from each pressure transducer. An additional DGPS receiver (Ag132, Trimble Navigation, Ltd., Sunnyvale, California) was used to read the GGA string using NI 9870 serial module. The voltage outputs 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 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 a GPS time stamp, RTK GPS coordinates, control section status (30 digit binary number), and the pressure from each transducer. 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) and plotted in Fig. 3. The calibration curve equation from these data was used to estimate the nozzle flow rate from the pressure transducer readings for the nearest pressure sensor to 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 which only slightly reduced the R^2 value.

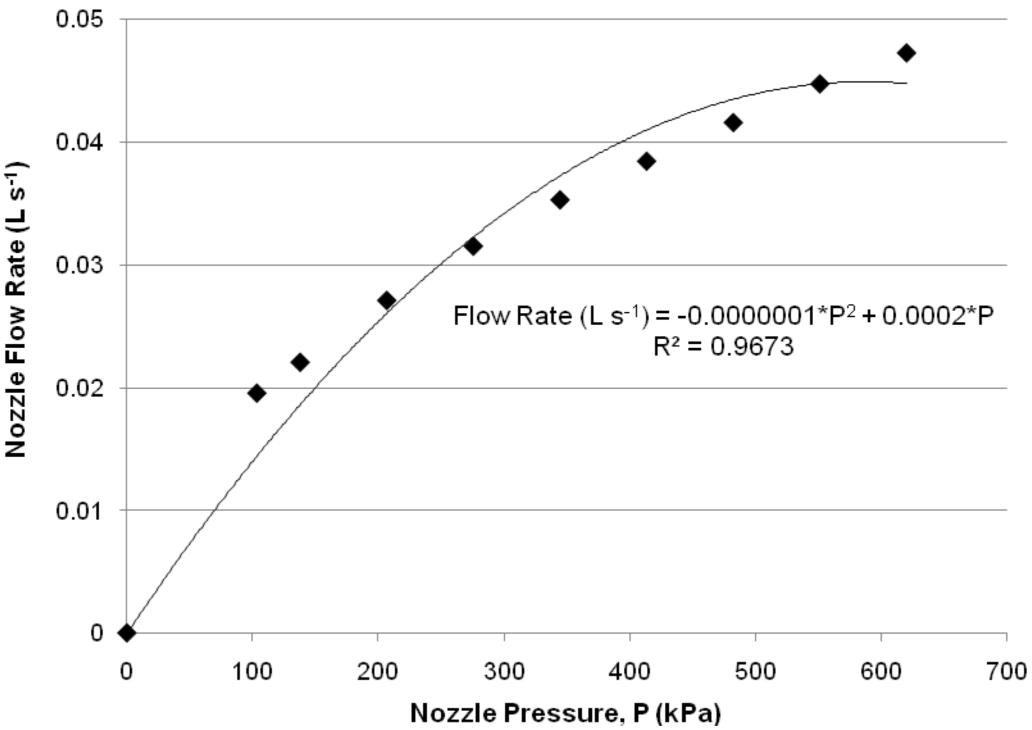

Fig. 3. Calibration curve for estimating nozzle flow rates from nozzle pressure sensor data (from manufacturer data).

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%. The variation in estimated application rates can be seen in Fig. 4 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. 4. The data shown in Fig. 4 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.

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

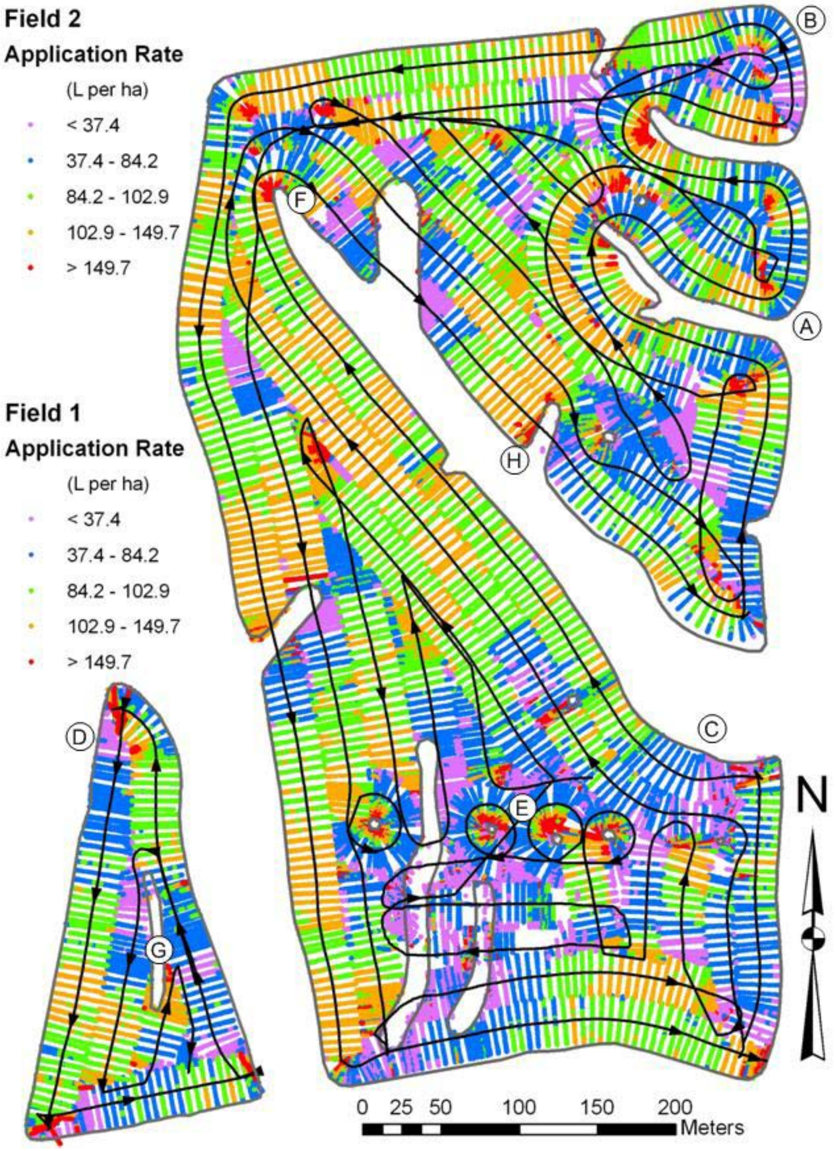

Fig. 4. Application rates reflecting boom pressure variation and sprayer turning movements for Fields 1 (left) and 2 (right) with sprayer path and direction.

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 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. 4 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, there was a delay before the nozzle pressures reached the necessary operating pressure. This may have occurred because of the control system used on the sprayer. A location may be seen in Fig. 4 (locations 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. 4 (locations 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. Examples of this can be seen in Fig. 4 (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 as the sprayer control system was configured to maintain flow rates based on ground speed. While the final effect on application rate is largely unknown, this likely caused some variation depicted in Fig. 4.

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 lower application rates which likely occurred from turning movements and control system delays in bringing the boom pressure back toward the operating range. This raises important questions regarding the efficacy of the pesticide in these areas. Additionally, if pesticides applied at these lower rates were effective, then substantial savings could accrue to the producer by reducing the target rate required to meet these needs, provided there is latitude to do so in accordance with product labels. Alternatively, the potential for crop damage from increased application rates may warrant further investigation.

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