EFFECTS OF FIELD GEOMETRY AND OPERATOR INFLUENCE ON DOUBLE-PLANTED AREAS IN ROW CROP FIELDS

Brandon M. Jernigan Michael J. Buschermohle William E. Hart John B. Wilkerson UT – Biosystems Engineering & Soil Science Knoxville, TN Margarita M. Velandia UT – Agricultural & Resource Economics Knoxville, TN Edward M. Barnes Cotton Incorporated Cary, NC

<u>Abstract</u>

Recent developments in precision agriculture have included the introduction of Automatic Section Control (ASC) technology for planters. ASC utilizes the Global Positioning System (GPS) and coverage maps to turn on/off individual planter row units or sections of planter row units within predefined field boundaries, no-plant zones, and previously planted areas to eliminate double-planted areas that typically occur in end rows and point rows. The cost of adopting planter ASC depends on existing technology in the tractor cab (i.e. monitor and GPS receiver) and the precision desired by the producer (i.e. individual rows vs. sections of rows). Producers are interested in rate of return on investment they can expect after adopting this technology, which depends on factors such as field geometry, number of acres planted, and equipment operator accuracy. A two-year study was conducted that focused on three objectives: 1) Categorize fields based on percentage of double-planted area so that producers can have a visual representation of the types of fields they farm, 2) Develop statistical and map-based models that can either predict or estimate the percentage of double-planted areas in fields, and 3) Determine the influence that operator accuracy has on double-planting. Real-Time-Kinematic (RTK) GPS position of the planter and planter status (i.e. planting or not planting) was recorded every 1/10th of a second in 52 fields across the state of Tennessee that totaled 1725 acres. Planting maps were generated in ArcGIS to calculate the minimum double-planted area that occurred in each field. Percentages of minimum double-planted area ranged from as low as 0.1% to as high as 15.6% with an average of 4.6%. Total minimum double-planted area across all fields was determined to be 54.7 acres. Stepwise variable selection in SAS showed that of the 18 field geometry factors tested, perimeter-to-area (PA) ratio, row length range difference to average row length (LSAvg) ratio, and circle perimeter to field perimeter (CPP) ratio were most significant (p < 0.05). Multiple regression analysis showed that a strong positive relationship existed between a combination of PA, LSAvg, and CPP in predicting percent double-planting with a R^2 of 0.80 and a standard error of 1.95%. Results from the operator accuracy analysis indicated that equipment operators over-planted or underplanted at the start or end of each planter pass. Equipment operators typically lowered the planter too early at the start of a pass or raised the planter too late at the end of a pass 59% of the time by an average of 8.2 feet, resulting in double-planting. An average under-planted distance of 9.0 feet was observed 41% of the time when the operator lowered the planter too late at the start of a pass and raised the planter too early at the end of a pass, resulting in skipped areas.

Introduction

Background

While average farm size has remained fairly constant over the past few decades, the distribution of total acres farmed in the U.S. has been trending to larger farming operations (> 1000 acres) (Key et al. 2007). Because of this increase in acreage, producers are utilizing wider equipment in order to speed up farming operations such as planting, spraying, tillage, and harvesting (Luck et al. 2009). As implement width increases, a potential risk of increasing swath overlap, especially in end rows and point rows has been shown to occur (Luck et al. 2009). This overlap causes the "doubling-up" of sensitive agricultural inputs such as seed, pesticides, and fertilizers. New precision agriculture technologies, known as Automatic Section Controls (ASC), have become available for planters. ASC for planters are used to control individual planter row units, or sections of planter row units, based on a GPS position and a planting coverage map of the field. This technology has been shown to eliminate or reduce

double-planting in areas where planter overlap is unavoidable such as end rows, point rows, and around internal field obstacles (Fulton et al. 2010).

Minimum double-planted areas occur in irregular-shaped fields when the planter intersects end rows and point rows that are not perpendicular to the direction of travel. Operator accuracy describes the ability of the equipment operator to raise or lower the planter at the precise moment to minimize double-planted and skipped areas in the field. Over-planted areas occur when the planter is raised past the minimum double-planting reference at the end of a pass or when the planter is lowered before the minimum double-planting reference at the start of a pass. Skipped areas occur when the planter is raised too early at the end of a pass or lowered too late at the start of a pass. Both situations are not favorable because over-planting increases total double-planted area and skipped areas result in profit losses for producers because of the potential yields that could have been made had the areas been planted. Potential planting problems that can occur near end rows and point rows are illustrated in Figure 1.



Figure 1. Examples of double-, skipped-, and over-planting.

Literature Review

Fulton et al. (2010) conducted a study to determine typical seed savings on farms in Alabama if ASC was used during planting. Results of this study indicated seed savings from as low as 1% to as high as 12% for each planter pass when planters were equipped with ASC (Fulton et al. 2010). An average of 4.3% seed savings were observed from the sample fields with some fields benefitting as high as 7% savings (Fulton et al. 2010). Similar studies have been conducted to analyze potential savings by adopting ASC for boom sprayers. Basically the same concept as planter ASC in that individual nozzles or boom sections were controlled to reduce over-application of chemicals in areas where sprayer overlap was unavoidable. According to Luck et al. (2010), ASC for sprayers can reduce the over-application of pesticides, resulting in decreased input costs and potential harmful effects to the environment. A Kentucky study revealed a reduction in over-application errors of 6.2% by switching from a five control section spray boom using manual section control (MSC) to a seven control section spray boom equipped with ASC (Luck et al. 2010). Another study conducted by Luck et al. (2011) focused on evaluating relationships between certain field shape factors and the percentage of sprayer overlap errors that occurred in fields using five control section MSC. seven control section ASC, and nine control section ASC. The following field geometry factors were calculated and used as independent variables for predicting over-application errors: Area (A), Perimeter (P), Length of the longest parallel pass (L), Perimeter-to-area ratio (P/A), Circularity (C), and Square-perimeter index (SPI). Both single and multiple regression analyses were used to determine if the variables alone or combinations of the variables could predict over-application errors. Results indicated that some multiple regression models were significant to the dataset, however, not considerably better than a simpler, single regression model using P/A for all three sprayer control configurations. Some research has also been directed at developing a computational tool used for estimating,

Objectives

There were three objectives to be accomplished by this research. The first objective was to categorize fields used for data collection in this study based on percentage of double-planted area to provide producers a visual representation of the types of fields they may be farming from a cost perspective focused on double-planting. The second objective was to develop both statistical and map-based models that can either predict or estimate double-planted areas in fields. The third objective was to determine the effects operator accuracy has on the amount of double-planting that occurs in end rows and point rows.

Materials & Methods

Data Collection

Geo-referenced planting data was collected for 52 fields that totaled 1725 acres. The sample fields were provided by eight cooperating Tennessee producers at various locations throughout the middle and western regions of the state. Real-Time-Kinematic (RTK) GPS planting data was collected using a data acquisition system mounted on producer planting equipment used at each location. The data acquisition system consisted of the following components: Trimble EZ-Guide 500 monitor with a built-in GPS receiver, Trimble AgGPS 25 antenna, Intuicom RTK Bridge cellular modem, netbook computer with a data logging program, and various implement switches depending on the manufacturer of the planter being used at each location. Real-time differential corrections were provided by the Tennessee Department of Transportation (TDOT) Virtual Reference Station (VRS) network. The data logging program recorded a typical GGA NMEA string with an additional column recording the planter status (i.e. planting or not planting) along with positional data (i.e. latitude and longitude) every 1/10th of a second.

Planting operations were monitored without interfering with producers' normal planting regimes. An implement switch was mounted on an individual planter unit on each planter to indicate planter status. The momentary switches closed the circuit when planters were lowered (i.e. planting) or opened the circuit when planters were raised (i.e. not planting). Appropriate wiring was connected to the switch output and routed from the planter to the tractor cab. The GPS antenna was located on the tractor cab roof or on top of the planter and centered left to right in order to obtain unobstructive satellite reception. Antenna output wiring was also routed into the tractor cab. Other components were stored inside the tractor cab. The netbook computer, GPS monitor, and cellular modem were housed in a fiberglass enclosure with appropriate wiring and electrical devices for communication between components. Electrical power for these components was obtained from the tractor's 12-Volt battery. At the beginning of each field, a data acquisition check was made by raising and lowering the planter to determine if the switch was functioning properly and to confirm that the system was receiving RTK-GPS positional data. Data was saved as a Comma Separated Values (CSV) file with new files being automatically created once the data logging program was started on the netbook computer. Files were generally saved in a specific folder for each producer and named by producer, field number, and date planted or by a specific field ID.

Data Analysis

Geo-referenced planting data was manipulated using ArcGIS software. Positional data was imported into ArcGIS using the NAD 1983 UTM Zone 16 projected coordinate system. GPS data points were shifted in ArcGIS in order to offset the distance between the location of the GPS antenna and the planter unit's seed drop tube equipped with the planting status switch. This offset distance was determined during equipment installation in the field. Points were shifted in ArcGIS by selecting points based on travel direction and the measured offset distance and correcting the planter status attribute for each point to the appropriate value. Data points were categorized based on planter status with green points symbolizing that the planter was lowered and planting and red points symbolizing that the planter was raised and most likely turning or crossing a no-plant zone.

Once data points were categorized, a new polyline shapefile was created to symbolize the centerline of the tractor and planter as they traveled across the field. Centerlines were created in ArcGIS by connecting line segments overlaying planting data points. On each side of the new centerlines, planting boundaries were offset half the width of a single planting pass, depending on the planter width used for each field. The area between these planting boundaries represented the planted area that occurred within each planter pass across the field. In order to accurately depict the minimum amount of double-planted area in each field, polygons were drawn over all planting pass lines that overlapped. Polygons were drawn such that double-planting in end rows would be at a minimum by drawing a perpendicular line from where the lagging planter edge crossed the end row to where the leading planter edge had traveled in relation to the end row (Figure 2). Polygon areas were calculated in acres using the "calculate geometry" feature in ArcGIS. Areas were summed to obtain the total amount of minimum double-planted area in each field. A polygon shapefile was created to represent the field boundary and drawn around the outside planter boundary lines. This field boundary area was used to calculate the total acreage planted for each field. Total double-planted area was divided by the field boundary area for each field resulting in a calculated percentage of double-planted area.



Figure 2. Zoomed portion of planting map created in ArcGIS.

Eighteen field geometry factors were calculated using ArcGIS and Microsoft Excel to determine if relationships existed between these factors and percentage of double-planted area in a field. Perimeter-to-area (PA) ratio was calculated by dividing the field boundary perimeters by the field boundary areas. Row length range difference to average row length (LSAvg) ratio was calculated by subtracting the length of the shortest parallel pass from the longest parallel pass and then dividing that difference by the average length of all parallel passes used to traverse the field. The standard deviation of the lengths between a field centroid and boundary vertices (CBSTDDEV) was calculated in ArcGIS. The remaining factors were calculated using the "minimum bounding geometry" (MBG) tools (i.e. rectangle by area, rectangle by width, convex hull, circle and envelope) in ArcGIS. The "rectangle by area" feature generated a rectangle with the smallest possible area around each field boundary while the "rectangle by width" feature produced a rectangle with the shortest possible width around each field boundary. The "convex hull" feature created the smallest convex polygon that could cover each field boundary. The "circle" feature generated the smallest circle that completely enclosed the field boundary and the "envelope" feature produced a box around each field boundary based on the northern, southern, eastern, and western extent of the field. All five MBG techniques were used to produce three relationships for each field. Each MBG perimeter and MBG area for a field was divided by the actual field perimeter and the actual field area and its corresponding MBG perimeter-to-area ratio divided by the actual field perimeter-to-area ratio. Statistical Analysis Software (SAS) was used to analyze relationships between the aforementioned field geometry factors and percentage of double-planted area for all 52 fields.

Two map-based models were developed in ArcGIS to estimate the amount of minimum double-planted area occurring in a field. One model required a field boundary shapefile and a GPS tracklog (i.e. yield map, planting map or spray map) indicating row orientation. The second model only utilized a field boundary shapefile. In each model, a negative buffer of two planter widths was generated inside the field boundary to simulate end and point rows. The GPS tracklog based model converted point data into polylines that simulated planter centerline passes and then buffered these lines to a specified planter width. Any locations where these planter pass buffers intersected end and point row areas were considered double-planted areas. The other model used a grid system known as "fishnet" to completely cover the portion of the field inside the end and point rows. Grid cell width was set to the planter width

and grid cell height was set to one meter to improve resolution. Any location where the grid shapefile intersected end and point row areas was considered double-planted area.

Operator influence was calculated by measuring the distance that planter centerlines extended past or fell short of the minimum double-planted areas in ArcGIS planting maps (Figure 3). Over-planting occurs when the planter is raised past the minimum double-planting reference at the end of a pass or when the planter is lowered before the minimum double-planting reference at the start of a pass. Under-planting occurs when the planter is raised too early at the end of a pass or lowered too late at the start of a pass. Both situations are not favorable because over-planting increases total double-planted area and under-planting results in skipped areas in a field.



Figure 3. Operator influence on planting accuracy.

Results

Relationship Between Field Geometry and Double-Planted Area

Data from 52 fields with a total of 1725 acres was analyzed to determine the relationship between field geometry (i.e., shape, size, and inclusion of terraces and waterways) and minimum double-planted area. Percentages of minimum double-planted area ranged from as low as 0.1% to as high as 15.6% with an average of 4.6% for these 52 fields (Table 1). The total minimum double-planted area across all fields was determined to be 54.7 acres.

	Slightly Irregular	Irregular	Highly Irregular
# Fields	16	21	15
% Double-Plant Range	< 2	2 - 5	> 5
Avg. % Double-Plant	0.8	3.2	10.5
Total Double-Plant (ac)	4.9	16.5	33.3
Field Range (ac)	8.1 - 106	6.6 - 58.8	1.9 - 42.5
Avg. Field (ac)	53.3	25.9	21.9
Total Field (ac)	852.6	544.3	327.8

Table 1. Summary of field characteristics for each field classification category.

Natural breaks in the percent double-planted areas for the 52 fields from this study were used to classify the fields into three categories; slightly irregular, irregular, and highly irregular. Fields that had less than two percent of the total field area double-planted were classified as slightly irregular. Fields in this category ranged from 0.1% to 1.9% double-planted with an overall average of 0.8%. Average field size for this category was 53.3 acres. General trends in the data showed that fields in the slightly irregular category were larger and had less boundary irregularity. These fields typically were more rectangular in shape and had parallel passes hitting end row passes nearly perpendicular

and therefore contained fewer point rows (Figure 4). It was also noticed that these fields contained fewer internal field obstacles.



Figure 4. Example of slightly irregular field.

Fields that contained double-planted areas between two and five percent of the total field area were classified as irregular shaped. The percent double-planted area in irregular shaped fields ranged from 2.2% to 4.8% and had an overall average of 3.2%. The average field size for this category was 25.9 acres. As fields began to change from the slightly irregular category to the irregular category, it was noticed that average field size had dropped by nearly half. These fields in general had more point rows as compared to the slightly irregular category, which was attributed to the increased boundary irregularity (Figure 5).



Figure 5. Example of irregular field.

Fields that had double-planted areas greater than five percent of the total field area were classified as highly irregular. The percent double-planted area in highly irregular shaped fields ranged from 6.9% to 15.6% and had an overall average of 10.5%. Average field size for this category was calculated to be 21.9 acres. A small decrease in average field size was observed between the highly irregular- and irregular-shaped fields; however, there was a substantial increase in field boundary irregularity and/or the presence of internal field obstacles (Figure 6). These fields were so irregular-shaped and unique that an overall general shape could not be easily distinguished as compared to the other two categories.



Figure 6. Example of highly irregular field.

Total double-planted acreage across all 52 fields was 54.7 acres. Multiplying the average percent double-planted area for all fields of 4.6% by the total 1725 field acres resulted in an over estimation of total double-planted area of 79.4 acres. After grouping the fields into categories, the average percent double-planted area for each category was multiplied by the total field acreage for each category to estimate the total double-planted area. This calculation resulted in an estimate of 58.6 acres which was much closer to the actual total double-planted area of 54.7 acres.

Statistical Model Results

Stepwise variable selection model in SAS was used to identify which of the 18 field geometry factors had the most influence on predicting percent double-planted area in a field. Based on the stepwise model, the three most influential factors were PA, LSAvg, and CPP with corresponding p values of < 0.0001, < 0.0001, and < 0.0028 respectively. A multiple regression analysis was conducted in SAS using PA, LSAvg, and CPP to predict percent double-planting. Results showed that a strong, positive relationship existed between the combination of these variables and percent double-planted area with a R² of 0.80 and a standard error of only 1.95% (p < 0.0001). Tests for normality indicated a normal distribution of the data. Also, collinearity tests indicated that the three independent variables were not closely related. These results showed that fields with lower values of PA and LSAvg in combination with higher values of CPP tended to have less double-planted area. The relationship between % Double-Planted Area and the Predicted % Double-Planted Area calculated using the multiple regression equation is shown in Figure 7.



Figure 7. Relationship between % Double-Planted Area and Predicted % Double-Planted Area.

One field was used to test both map-based models. This field was classified as highly irregular with an actual calculated percent double-planted area of 6.4%. Both models estimated percent double-planted values to within 0.5%. The model that required a field boundary shapefile and a GPS tracklog under estimated double-planting by 0.3%. The model that required only a field boundary shapefile over estimated double-planting by 0.4%. This field with each estimation model is shown in Figures 8 and 9. These models were only able to account for double-planted areas occurring in end rows and point rows around field boundaries. To date, the models have received limited testing and further analysis will be required.



Actual % Double-Planted = 6.4% Estimated % Double-Planted = 6.1% Figure 8. Field boundary shapefile plus GPS tracklog.



Estimated % Double-Planted = 6.8% Figure 9. Field boundary shapefile only model.

Operator Accuracy Influence

Results from the operator accuracy analysis indicated that over- or under-planting occurred at the start or end of all planter passes studied. Of the 448 planter passes analyzed, equipment operators increased double-planting 59% of the time by lowering the planter too early at the start of a pass or raising the planter too late at the end of the pass. The average over-planted distance was observed to be 8.2 feet. An average under-planted distance of 9.0 feet was observed when the operator lowered the planter too late at the start of a pass and raised the planter too early at the end of a pass. Equipment operators tended to under-plant at the start or end of a planter pass 41% of the time which resulted in skipped areas that were not planted.

Summary

A two-year study was conducted to analyze certain field and operator characteristics to determine how these characteristics affected percentage of double-planted area that may occur in field. The purpose of this study was to devise a mechanism to provide producers with tools to evaluate the potential cost of adopting ASC for planters based on various field geometry factors and operator accuracy measurements. Data from 52 fields with a total of 1725 acres was analyzed to determine the relationship between field geometry (i.e., shape, size, and inclusion of terraces and waterways) and minimum double-planted area. Percentages of minimum double-planted area ranged from as low as 0.1% to as high as 15.6% with an average of 4.6% for these 52 fields. The total minimum double-planted area across all fields was determined to be 54.7 acres. Multiple regression analysis revealed that a combination of PA, LSAvg, and CPP could predict percent double-planted area with an R² of 0.80 and a standard error of 1.95% (p < 0.0001). Equipment operators increased double-planting 59% of the time by lowering the planter too early at the start of a pass or raising the planter too late at the end of the pass by an average of 8.2 feet. An average under-planted distance of 9.0 feet was observed when the operator lowered the planter too late at the start of the pass and raised the planter too early at the end of the pass. Equipment operators tended to under-plant at the start or end of a planter pass 41% of the time which resulted in skipped areas that were not planted.

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