Quantifying seed uniformity and yield advantage of precision planter technologies through use of field tests and machine data

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Abstract

In recent years, technologies in the agricultural industry have gotten increasingly advanced. In past decades, most of the machines utilized by farmers were almost entirely mechanical with only a few electronics and computers, if any. Today these mechanically operated machines are increasingly being replaced by highly automated computer-controlled systems. One sector of agricultural equipment where this is especially apparent is precision planters for row crops. In recent years, these machines have gone from ground driven mechanical systems with spring downforce to electrically driven meters utilizing individual row hydraulicly controlled downforce. This research was conducted to examine some of the purported benefits of these newer technologies found on modern planters.

The initial investigation of the planter technologies was on the utilization of turn compensation when using electrically driven seed meters. Turn compensation refers to the ability of a planter to adjust seed and fertilizer application rates across the toolbar in order to account for the speed differential caused by planting around a turn or curvilinear pass. In the past, significant research has been conducted on the accuracy of turn compensation utilized by electric driven seed meters, though no existing research could be found on the amount of ground covered in an average field when the technology is being utilized. This research examined a sample of fields with various sizes and shapes to determine the amount of area planted in a typical field where turn compensation is active. In addition to turn compensation, we also conducted research on the advanced hydraulic downforce systems utilized by many of the modern planters. This research was split into two different parts, one looking at the difference between a fixed downforce system and an active downforce system and another part looking at the effect of downforce setting and operation speed choices across two different planting systems. To examine the difference between fixed downforce, which always applies a constant hydraulic pressure, and active downforce, which constantly adjusts the hydraulic pressure to maintain a target downforce, plots were planted at two different locations. For this study plots were planted side by side with each type of downforce to examine the effect on plant spacing, emergence, and ultimately yield. In addition to this research one location was also planted at three different speeds and two different levels of active downforce with two different planter systems. This

planting was done to determine the ideal combination of planter downforce and speed that should be utilized for each system to achieve the best combination of seed spacing, depth, emergence, and ultimately yield for each planter system.

All of these studies have provided useful insight into the value of these new planter technologies. To continue this research in the future I would recommend that additional investigation be conducted on the turn compensation with a larger toolbar planter. Additionally, I would recommend a second year of testing be conducted on the downforce and speed combinations for the two planter systems.

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Chapter 1 - Introduction

Corn is one of the most important crops grown within the United States. In 2018 corn was harvested from 81.7 million acres to produce $51.9 billion according to the USDA. The state of Kansas alone accounted for 5 million of these acres in 2018 to produce 645 million bushels, which makes it the second most widely planted crop in Kansas behind wheat. However, corn is also one of the most expensive grains to produce. According to the USDA, wheat has a production cost of around $350 per acre while corn has a cost of almost $650 per acre. The major difference in production cost is due to the extremely high seed and fertilizer costs associated with growing a corn crop. Of the $28.5 billion in operating costs for corn producers in 2018, 29% and 33% were spent on seed and fertilizer, respectively. With the importance of corn production and the high costs associated with it in mind, this research was motivated by the desire to understand recent developments in the technologies used in corn production and how they can benefit producers.

Precision agriculture technologies seek to maximize food production, reduce production costs, and minimize the effects of over-application of inputs into the environment. Precision planters are examples of precision technologies used to maximize potential yield of crops as they allow planting with consistent seed placement and seed depth. Attempts to achieve the maximum potential yield of crops not only involves placing the seeds in the right place but also at the right time. Observing recommended planting dates allows crops to reach optimum maturity, which could significantly improve corn and soybean yields. The planting window in Kansas and most Midwestern states ranges from late March in southeastern counties to mid-May in the northwest. However, unsuitable planting conditions due to excessive moisture, mostly due to rains, could typically reduce suitable time for planting to only less than 15 days. Studies have shown yield loss per day from about 1 bu/acre/day in early May to nearly 2 bu/acre/day by the end of May (Nielsen,2001). In addition, the average size of U.S. farms has been increasing and the number of people engaged in food production constantly declining (USDA-NASS,2012). The collective impact of fewer days available to plant larger acres with fewer people involved has made growers decide to increase planting speed to get more acres covered per day within the available dates of ideal planting. However, this faster planting could result in uneven seeding depth and seed placement, especially as fields tend to vary in terms of soil texture, moisture, crop residue, and terrain. Several studies have shown when using traditional planting systems, speed influences uniformity of plant spacing and emergence, which affects the potential yield of corn (Liu et al., 2004). The same study also indicated a 4.7 bu/acre reduction in yield could occur whenever the time to 50% emergence is delayed beyond three days and 0.58 bu/acre yield loss for every centimeter of standard deviation from uniform plant spacing. Poor depth control of the planting system might have caused this delay in emergence and variability in spacing (Liu et al., 2004). Planting speed has also been shown to impact yield. Studies conducted in Kansas have shown a yield reduction of 2.4 bu/acre for every unit increase in planting speed from 4.5 mph to 7.0 mph due to nonuniformity in spacing. The study reported a decrease in seed placement accuracy with increasing speed and suggests that variability in spacing might be related to seed bounce in the trench due to planter unit vibration (Staggenborg et al., 2004). With a current unit cost of $3.62/bu for corn in Kansas (USDA-NASS, 2019), revenue losses due to nonuniform depth, emergence, and spacing could range from $1.9/acre to $15/acre. Such key results from previous studies indicate that implementing a consistent depth-control mechanism and row-unit vertical acceleration is essential in maintaining a uniform seeding depth and reducing variability in spacing that could negatively impact yield and income of growers.

Newer precision planter technologies are being designed with a focus on row by row control of various operational parameters, including seed spacing, seeding depth and seed trench closure. This shift from section-control approach to row-by-row is primarily driven by wider tool bars, and field variability presenting unique planting requirements (Badua et al., 2018). The current technologies like electric seed meters not only offer expected seed metering and singulation capabilities but also add capability to control seeding rate (Mangus et, al., 2017 and Strasser et. al., 2019). One of the critical technology which became possible with electric seed meters is the turn compensation feature. Turn compensation refers to the ability of a planter to adjust the seeding and fertilizer rates on individual rows as the planter navigates a turn. This is necessary since a turn introduces large speed differentials between the two sides of the planter which could cause one side to over-apply seed and fertilizer and the other to under-apply these same things. Typical fields in Kansas and most of Midwest have variable irregular shape. These fields when planted with wider toolbars and faster planting speeds could generate substantial speed differentials (Mangus et al., 2017), posing challenges to maintain seeding rate especially on curvilinear passes. In recent years, studies have been conducted to determine the validity and effectiveness of turn compensation systems (Mangus et. al., 2017; Strasser et. al., 2019), but there have been no studies to determine the extent of turn compensation feature actuation and amount of area planted in a typical field. Additionally, there is a gap in knowledge in term accuracy of precision planter technologies having electric seed meters and individual row hydraulic control downforce, when planting at varying planting speeds. Therefore, this research was conducted with two key objectives 1) quantify the extent of turn compensation feature actuation available on precision planter technologies on typical fields; and 2) quantify seed placement and Emergence Uniformity when using two different precision planter systems.

Chapter 2 - Quantifying the Extent of Turn Compensation Feature Actuation Available on Precision Planter Technologies on Typical Fields

Introduction

In agriculture today, the size of farms continues to increase as time goes on, and with that increase the average equipment size and input costs have also increased. From 2000 to 2015 corn input costs dramatically increased. Fertilizer, pesticide, and seed costs per acre have each risen by 213%, 106%, 256% respectively while yield and corn prices have only increased by 21% and 91% respectively (Schnitkey and Sellars, 2016). Also, as farming operations grow in size, operators are forced to plant increasingly large areas within the same narrow window of time as before. Therefore, with rising input costs and acreage, it is crucial that operators utilize technology that can help them plant their fields faster and more efficiently to maintain profitability.

Today, many farms have started utilizing 16 and 24 row planters to cover more ground in a shorter amount of time. These large planters which have widths of 40 and 60 feet respectively can cover large amounts of area, but this large width can lead to seed placement issues when planting on curvilinear passes if not corrected (Strasser et. Al., 2019). On curvilinear passes, the row units on the inside of the toolbar travel at slower speeds and the ones on the outside travel at a higher speed. The magnitude of the speed differential for row units on the inside and outside of the toolbar increases with decrease in the turning radius. The frequency of curvilinear travel instances primarily depends on field shape irregularity, conservation area like grassed waterways, and field obstacles, among others. The planting system implementing uniform seed meter speeds, would invariably see higher seeding rate for row unit on the inside and lower for ones on the outside. The areas where seed population is significantly lower than target could become potential weed site and one's high population may pose competition for nutrients, moisture, sunlight and other input for appropriate plant growth. The seeding rate errors have been associated with yield losses with a high correlation between plant density and corn yields (Miller et. al., 2012; Staggenborg et. al., 2004).

In recent years, the driving component of many planters has shifted from mechanically driven seed meters to electrically driven meters. The planter controllers calculated row unit speed to implement seed meter speed (revolutions per minute) to drive electric drive seed meter to achieve target seeding rate. This technology feature to derive real-time row unit speed and implement representative row meter speed is typically referred as turn compensation. The electric seed meter have integrated drives to change the speed of the seed meter in real-time and manage the seeding rate. The turn compensation feature has been shown to work (Mangus et. al., 2017), but there is very little information about how much of an average field is planted while this technology actuated and the impact it might have potential yield goals. Therefore, the purpose of this study is to 1) develop a methodology to extract area planted at different turn radii; and 2) quantify the extent of area planted with turn compensation actuated on field with various acreage and varying boundary.

Methodology

Planter Setup

A John Deere Exact Emerge Planter with 16 row units spaced at 30 inches apart was used for this experiment. This planter utilized individual row control using electric drive seed meters and seed tubes. This planter was also equipped with inertial measurement units, that can detect the yaw change rate of the planter toolbar. The planter controller utilized yaw change rate to calculate speed of each row unit and communicated target seed meter speed (revolutions per minute) to row control modules. The row control modules speed up or slow down the electric drive to implement target seed meter speed needed for the programmed seeding rate per acre.

Field and Study Layout

For this study machine as-applied data was collected from eight different fields that including the GPS coordinates, speed, heading across the field and other operating parameters. Various field shapes and typical field sizes in Kansas were discussed with different producers. Based on the field size and shape observations, field were selected with varying sizes and irregular boundary shapes (Table 1). For each field, the following process was used to quantify the areas planted with active turn compensation using Microsoft Excel and ArcMAP software.

Required Data:

- Toolbar Width
- GPS point data for the center of the planter with the following attributes
  - Heading
  - Duration Between Points in seconds “Duration”
  - Speed

Process:

- In the Excel file containing the required GPS data complete the following steps
  - Create a column called “Track Change” that calculates the change in degree heading from point to point by taking the difference.
  - Calculate the “Turn Speed” in degrees/second in a new column using the formula:
    - “Track Change” ÷ “Duration”
  - Filter the “Turn Speed” data to ignore any irregularly high values that fall within a set of otherwise small values.
  - Create a column called “TC State” that will indicate if turn compensation is active based on the triggering parameters set forth by the machine’s program. For our case, these parameters were as follows:
    - If “Turn Speed” is greater than or equal to 0.75 deg/sec, turn compensation is activated.
    - Once activated, if “Turn Speed” falls below 0.5 deg/sec turn compensation is deactivated.
  - Create a column called “Turn Radius”. This column gives the radius of the turn being executed when turn compensation is active in meters using the following formula.

    - “Speed” ÷ (“Turn Speed” * PI÷180)

- The GPS data now contains all information needed to display the area of each field planted with turn compensation as well as the radius of said area.
- Using the “Buffer” tool create a complete field boundary with no gaps or holes. Use a distance of half of the toolbar width with additional distance of one extra row
- Using the tool “Create Thiessen Polygons” convert the point data from the DAQ system to polygons
    - Output Fields: Only_FID
- Using the “Clip” tool, trim the output from the Thiessen Polygons tool to the boundary of the field
- Using the “Spatial Join” tool, conduct a one to one join to combine the results from the previous to produce an output of polygons with the same attributes as the point data from the DAQ system with the addition of area.

Various turning radii encountered within fields were classified into extreme, medium slight and straight passes (Table 2). The turning radii were classified to provide differentiation in varying magnitude of speed differential between the inside and outside of the toolbar.

This method was applied to each of the eight fields which range in size from 37 acres to 220 acres with some of the fields having very irregular boundary and some having more rectangular boundaries.

Table 2.1. Various Fields with sizes utilized for as-applied machine data collection.

Field Number	F1	F2	F3	F4	F5	F6	F7	F8
Size (Hectares)	27.6	52.8	33.2	42.8	89.1	30.7	14.9	16.3
Seeding rate (seeds/ha)	271.8k	69.2k	79.1k	56.8k	73.6k	66.7k	64.2k	64.2k

Table 2.2. Turn classification for different ranges of turning radii.

Turning radius (m)	Turn classification	Expected Speed differential
r < 20m	Extreme Turns	Turns with small radii resulting in over 85% speed increase from inner to outer row of the planter.
20m < r < 50m	Medium Turns	Average sized turns with at least 25% speed increase from inner to outer row of planter
50m < r < 100m	Slight Turns	Turns just above the threshold for activating turn compensation
r > 100m	Straight run	Any pass with no discernible turn that would enable turn compensation

After converting the data from the DAQ system to polygons, the fields were analyzed to determine the amount of each field planted within each type of turn classification.

After planting, 5 turns were examined in 2 of the different fields to determine the accuracy of the turn compensation. This was done by measuring the spacing on 50-foot strips in the inner, outer, and middle rows of a single planter pass around a curve of known radius.

Results and Discussion

GPS Analysis

When examining the results from the 8 fields in this study, it is evident that there was a significant benefit to having a turn compensation enabled planter. Across the 8 fields in this study, turn compensation was used to some extent 7.04% of the time, though it was used up to 12.01% of the time on one of the fields and as little as 4.64% on another. The variability between the fields is shown in the below figures, with the first 2 showing the extremes. The effect of using turn compensation on these fields could have a significant impact on yield and input costs when added up across an entire crop.

For corn crop, lack of targeting for the optimal plant density will produce suboptimal productivity, with seeding rate below the optimal level reducing attainable yield and with the above the optimal potentially decreasing yields and increasing the overall seed costs (Lacasa et al., 2020). Overall, the agronomic optimum plant density in corn depends on the yield potential (Assefa et al., 2016). In the present, increases in agricultural production are limiting farmers' income; therefore, new technological approaches can assist to fine-tune management input use and improve overall profitability. Few studies are published from a machinery perspective showing benefits of technology on agronomic management (for example on automatic section control, Fulton et al., 2011; Larson et al., 2016; Corassa et al., 2018). Optimizing the plant density for the right zones of the field will improve input efficiency and profits, from a plant density perspective it has been well documented that increases in optimal density will cause yield reduction (Sangoi et al., 2002; Assefa et al., 2016), with the additional complexity that planting above optimal density can cause larger reductions based on the type of hybrid and the density-dependency (more or less responsiveness to this factor) (Tokatlidis and Koutroubas, 2004). Therefore, utilization of a turn compensation system could help to improve the right seed number in those complex zones of the field, below optimal will leave behind while above optimal density will increase plant-to-plant competition (Maddonni and Otegui, 2004) reduce yields in water-limited environments (or resource limited by nutrient or other factors) and increase seed costs. In summary, the more field irregularities (more curvature) are present faster this technology will pay for itself with less number of acres, with similar demonstrated benefit already reported by the use of automatic section control technology (Corassa et al., 2018).

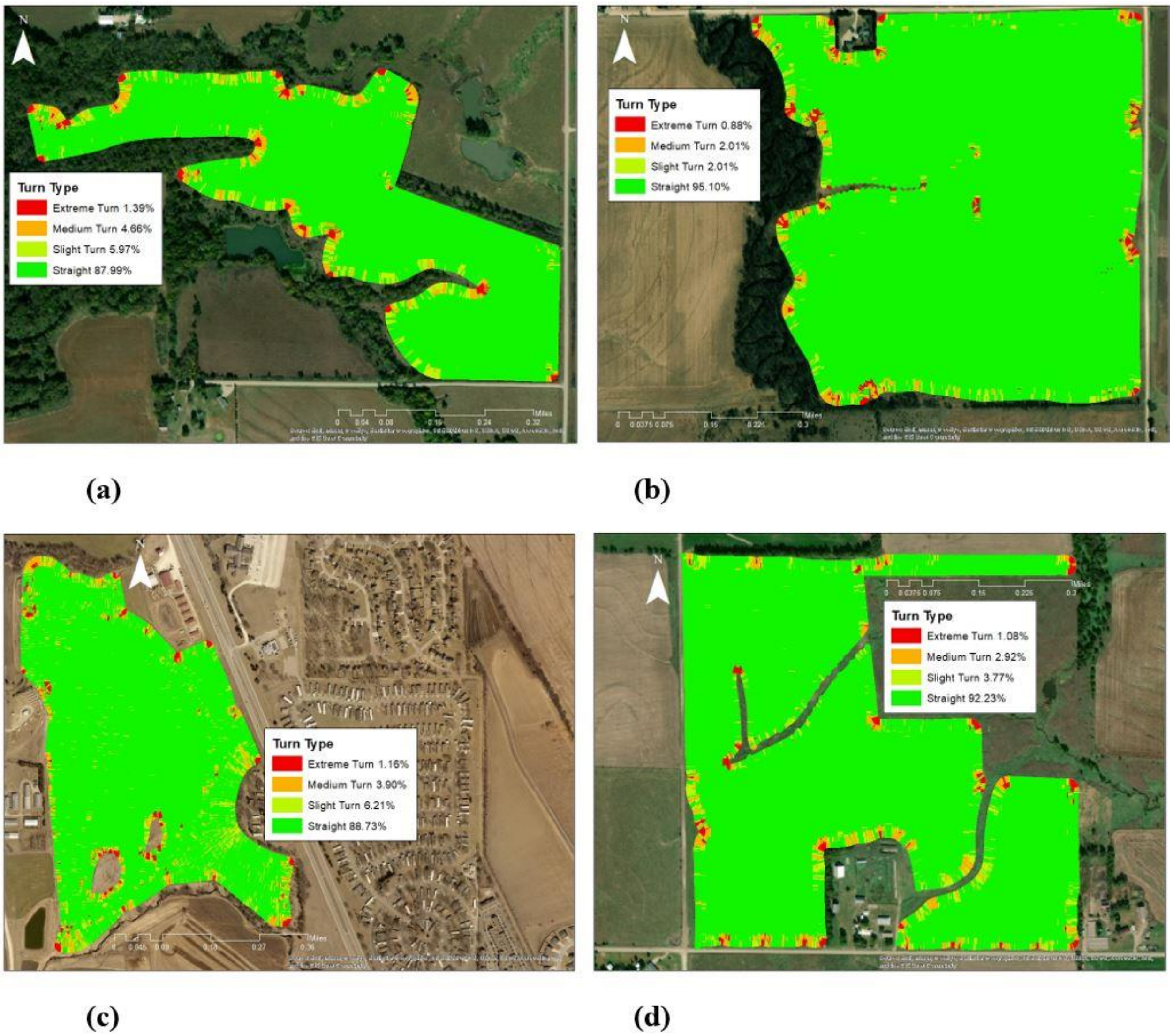

Figure 2.1. Example fields F1 (a), F2 (b), F3(c) and F4(d) showing varying degree of turns and area typically planted on curvilinear paths.

Spacing Analysis

To confirm the effectiveness of using a turn compensation system, we analyzed 5 different turns in two of the fields to determine how well the turn compensation corrected the plant spacing. This analysis showed that the turn compensation system was effective in correcting the planting rate to the desired value for both extreme and gradual turns. The table below show the population that would be expected for the given turn radius if turn compensation were not used compared to the population that was present in the field.

Table 2.3. Comparison of population with Turn Compensation to Population Expected without Turn compensation

Turn Radius (m)	Row	Turn Comp. Pop. (Seed/Hectare)	Pop. W/O Turn Comp. (Seed/Hectare)
12.19	Inside	58,308	117,343
	Middle	62,329	62,329
	Outside	49,687	42,434
13.92	Inside	71,105	107,936
	Middle	63,621	63,621
	Outside	63,141	45,103
20.90	Inside	60,287	69,573
	Middle	50,549	50,549
	Outside	57,728	39,694
26.06	Inside	59,465	76,510
	Middle	59,731	59,731
	Outside	57,574	48,988
34.01	Inside	61,879	69,877
	Middle	58,135	58,135
	Outside	59,334	49,771

This table shows that the seeding rate is accurately adjusted to the desired value even on small radii turns which can improve yields and reduce inputs on fields with many turns.

Conclusion

After examining both GPS machine data and gathered post planting data, it is clear that a planter equipped with turn compensation could have a major advantage when trying to improve yields. The planter was able to successfully correct planting seeding rate around both turns with both large and small radii, which could have a large impact on inputs and yields on fields with many turns, such as fields with irregular boundaries, or fields planted with contour farming around terraces. With these obvious benefits, it is clear that turn compensation should be part of the consideration when choosing between mechanical and electric driven seed meters.

Chapter 3 - Quantifying Seed Placement and Emergence Uniformity Using Two Precision Planters

Introduction

Planting accuracy and efficiency to maximize yield potential can be attained through optimization of field management practices and adoption of latest equipment technology. Right conditions at planting can highly influence how the plant progress for the rest of the growing season. Soil temperature level and moisture determines the producer desired seeding depth, for optimum growth and development of corn. Thus, weather conditions during the planting season, as well as the timeliness of planting, impacts the yield outcome. In northeast Kansas, optimum planting window for corn ranges from April 15 to May 10 where the ideal soil temperature of 55 degrees Fahrenheit at a 2-inch depth is reached for favorable planting operations. Planting within ideal planting dates have shown to affect potential yield (Lauer et al., 1999; Nielsen, 1995). However, frequency of extreme precipitation events that may be due to climate change (Urban et al., 2015) resulting to fields becoming too wet restricting access for planting machinery potentially typically reduce the planting window (Urban et al., 2015). Moreover, seeds on wet soil may be exposed to very low or fluctuating soil temperatures affecting germination and seedling emergence (Abendroth et al., 2017). Thus, farmers adopt several management practices to compensate for reduced planting days through selection of suitable tillage systems (Long et al., 2017), longer or shorter maturity hybrids when planting early or late, and planting with higher ground speed to cover more acres.

In the context of advanced planting machinery, manufacturers have developed technologies to continuously improve planter performance in the field. Among them is how to consistently plant at the target seeding depth by effectively selecting and implementing the ideal downforce on planter row units regardless of operating speed. Downforce is the amount of load applied on the row unit to achieve the desired seeding depth. This load is distributed to the opening disc for soil penetration (representing soil strength) at the desired seeding depth and the excess load is taken up by the gauge wheel. The gauge wheel load can be used anytime by the opening disc when additional load is required for soil penetration usually at heavier textured soil (clay). As such, it is important to always maintain an optimum level of load on the gauge wheel to prevent shallow planting and potential compaction of side walls. More often, downforce requirement varies across the field due to inherent spatial field variability which can significantly influence the selection of row unit downforce applied during planting (Badua et al., 2018). Soil moisture, texture, crop residue, and planting speed are several field conditions that can affect openings discs' ability for proper soil penetration which could result in shallow seeding depth or sidewall compaction. Insufficient load on the row unit and excessive planting speeds both have the potential to produce too much row unit acceleration (bounce) resulting in uncertain seeding depth and non-uniform seed spacing, while excessive load on the row unit could cause sidewall compaction and overly deep planting depth. Thus, proper speed and downforce selection are critical to achieve desired seed placement consistency. Badua et al. (2018) reported that proper selection of planter downforce setting could potentially result in uniform seed placement even at faster planting speed. The newer planters are typically utilizing individual row hydraulic downforce control (IRHC) providing greater flexibility to each row to respond to varying soil strengths and manage downforce on row-by-row. Additionally, as the tool bar width increase, there is greater dynamics on weight transfer and distribution, which if not distributed evenly could limit the ability of the system to correctly implement desired downforce, and gauge wheel load targets. Producers are also concerned about operational accuracy across wing, pinch and non-track row units to achieve equivalent seed placement, especially when operating at greater than traditional planting speeds (> 5 - 6 mph). Therefore, this study aims to quantify seed placement uniformity and grain yield difference when implementing different levels of downforce and speed settings using two commercial precision planter systems.

Methodology

Planter Setup

Two planters were used for this study, a John Deere Exact Emerge Planter (referred henceforth as Planter-A) and a Case IH Early Riser Planter (referred henceforth as Planter-B), both with 16 row units spaced at 76.2 centimeters apart. Both planters were equipped with electric seed meters, mechanical seed delivery tubes/brush belt, and individual row hydraulic downforce control systems. Planter-A utilized ExactEmerge® technology; and John Deere IHRC, controllers and Deere field computer (Gen4, Deere and Company, Moline, IL, USA); and Planter-B had Precision Planting Vset® seed meters with vDrive® electric motors, mechanical seed delivery tubes, and Deltaforce® IHRC (Precision Planting – AGCO, Tremont, IL, USA), which was implemented utilizing CaseIH field computer (AFS Pro 700, CNH Industrial, Burr Ridge, IL, USA). Both the planters were programmed to plant using two different active downforce settings, 54.4 kgf and 99.8 kgf, and three speeds, 9.7 kph, 12.1 kph, and 16.1 kph. Both planters utilized central commodity systems (CCS).

On Planter-A, each odd numbered row was equipped with a hydraulic pressure transducer (HAD 844L-A-0250-161, Hydac, Glendale Heights, IL, USA and Model KM41, Ashcroft Inc., Stratford, CT, USA) to measure the real-time hydraulic oil pressure applied. Hydraulic oil pressure readings were utilized to deduce actual real-time downforce applied by the hydraulic system on row units to implement desired gauge wheel load target during planting. These rows were also equipped with proprietary loadcells, which measured the real-time gauge wheel load (GWL) during planting. The actual real-time GWL data from loadcells was collected using the CAN Bus built into the tractor and planter.

On both planters, accelerometers (Model 3741E1210G, PCB piezotronics, Depew, NY, USA) were mounted on the odd numbered rows to measure vertical acceleration of the row units during planting in real-time. Location and travel speed were measured using a sub-inch accuracy GPS unit (GR5, Topcon Positioning Systems, Inc., Livermore, CA, USA). Load cells, hydraulic pressure transducers, accelerometers, CAN Bus data, and GPS signals were recorded using laptop computer (Latitude 14 3470, Dell, Round Rock, TX, USA) and a NI cRIO chassis via C Series modules (National Instruments, Austin, TX, USA) at 100 Hz sampling frequency.

Field and Experimental Layout

The experimental plot location for this field is shown outlined in Figure 1 below. Per the producer's request, the field was planted at a population of 64,300 seeds per hectare with a target seed depth of 5.1 cm. For the purposes of this study, the planter was operated at three speeds and two downforce settings. The speeds selected for this study were 9.7, 12.1, and 16.1 kph which will be named S1, S2, and S3 respectively from here on. The downforce settings selected were 54.4 kgf and 99.8 kgf which will be named D1 and D2 respectively.

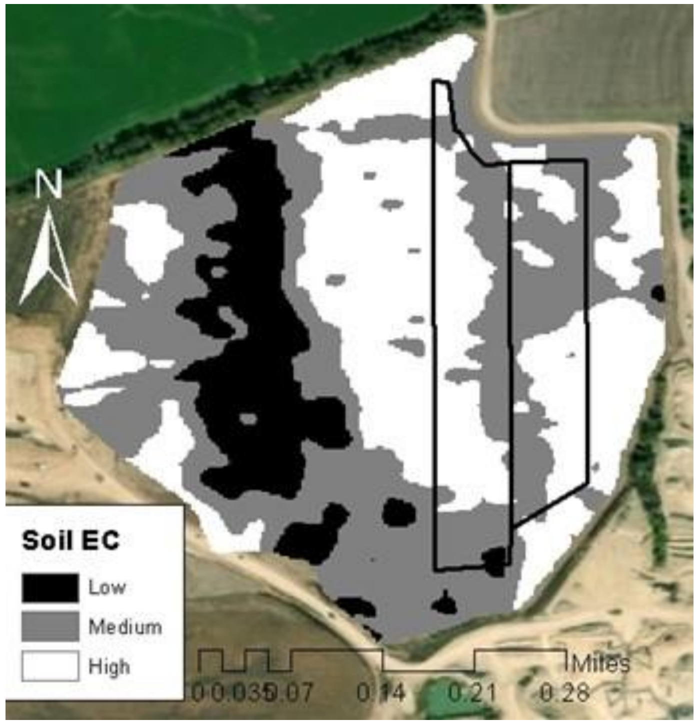

Figure 3.1. Soil Electroconductivity map of field: Low (10-32), Medium (32-52), High (52-75). Study plots outlined in black

Data was collected from three replicates of three strips for each combination of speed and downforce settings used with each planter. For each replicate, one strip was selected from each of the three row types, wing, track, and non-track shown in Figure 2 below. These strips were staked at a length of 5.33 meters which corresponds to 4/10,000th of an acre for a row width of 76.2 cm. Figure 3 below shows the plot layout for this study, which was setup using a split-split plot design. Post planting data including plant spacing, emergence, seeding depth and yield were collected from all these strips.

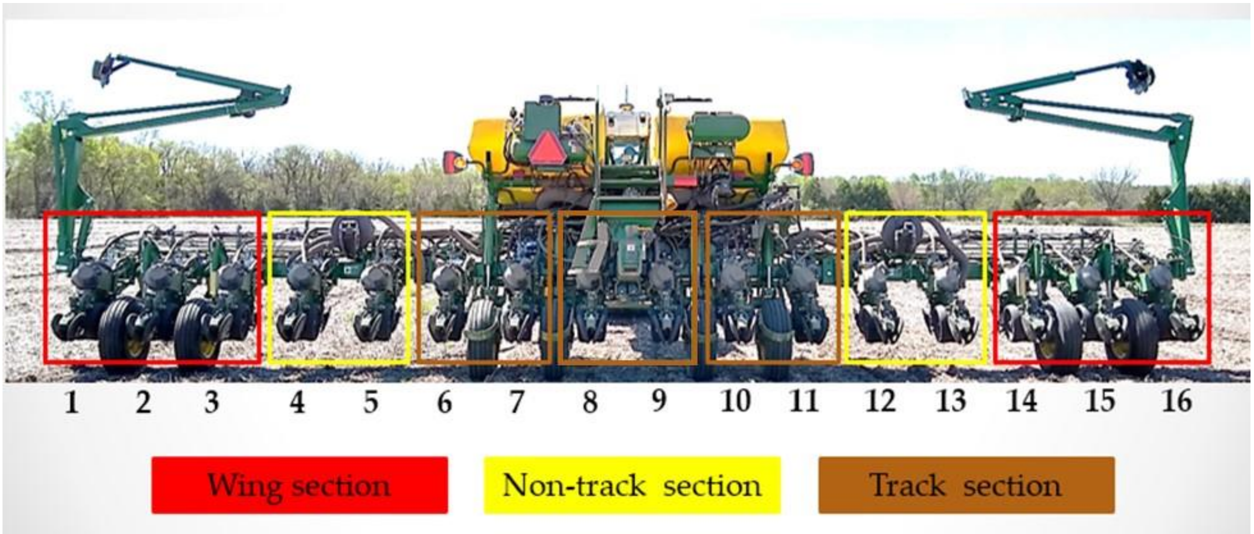

Figure 3.2. Row Classifications for a 16 row planter shown on Planter A

Figure 3.3. Strip layout for studies as planted in the field. Buffer areas between strips allow systems to achieve equilibrium after changes

Field Description

This experiment was conducted during the 2020 corn planting season in a field located near Clay Center, KS (39.306676º, -96.998120º). The field utilized no-till management with moderate crop residue from a previous soybean crop. The soil type found predominantly in the field is Crete Silt Loam according to the USDA Web Soil Survey (USDA-NRCS 2020). Soil-apparent electrical conductivity (EC) was collected using the Veris mobile sensor platform (MSP) (EC

Surveyor 3150, Veris Technologies, Salina, KS, USA). Shallow-soil EC data was then used to create a map of three EC zones within the field, low, medium, and high seen in the figure above using ArcMap in ArcGIS (ESRI, Redlands, CA, USA). This map allowed for the selection of a portion of the field with flat terrain and evenly distributed soil EC between the areas planted with the two systems.

Field Data Collection

Spacing Analysis

The plant to plant spacing for this study was studied for each strip using a POGO stick tool as shown in Figure 4 (Pogo Stick, Precision Planting, Tremont, IL, USA). This tool measured and recorded the spacing between each plant in a strip allowing for the detection of skips and doubles within the strips. The field was planted at a target population of 64,300 seeds per hectare, resulting in a target spacing of 20.3 cm based on calculations for the planter's 76.2 cm row spacing. For each strip, the spacing was measured between each plant and was then compared to the target spacing to quantify planter performance for each treatment combination.

Figure 3.4. Spacing Collection using Precision Planting POGO Stick and iPad was done after emergence was complete. Plant to plant spacing was collected for full length of each test strip.

Emergence Analysis

The emergence analysis for this study was performed by marking each plant on the day that it emerged for each strip with a numbered stake. These stakes were marked with the number of days from when the first plants began emerging from the soil starting at day one. The strips were monitored for 15 days after the start of emergence until no more plants were emerging. An example of two plants that emerged on day one is shown in Figure 5. After all plants were emerged this data was collected to determine the Emergence Rate Index (ERI), or the percentage of total plants that have emerged for each day. This was then used to determine the emergence response of each treatment within the study. It is desirable that emergence take place over a short period of time to reduce effects caused by uneven plant height. Therefore, statistical analysis for this study was performed ERI from day three for each treatment.

Figure 3.5. Emergence Stakes for 2 Plants that Emerged on Day 1 of Emergence. Stakes were placed each day after emergence started until all plants had emerged.

Depth Analysis

The depth emergence analysis for this study was performed by manually digging and measuring seed depth for the 10 plants adjacent to each test strip. Since yield quantification was one of the goals, the seeds adjacent to each strip were selected for depth quantification instead of from within the strip. This depth was measured using a pair of electric calipers with a precision of 0.01 millimeters as shown in Figure 6. The measurments were performed by digging away the soil around the seed of an emerged plant, followed by placing a flat bar along the furrow. The electric calipers were then used to measure the depth by using the depth measurement portion of the tool to find the distance from the bar to the bottom of the seed. This depth data was then compared to the target depth of 5.1 cm to determine the performance of the planter with regards to both its accuracy and variability in seed depth placement.

Figure 3.6. Data collection for Depth of Seed Placement conducted using digital calipers with 0.01 mm accuracy. Depth was collected on 10 plants adjacent to test strip as to not affect plant response

Grain Yield Calculation

The grain yield calculation for this study was performed by manually harvesting each strip by hand. These strips were 17.5 ft long with 24 to 30 ears per strip. The tools used for processing the corn after harvest are shown in Figure 7 below. After removing all of the husks, the ears were individually shelled using a single ear electric corn sheller (Maizer SES, ALMACO, Nevada, IA). After shelling, the grain from each ear was weighed using a digital scale (Scout II, Ohaus Corp., Florham Park, NJ) and the moisture was measured using a grain moisture meter (Ag-MAC PLUS, agraTronix, Streetsboro, OH). Corn yields for each strip were calculated using the procedure described by Lauer (2002).

a b c

Figure 3.7. Scale used for weighing corn ear and grain weight in grams (a), ALMACO single ear sheller for separating grain from cob (b), and moisture tester for grain moisture measurement

Data Processing

With all plants emerged by day 15, the percent of emergence for a row was calculated as

$$\frac{\text{Number of Plants Emerging within 3 Days of First Plant in Row Emerging}}{\text{Total Number of Plants Emerging by Day 15}}$$

For the analysis of this experiment, the bias, precision, and accuracy of the data compared to the target value was calculated for both spacing and depth. The bias of the data refers to the general distance between the measured data and the target data while the precision is indicative of the general variation within the data. The accuracy is somewhat of a combination of the bias and precision of the data (Accuracy=Bias^2+Precision). The calculations for each of these values is shown below.

Let n_i be the number of plants in row i measured. The bias, precision, and accuracy for planting depth and spacing are based on the following formulas:

$$\text{Bias for row i} = \frac{\sum_{\text{j}=1}^{\text{n}_\text{i}}(\text{measurement from plant j} - \text{target value})}{n_i}$$

$$\text{Precision for row i} = \frac{\sum_{\text{j}=1}^{\text{n}_\text{i}}(\text{measurement from plant j} - \text{Average Response in Row i})^2}{n_i}$$

$$\text{Accuracy for row i} = \frac{\sum_{\text{j}=1}^{\text{n}_\text{i}}(\text{measurement from plant j} - \text{target value})^2}{n_i}$$

The target values for spacing and depth are 8 in and 50.8 mm (2 in.), respectively. These calculations also mean that it is desirable to have the lowest possible value for all 3.

Data Analysis

The data of this experiment was collected for every plant found in each experimental unit. This was about 27 plants per strip with data collected on emergence and spacing. As stated before, the depth data was taken on 10 plants adjacent to each strip which were then discarded. The yield data for this experiment was collected by calculating the total yield for each strip based on the plants within it.

The precision and accuracy were subjected to natural log (ln) transformation before being subjected to linear mixed model analysis. Bias, Yield, and % of Emergence were analyzed without any transformation. The fixed effects of the model are replicate (1, 2, 3); speed (9.7 kph, 12.1 kph, and 16.1 kph); downforce (54.4 kgf and 99.8 kgf); row type (Wing, Track, and Non-Track); Speed-by-Row-Type interaction; Downforce-by-Row-Type interaction; Speed-by-Downforce interaction; and Speed-by-Downforce-by-Row-Type interaction. The random effects include the replicate-by-downforce (the whole plot error term), the replicate-by-speed-by-downforce (the sub-plot error term), and the replicate-by-speed-by-downforce-by-row-type (sub-sub-plot error term; the residual error term). Due to limitation of the experimental design, comparisons cannot be made between Planter A and Planter B.

Model fixed effects were evaluated via type III tests. For precision and accuracy, the back-transformed least squares means (LSMeans), i.e. median, and their back transformed standard errors were reported. For bias, the LSMeans plus the target value (i.e., mean) and their standard errors were reported. For yield and % of emergence, the LSMeans and their standard errors were reported. The p-value for accessing specific treatment(s) was based on the 2-sided tests. When applicable, the adjustment for multiplicity was carried out using Tukey's method. All tests were conducted at the 0.05 significance level.

Statistical analysis was executed via Statistical Analysis Software (SAS version 9.4; Cary, NC) PROC MIXED with option DDFM=KR in MODEL statement.

Results and Discussion

Plant Spacing

The results of plant spacing for both planters are shown in Table 1. The average plant spacing for all treatments was 21.3 cm for Planter-A and 21.7 cm for Planter-B respectively. The standard deviation indicated that plant spacing was within 7.4 cm of target spacing.

Table 3.1. Summary of Spacing data in centimeters for Planters A and B including average, Standard Deviation, and Coefficient of Variation

		Planter A					
Speed, kph	Downforce	54.4 kgf			99.8 kgf		
	Row Type	Track	Non-Track	Wing	Track	Non-Track	Wing
9.7	Average	21.4	21.0	20.9	21.5	23.6	21.4
	Std. Dev.	6.2	5.0	5.2	6.2	7.8	6.0
	CV	29.0%	23.8%	24.9%	28.8%	33.1%	28.0%
12.1	Average	20.5	20.1	21.2	20.6	20.9	21.1
	Std. Dev.	5.8	4.7	6.1	6.0	5.8	6.0
	CV	28.3%	23.4%	28.8%	29.1%	27.8%	28.4%
16.1	Average	21.5	21.1	20.6	21.1	23.6	21.8

	Std. Dev.	6.0	5.5	5.4	5.7	9.3	6.2
	CV	27.9%	26.1%	26.2%	27.0%	39.4%	28.4%
		Planter B					
Speed, kph	**Downforce**	**54.4 kgf**			**99.8 kgf**		
	Row Type	**Track**	**Non-Track**	**Wing**	**Track**	**Non-Track**	**Wing**
9.7	**Average**	23.0	21.2	21.4	22.2	21.7	21.8
	Std. Dev.	8.5	5.8	7.3	8.8	9.3	7.3
	CV	37.0%	27.4%	34.1%	39.6%	42.9%	33.5%
12.1	**Average**	21.0	22.0	20.6	23.8	21.2	21.4
	Std. Dev.	6.6	6.7	6.5	9.6	6.8	5.9
	CV	31.4%	30.5%	31.6%	40.3%	32.1%	27.6%
16.1	**Average**	21.3	22.3	20.8	20.8	23.4	21.1
	Std. Dev.	6.1	7.2	6.1	6.7	10.1	6.3
	CV	28.6%	32.3%	29.3%	32.2%	43.2%	29.9%

Statistical analysis showed no significant treatment effects on spacing for Planter B, however Planter A showed significant effects on spacing bias from the interaction between Row Type and Downforce as well as speed(Table 2).

Table 3.2. ANOVA test p-values for treatment effects on Spacing for Planter A

System: Planter A		P-value for Type 3 Tests of Fixed Effect						
Endpoint		Row Type	Speed	Row Type x Speed	Downforce	Row Type x Downforce	Speed x Downforce	Row Type x Speed x Downforce
Spacing (cm)	Bias	0.136	0.042	0.144	0.020	0.008	0.449	0.624
	Precision	0.576	0.551	0.660	0.040	0.368	0.682	0.876
	Accuracy	0.516	0.520	0.620	0.034	0.299	0.611	0.867

Planter A

Statistical analysis showed that Planter A had significant treatment effects on spacing from the interaction of Row Type and Downforce. Analysis shows that, while there is no difference in the spacing between D1 and D2 for the wing and track rows, Non-Track rows had different average spacing from D1 to D2. The average spacing at D1 was found to be 2.0 cm closer to the target spacing of 20.3 cm than the average spacing at D2. There were no other significant effects on spacing detected for Planter A.

Planter B

Planter B showed no significant treatment effects on plant spacing from Downforce, Speed, or Row-Type.

In summary, at the selected downforces of 54.4 kgf and 99.8 kgf and the 3 speeds of 9.1 kph, 12.1 kph, and 16.1 kph showed no effect on plant spacing at all for Planter B and speed had no effect in Planter A. However, Planter A showed that row type and downforce had an effect on plant spacing. The analysis shows that plant spacing was significantly lower at low downforce for Non-Track rows by 2.0 cm closer to the target spacing of 20.3 cm. Though this effect was observed, the cause is unclear.

Emergence

The summary data collected for emergence is shown in Table 3. Summary data was calculated with an ideal emergence taking place by day three. Therefore, values shown are the Day 3 emergence rate indices calculated for each treatment.

Table 3.3. Day 3 Emergence Rate Index for each treatment separated by Planter

Downforce, kgf	Speed, kph	Row Type	Day 3 ERI	
			Planter-A	Planter-B
54.4	9.7	Wing	94.9%	87.5%
54.4	9.7	Track	76.0%	82.6%
54.4	9.7	Non-Track	84.4%	69.9%
54.4	12.1	Wing	82.9%	87.0%
54.4	12.1	Track	72.2%	90.7%
54.4	12.1	Non-Track	84.2%	83.3%
54.4	16.1	Wing	85.7%	96.1%
54.4	16.1	Track	78.4%	87.8%
54.4	16.1	Non-Track	85.5%	84.3%
99.8	9.7	Wing	76.0%	57.7%
99.8	9.7	Track	75.0%	66.2%
99.8	9.7	Non-Track	64.7%	60.3%
99.8	12.1	Wing	76.9%	70.3%
99.8	12.1	Track	82.9%	61.8%
99.8	12.1	Non-Track	74.0%	64.0%
99.8	16.1	Wing	70.7%	80.6%
99.8	16.1	Track	57.1%	71.2%
99.8	16.1	Non-Track	75.0%	74.6%

ANOVA results indicated that the Planter A had no significant treatment effects on plant emergence. However, Planter B shows a significant interaction effect between Row Type and Downforce on emergence as shown in Table 4. In depth statistical analysis shows that Planter B exhibits a difference in emergence between 54.4 kgf of downforce and 99.8 kgf of downforce for track rows. Track rows displayed a 21% higher ERI by Day 3 at 54.4 kgf compared to the same rows at 99.8 kgf (Table 5). This increased emergence percentage could potentially be from reduced compaction due to the lower downforce within the track rows. This was the only significant treatment effect found regarding emergence for Planter B.

Table 3.4. ANOVA test p-values for treatment effects on Emergence for Planter B

System: Planter B	P-value for Type 3 Tests of Fixed Effect						
Endpoint	Row Type	Speed	Row Type x Speed	Downforce	Row Type x Downforce	Speed x Downforce	Row Type x Speed x Downforce
% of Emergence (w/in 3 days)	0.022	0.313	0.122	0.007	0.038	0.737	0.239

Table 3.5. Interaction table for Row Type and Downforce on emergence in Case System

Interaction effects of Row Type x Downforce			Mean		
System: Planter B					Diff (Adjusted p-Value) to
Endpoint	Row Type	Downforce	LSMean	Std. Err.	99.8 (kgf)
% of Emergence (w/in 3 days)	Non-Track	54.4	0.82	0.04	0.07 (0.746)
		99.8	0.75	0.04	---
	Track	54.4	0.94	0.04	0.21 (0.003)
		99.8	0.72	0.04	---
	Wing	54.4	0.92	0.04	0.09 (0.435)
		99.8	0.82	0.04	---

In summary, none of the treatment factors in this study showed a significant effect on emergence for Planter A. In Planter B there were no significant effects observed due to speed. However, the interaction between row type and downforce showed a significant effect on emergence with Track rows achieving 21% higher emergence by day 3 at 54.4 kgf compared to 99.8 kgf. This difference could be caused by the higher downforce potentially resulting in seed compaction in track row more than in other rows causing a delayed emergence in track rows at higher downforce.

Seed Depth

Seeding depth observed from both Planter A and Planter B is shown in Table 6.. The average seeding depth for all treatments was 4.4 cm for Planter-A and 5.2 cm for Planter-B respectively. The standard deviation indicated that seeding depth was within 0.9 cm of the target depth.

Table 3.6. Summary of Seeding Depth data in centimeters for Planters A and B including Average and Standard Deviation

		Planter A					
Speed, kph	Downforce	54.4 kgf			99.8 kgf		
	Row Type	Track	Non-Track	Wing	Track	Non-Track	Wing
9.7	Average	3.9	4.5	4.7	4.7	4.8	4.7
	Std. Dev.	0.7	0.5	0.7	0.6	0.8	0.7
12.1	Average	4.1	4.3	4.5	4.7	3.8	4.9
	Std. Dev.	0.8	0.6	0.9	0.5	0.9	0.6
16.1	Average	4.4	4.5	4.3	4.6	4.6	4.1
	Std. Dev.	1.0	0.8	0.9	0.8	0.9	1.3
		Planter B					
Speed, kph	Downforce	54.4 kgf			99.8 kgf		
	Row Type	Track	Non-Track	Wing	Track	Non-Track	Wing
9.7	Average	5.4	5.0	5.3	5.2	5.6	5.3
	Std. Dev.	0.5	0.7	0.5	0.4	0.4	0.4
12.1	Average	5.1	5.1	5.1	5.2	5.3	5.3
	Std. Dev.	0.5	0.4	0.4	0.5	0.5	0.7
16.1	Average	4.9	5.3	5.2	5.0	5.0	5.4
	Std. Dev.	0.4	0.3	0.3	0.3	0.6	0.5

Planter A

In depth statistical analysis found that there was a significant effect due to the interaction between row type and downforce level on seeding depth accuracy (Table 7). Analysis showed that the accuracy of seeding depth was over 3 times better at 99.8 kgf of downforce compared to 54.4 kgf of downforce for track rows. This effect did not extend to the other row types. Planter A also experienced an effect on seeding depth from operating speed. Although there was no difference found between 9.7 kph and 12.1 kph, analysis showed that the precision in depth management for these slower speeds was twice as good as the precision in seeding depth at 16.1 kph.

Planter B

Analysis showed that there was no effect on seeding depth for Planter B from any of the treatments.

Even with the differences in seeding depth by Planter A, both planters performed well and consistently placed the seed within a window of depth acceptable (0.64 cm) to most producers, except for the combination of low 54.4 kgf downforce and high 16.1 kph speed.

Statistical analysis showed no statistical treatment effects on seeding depth for Planter B, however Planter A showed significant treatment effects on seeding depth both from Speed (precision), interaction between Row Type and Speed (for bias) and the interaction between Row Type and Downforce (for accuracy).

Table 3.7. ANOVA test p-values for treatment effects on depth for Planter A

System: Planter A		P-value for Type 3 Tests of Fixed Effect						
Endpoint		Row Type	Speed	Row Type x Speed	Downforce	Row Type x Downforce	Speed x Downforce	Row Type x Speed x Downforce
Depth (mm)	Bias	0.600	0.644	0.043	0.453	0.076	0.805	0.377
	Precision	0.488	0.015	0.871	0.876	0.056	0.718	0.327
	Accuracy	0.441	0.106	0.086	0.272	0.003	0.718	0.150

Yield

The treatment effects on yield were analyzed for each system based on the average harvested yield without bias, precision, or accuracy calculations since there was no "target" value. The summary of the yield data collected is shown in Table 8 for both Planter A and Planter B. The average yield for all treatments was 13,913 kg/ha for Planter-A and 14,330 kg/ha for Planter-B respectively. The yields for Planter-A varied from 11,813 to 14,865 kg/ha and for Planter-B 13,276 to 15,053 kg/ha. Statistical analysis showed that there was no significant difference in yield between any of the treatments for either planter. Also, small variations in yield cannot reliably be attributed to planter performance due to the numerous factors that can affect yield.

Table 3.8. Summary of Yield data in kilograms/hectare for Planters A and B including Average and Standard Deviation

			Planter A				**Planter B**			
DownForce, kgf	**Speed, kph**	Row Type	Wing	Track	Non-Track	Overall Average	Wing	Track	Non-Track	Overall Average
54.4	**9.1**	Average	14476	14017	14181	14225	13832	13865	14533	14077
		Std. Dev	1117	741	283	714	234	859	711	665
	12.1	Average	13408	13835	13783	13675	14324	14833	14642	14600
		Std. Dev	1384	469	1375	1023	442	1583	1085	1010
	16.1	Average	14167	13789	14742	14233	13321	14940	15053	14438
		Std. Dev	1023	751	952	896	830	887	796	1110
99.8	**9.1**	Average	13896	14865	11813	13524	14409	14225	14169	14268
		Std. Dev	961	574	1236	1587	600	1691	1541	1187
	12.1	Average	13937	14522	13554	14004	15052	13276	13989	14106
		Std. Dev	711	539	575	678	809	297	1237	1080
	16.1	Average	14161	14230	13064	13818	14398	14320	14750	14490
		Std. Dev	935	932	331	885	279	1086	568	659

Conclusion

This research study provided the following findings:

1. Both planters provided accurate seed to seed spacing with some minor effects from treatments. Results show that if more accurate seed spacing is the priority of the operator Planter A would benefit from a lower downforce such as 54.4 kgf and Planter B would provide similar spacing regardless of downforce or operating speed
2. There were minimal differences between the emergence within each treatment for both planters. Planter A displayed uniform emergence across all treatments and Planter B displayed more uniform emergence at higher 99.8 kgf downforce.
3. Seeding depth control was very good for both systems. Both planters were able to maintain adequate and consistent depth control across all treatments with the exception of the combination of 54.4 kgf and 16.1 kph with Planter-A

Finally, the effects of planter downforce and speed on yield were examined for both systems. For both Planter A and Planter B there was no significant difference found between the yields of the different treatments.

In summary, both Planter-A and Planter-B are high quality systems that provide consistent and accurate seed placement in real world planting conditions. As long as the machine parameters are properly set for the planting conditions, both Planter-A and Planter-B will perform adequately.

Chapter 4 - Conclusion

Summary of Findings

Modern precision planters utilize advanced technologies such as electric seed metering units and hydraulic downforce systems. These technologies have allowed more precise control of seed placement when planting corn and other row crops. This research was focused on determining the useful benefits of these technologies and provided the following findings.

Turn compensation feature could provide accurate adjustments of seed and fertilizer inputs while planting on curvilinear areas. Research showed that in a typical field, when using a 16-row planter, turn compensation could be actuated on between 4.6% and 12.0% of the area. Collection of spacing data also confirmed that the turn compensation accurately corrected the seed spacing when planting on tight turns.

The relationship between speed and downforce setting was found to have an impact on seed spacing, depth, and emergence for two different planter systems. The two commercial precision planter technologies provided accurate seed to seed spacing with only minor effects from treatments. Planter-B (CASE IH planter with Precision Planting technology) would provide similar spacing regardless of speed and downforce settings, while planter-A (John Deere planter) would benefit from a lower 54.4 kgf downforce to improve spacing. Emergence was also very good across treatments for both planters with Planter-B having a more uniform emergence at the higher 99.8 kgf downforce. Depth control for both planters provided consistent seed placement across the planter toolbar. The only exception of this came from the combination of low 54.4 kgf downforce and high 16.1 kph speed while using Planter-A.

Implications

The significant utilization of turn compensation on a typical field when planting corn has the potential to reduce unnecessary seed and fertilizer inputs in addition to improving yield on curvilinear planted areas. This means turn compensation has the potential to improve profitability in corn production by both reducing inputs and increasing yield at the same time. With this added benefit, electric seed meters provide measurable value to a modern precision planter.

Examination of the combination of different downforce settings and speeds with two planter systems has shown that modern precision planters can provide accurate seed placement at many setting combinations. Modern technologies, like electric seed meters and hydraulic downforce, can allow growers to plant larger areas and be more efficient with their time using larger planters at high speed with confidence.

Future Work

Future work is recommended for each of the studies discussed in this paper. Further investigation on the typical use of turn compensation should be conducted using a larger 24 row planter to account for the growing popularity of larger planters. For the investigation of speed and downforce interactions, it is recommended that this research be conducted for an additional year to confirm results. It is also recommended that an additional downforce of 145 kgf be used to investigate potential compaction concerns raised by some growers.

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