Influence of Planter Downforce Setting and Ground Speed on Seeding Depth and Plant Spacing Uniformity of Corn

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A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada

Abstract. *Uniform seed placement improves seed-to-soil contact and requires proper selection of downforce control across varying field conditions. At faster ground speeds, downforce changes and it becomes critical to select the level of planter downforce settings to achieve the desired consistency of seed placement during planting. The objective of this study was to assess the effect of ground speed and downforce setting on seeding depth and plant spacing and to evaluate the relationship of ground speed and row unit ride quality on gauge wheel load and its impact on seed placement consistency. A 12-row Horsch planter equipped with a hydraulic downforce control was used for planting non-irrigated corn. Three levels of fixed downforce (FDF) and two levels of active downforce (ADF) settings along with four levels of planting speed (7.2, 9.7, 12.1 and 16.1 kph) were utilized in the experiment. The planter was programmed to plant corn at 5.08 cm (2 in)and 6.35 cm (2.5 in.) target seeding depths with seeding rate varying from 65,500 to 72,400 seeds/hectare (30,000 to 32,000 seeds/acre). Results suggests that planting speed and downforce setting influenced consistency in seed placement. Slower ground speed, medium setting for fixed downforce control and high setting for the active downforce control resulted in a more uniform seed placement as measured by significantly lower frequency of misses and doubles. Seeding depth was maintained within the range of the target by the medium and high setting for the fixed downforce control. Increasing the seeding depth by half inch resulted in an average of 77% reduction the gauge wheel load which caused the seeding depth to be outside the target range all the time. Both settings for the active downforce control exhibited an average seeding depth of within the range except at higher ground speed for the low setting. Row unit bounce increases with speed for both fixed and active downforce control.*

Keywords. *Downforce control, high-speed planting, seeding depth, uniform spacing, ride quality.*

Introduction

The goal of precision planters is to place the seeds in the soil that will provide conducive environment for even emergence. Proper seed placement is important to allow adequate moisture for the seed to germinate and prevent exposure to undesirable environmental conditions (Grassbaugh and Bennett, 1998). Controlling seed placement can be difficult when planter are operated at faster speed. Increasing the operation speed could cause the seeds to bounce around the seed tube which could result in uneven depth and spacing. Studies have shown the importance of planting at optimum depth where planting beyond the threshold depth could result in poor crop performance (Ozmerzi et al., 2002). Da Silva et al (2004) showed that seeding depth was the main factor underlying the emergence and vegetative development of corn. Results of the experiment revealed that emergence time significantly increased as seeding depth increases from 3 cm to 7 cm. Similarly, Molatudi and Mariga (2009) investigated the effect corn seeding depths on emergence on corn planted on a green house and results showed significantly difference on emergence at increasing seeding depth. Ozmerzi et al (2002) conducted a study using a precision seeder and examined the effects maximum emergence rate index and sowing uniformity at three different seeding depths. Results revealed no significant difference on sowing uniformity at varying seeding depths but maximum rate of emergence was achieved at nominal seeding depth of 6 cm. Likewise, planting at higher speed cause vibrations in the row units (Staggenborg, et al., 2004) which could reduce the gauge wheels rolling resistance due to inadequate application of downforce. Finding optimum down force can be challenging in terms of providing just enough load to prevent loss of ground contact of row units at varying soil conditions and at increasing speeds. Previous researches have demonstrated the negative effects of applying excessive load on the depth and emergence of corn. Planting with excessive load could over compact the soil (Hannah, 2009) while not enough load could result in a shallower seeding depth (Karayel, et al, 2011) and both situations could result in poor root development (Raper and Kirby, 2006) and uneven plant emergence (Karayel, et al, 2011, Hannah, et al, 2010, and Gratton, et al, 2003). Janelle et al. (1993) conducted a study on seed placement using different levels of double disc openers and downforces. Results suggested that insufficient seeding depth was achieved at the smallest downforce thus negatively affecting the crop emergence. Similarly, Neto et al (2012) conducted a static test on the effect of applied weights on press wheels on seeding depth and seedling emergence on corn. Results showed a significant effect on emergence time and seeding depth caused by the applied static load on press wheels. Thus, the two key planter performance parameters that can influence corn stand establishment are load on gauge wheels and planting speed in which it determines the quality of crop stand such as desired seed density, uniform emergence and planting depth. No single parameter is responsible for differences in final stand establishment among fields rather often a combination of factors during the planting operation (Lauer and Rankin, 2004). Several researches have examined the effect of ground speed on final stand establishment (Nielsen, 1995, Liu et al, 2004, Ozmerzi et al, 2002 and Staggenborg et al., 2004) however no data have been published to determine the effect of different downforce settings at varying ground speeds. Previous study (Sharda et. al, 2016) showed the variability on the gauge wheel loading on a planter equipped with a fixed downforce control setting during field operation and suggested future studies to quantify the influence of different planting speeds and downforce settings on seed placement uniformity under varying field conditions. Therefore, the objectives of this study was to assess the effect of planting speed and downforce setting on seeding depth and spacing and to evaluate the relationship of planting speed and row unit ride quality on gauge wheel load and its impact on seed placement consistency.

Methodology

Equipment set up and instrumentation

A Horsch Maestro 12 30 SW planter (Horsch Maschinen GmbH, Schwandorf, Germany) with variable rate and section control technology operated by a 4-wheel tractor (John Deere 8250R, Deere and Company, Moline, IL, U.S.A.) was used in planting. The 12 row units of the planter are spaced at 762 mm. The planter control was accomplished using a 2630 John Deere (GreenStar-3, Deere and Company, Moline, IL, U.S.A.) field computer connected to the planter electric control unit (ECU) (Horsch Maschinen GmbH, Schwandorf, Germany) through ISOBUS. The planter was programmed to implement automatic section control by automatically turning off electric motors (BG 45x15 SI, Dunkermotoren GmbH, Schwarzwald, Germany) of individual row units based on previously planted areas as recorded by the GPS on the planter. The ECU utilized the speed recorded by the GPS to generate the desired motor rpm to achieve the desired population. A seed sensor (Hy Rate Plus, Dickey-John Corp., Auburn, IL, U.S.A.) was placed along the seed tube on each row unit to provide feedback on seed singulation, doubles and misses shown in field computer. Each row unit was mounted with a load cell or sensors (Model 6784, Horsch Maschinen GmbH, Schwandorf, Germany) having a measuring range from 0 to 1000 kilogram-force (kgf) with a linear analog output of 4 to 20 mA. The load cells were calibrated to establish the correlation between the sensors analog output in mA to the sensors measurement range in kgf. Calibration was done by using the sensor to measure known weights and the resulting regression curve was used in calculating the gauge wheel load (GWL) by converting the real-time load sensor signal mA into kgf. The row units were grouped into control sections (Fig.1) wherein a pressure transducer was equipped on each section to measure the real-time hydraulic oil pressure applied during planting operation.

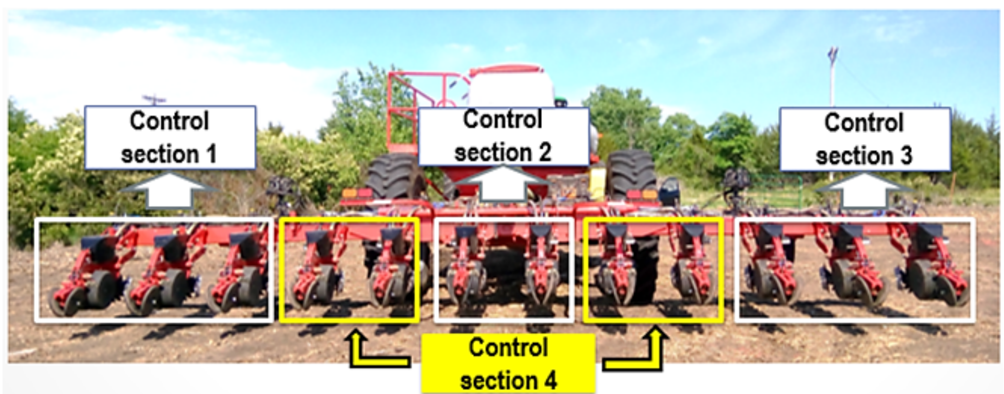

Figure 1. The planter toolbar segregated into 4 different control sections.

Oil pressure readings will show the hydraulic system applying constant pressure on row units thus maintaining a constant downforce during the planting operation. Control section 1 included the first three row units (rows 1, 2, 3), control section 2 consisted of row units in the middle of the toolbar (rows 6 and 7), control section 3 will contained the last three row units (rows 10, 11 and 12) and section 4 comprised the row units along the tire tracks (rows 4, 5, 8 and 9). Section 4 was included in the measurements and data analysis to remove load variability due to compaction effects by the tire tracks. Control sections 1, 2 and 4 were fitted with transducers having a measuring range between 0 to 25 mPa with an output signal of 4 to 20 mA (HDA 844L-A-0250-161, Hydac, Glendale Heights, IL, USA). Control section 2 was equipped with a transducer with measurement ranges from 0 to 52 mPa with an output signal of 0.5 to 4.5 V_{dc} (Model KM41, Ashcroft Inc., Stratford, CT, USA). Four row units (rows 1, 5 7, and 12) were equipped with accelerometers (Model 3741E1210G, PCB piezotronics, Depew, NY, USA) to record vibration which is a measure of ride quality of row units during planting. A potentiometer (Model 424A11A090B, Elabou sensor Technology Inc., Waukegan, IL, USA) was mounted on one row unit per control section to measure the vertical movement that will determine its operating position. It has a measurement range of 0 to 90 degrees with an output signal ranging from 4 to 20 mA.

RTK GNSS receiver (GR5, Topcon Positioning Systems, Inc., Livermore, CA, USA) was used to collect the location and speed simultaneously during planting. Output signals from the load cells, transducers, accelerometers, potentiometers and GPS data were recorded using a data acquisition system at 10 Hz sampling frequency.

Field test layout and analysis

The experiment was conducted in a no-till 27.8 hectares (69.5 acres) non-irrigated field located at Wamego, KS. Variable seeding rate of 74,000 to 79,000 seeds/ha (30,000 to 32,000 seeds/acre) was applied during planting which is equivalent to 16.5 cm to 17.8 cm (6.5 in to 7 in) plant spacing. The target seeding depths were 5.1 cm (2 in) and 6.35 cm (2.5 in). The target seeding population and depths was in accordance with the owner of the field. Location of experimental plots (Figure 2) were selected according to homogeneity in soil texture and terrain.

Figure 2. Measurement strips bounded by stakes along randomly selected rows in the experimental field.

Two experimental designs were implemented in the conduct of the study. For FDF experiment, two sets of experimental plots for each seeding depth were arranged in a split-plot design structure where four levels of planting speed (4.5 mph, 6.0 mph, 7.5 mph and 10 mph) were assigned to the whole plot and three levels of downforce setting (low, medium and high) to the subplot. Three different pulse width modulation (PWM) signals were selected to implement the low, medium or high fixed downforce setting. Controlling the downforce was done by adjusting the duty cycle for each setting such that low is set at a 50% duty cycle, medium at 75% duty cycle and high at 100% duty cycle. This is equivalent to a constant hydraulic oil pressure of 500, 700 and 1000 psi for low, medium and high settings, respectively. Each planting speed corresponds to a combination of downforce settings across the control sections and each combination had its own control shown in the monitor. A program was created to apply one combination of settings by selecting the appropriate control that corresponds to the treatment being applied for a particular planting speed as the planter traveled along the test plots. For the ADF experiment, test plots for each of the two levels of downforce control (active and high) were arranged in a randomized complete block design structure. Three blocks of four treatment plots were selected to which all four levels of speed treatments (4.5 mph, 6.0 mph, 7.5 mph and 10.0 mph) were randomly assigned. Active low setting was implemented by applying a pressure of 1,700 psi which is equivalent to a 140 lbf of target gauge wheel load (TGWL). A pressure of 2,100 psi equivalent to 220 lbf of TGWL was applied to implementation of the active high setting. The selected pressure for each level of setting remained the same across all speed levels along the test plots. Each level of planting speed was implemented by selecting the corresponding gear level on the tractor. A 0.6 m (17.5 ft) long measurement strips, which is the experimental unit (EU), were staked at randomly selected rows within the subplots were measurements of planting depth and plant spacing were made. This length is equivalent to 1/1000th acre for a row width of 30 inches which is recommended to achieve an adequate sample that would represent the rest of the field (Benson, 1990). Analysis of variance (ANOVA) were performed using the mixed procedure in SAS University Edition software (SAS Institute Inc, Cary, NC, USA). Comparison of between treatment levels and combinations were done using Fishers protected (Least significant difference) LSD test. Unless otherwise indicated, effects were considered statistically significant at the 0.05 level of probability.

Soil texture and electrical conductivity

Measurements of soil electrical conductivity (EC) and soil texture were made prior to planting. Soil EC was measured using a DualEM-1S electromagnetic induction sensor (Dualem, Inc., Milton, Ontario) mounted on a plastic sled attached to the drawbar hitch of a utility vehicle (John Deere Gator XUV825i, Deere and Company, Moline, IL, U.S.A.) equipped with a GPS guidance system (John Deere Starfire 3000 RTK GPS, Deere and Company, Moline, IL, U.S.A.) (Figure 3).

Figure 3.The DualEM-1S electromagnetic induction sensor used to collect soil EC_a

The DualEM-1S sensors utilizes electromagnetic induction (EMI) to measures apparent soil electrical conductivity (EC_a) hence direct ground contact in not needed. The EMI sensor was programmed to measure EC_a on both topsoil (30.5cm) and subsoil (60.9 to 91.4 cm) layers of the soil profile. The system (Figure 3) was used to acquire EC_a measurements every 6. 1 m (20 ft) across the field at an average speed of 9.4 kph (15 mph). EC_a and GPS data were recorded in TerraLogga (PCT, NSW, Australia) data logger. Results of the EC_a measurements were analyzed and EC_a maps were created showing distribution of soil textures (sand, silt and clay) across the field. Different locations representing each soil textural class were randomly selected and soil samples were collected using a standard soil core sampler. Soil moisture were measured using a portable soil moisture meter probe (FieldScout TDR 300, Spectrum Technologies, Inc.,Aurora, IL, USA). Collected soil samples were submitted for EC_a and soil textural analysis at the Department of Agronomy Soil Testing Laboratory at Kansas State University. Laboratory results showed correlation between the soil texture and soil EC_a where low textured soil resulted in a lower EC_a and vice versa. Soil EC_a data was themed using the natural breaks (jenks) method of classification in ArCMap 10.3 (ESRI, Redlands, CA, USA) in generating the soil EC_a map.

Field data collection

Plant spacing and population

Plant spacing was measured after emergence was completed. A 7.6-meter (25-feet) standard measuring tape (Leverlock, Stanley Black and Decker, New Britain, CT, USA) was laid out along the 0.6 meter strip and accumulated spacing readings were recorded. Theoretical plant spacing was calculated based on the plant population applied during planting and spacing of planter row units. Using the prescribed plant population for FDF and ADF experiments and spacing of the planter row units, the equivalent theoretical plant spacing was calculated to be 16.5 cm and 17.8 cm (6.5 in and 7 in) for FDF and ADF, respectively. Since standard deviation alone does not indicate uniformity in stand (Nafziger,1996), multiples and doubles along with singulation and precision were determined to quantify the consistency of plant spacing relative to the theoretical spacing (S_t). Thus, measures of plant spacing uniformity used in this study was in accordance with the indices set by the International Organization for Standardization (ISO) also used in the study by Kachman and Smith (1995). These are multiples index, miss index, quality of feed index and precision. Multiples index (D) specifies the number of spacings on each EU less than or equal to 0.5 times the S_t. This was calculated using the formula:

$$D = n_D / N \quad (1)$$

where n_D is the number of measured spacings less than or equal to 8.25 cm for the FDF and 8.9 cm for the ADF. N is the total number of spacings measured on each EU. Miss index (M) indicates the number of spacings on each EU that are greater than 1.5 times the S_t. This index was calculated using the formula:

$$M = n_M / N \quad (2)$$

where n_D i is the quantity of measured distance between successive plants that are greater than 24.75 cm and 26.7 cm for FDF and ADF, respectively. Quality of feed index (A) or singles calculates the proportion of measured spacings on each EU that are within 0.5 and 1.5 times the S_t. The following formula was used to calculate this index:

$$A = n_A / N \quad (3)$$

where n_A is the number of spaces measured that are within 8.25 cm to 24.75 cm for the FDF and 8.9 cm to 26.7 cm for the ADF. Precision (C) quantifies the variability of plant spacing after skips and doubles are removed or spacings that are are considered singles and was calculated using the following formula by Kachman and Smith (1995). Lower value indicates lower spacing variability.

$$C = s_A / S_t \quad (4)$$

where s_A is the standard deviation of n_A.

Seeding depth

Determining the seeding depth was performed by digging the seed of the emerged plants and measuring the distance of the seed from the ground surface. Measurement was done by scraping away loose soil to get down to the bare field level and a flat stick was placed on the furrow along the direction of travel of the planter. A standard 0.47-meter (1 –foot) ruler (Westcott, Fairfield, CT, USA) was used to measure the depth by placing it perpendicular to the flat stick with the zero end placed on the seed. Readings were recorded to the nearest 1.0 centimeter resolution.

Results and discussion

Plant spacing

Plant spacing measurements revealed no-significant differences on the average spacing and standard deviation (SD) across all downforce settings (Table 1) and across all planting speeds (Table 2). Although, an SD value of 6.7 cm is an acceptable precision in mechanical planting considering the planter performance and germination rate of seeds (Liu, et al, 2004). Differences on the multiple index shows that the incidence of doubles was influenced by downforce setting and speed. Medium setting resulted in a significantly lower frequency of doubles as shown by lower multiple index values compared to the low and high settings. Significantly different multiple index values were observed across ground speeds. Slower ground speed resulted in a lower incidence of doubles. No significant differences were observed for the miss index across all treatments. Quality of feed index and precision were significantly different for the downforce settings and planting speeds. Medium downforce setting and slower planting speed resulted in a higher feed index which caused a uniform spacing shown by the high precision. Effects observed for the downforce settings suggests insufficient load may have been applied at low setting and excessive load at high setting. Both situation could have affected the stability of row units during planting. Row units could have experienced too much bounce due to variability in terrain, texture and residue which caused the seeds to bounce inside the seed tube before dropping in the trench resulting in higher incidence of both misses and doubles thus lowering the feed index and precision. Influence of ground speed on spacing variability shows that seed placement can be affected as speed of planting increases. Although not significantly different, lower standard deviation of average spacing measurements shows less spacing variability at slower speed. These results are consistent with previous research findings on the effects of planter speed on variation in plant spacing (Staggenborg, et al., 2004 and Nielsen, 1995). While miss index is not statistically significant, quality of feed index was significantly higher at 7.2 kph (4.5 mph) to 9.6 kph (6 mph) ground speeds along with their precision. Faster ground speed showed the highest frequency of multiples and skips which caused the quality of feed index and precision to be low. Planting at faster speed may have affected the performance of the seed meters due to the row unit bounce. These vibration may have caused the seeds to be released inconsistently and bounced off along the seed tube before reaching the trench which resulted in non-uniform seed spacing. No significant differences can be observed on percent live population among all treatments but incidence of misses and doubles may result in varying final plant stands.

Table 1. Average plant spacing measurements and uniformity indices for the fixed downforce as influenced by the downforce settings.

Setting	Average spacing (cm)	SD, cm	Multiple index (%)	Miss index (%)	Quality of feed index (%)	Precision (%)	Live population (%)
Low	18.0 ^{ns}	7.65 ^{ns}	9.0 ^{a}	13.1 ^{ns}	75.8 ^{e}	21.9 ^{a}	94.3 ^{ns}
Med	18.0 ^{ns}	6.70 ^{ns}	5.3 ^{b}	10.0 ^{ns}	82.0 ^{f}	19.5 ^{b}	94.3 ^{ns}
High	18.1 ^{ns}	8.25 ^{ns}	6.8 ^{ab}	12.6 ^{ns}	79.8 ^{e}	21.3 ^{a}	94.3 ^{ns}

$^{e-f}$: similar letter notations indicates no significant differences at α=0.1.

Table 2. Average plant spacing measurements and uniformity indices for the fixed downforce as influenced by the planting speeds.

Speed, kph	Average spacing (cm)	SD (cm)	Multiple index (%)	Miss index (%)	Quality of feed index (%)	Precision (%)	Live population (%)
7.2	18.0 ^{ns}	6.5 ^{ns}	1.9 ^{a}	11.5 ^{ns}	87.4 ^{a}	18.2 ^{a}	94.4 ^{ns}
9.6	18.6 ^{ns}	6.9 ^{ns}	3.6 ^{a}	11.0 ^{ns}	81.4 ^{ab}	18.4 ^{a}	92.4 ^{ns}
12	17.6 ^{ns}	8.6 ^{ns}	9.2 ^{b}	11.0 ^{ns}	78.3 ^{b}	21.5 ^{b}	96.2 ^{ns}
16	17.9 ^{ns}	8.1 ^{ns}	13.3 ^{c}	14.1 ^{ns}	69.7 ^{c}	25.6 ^{c}	94.1 ^{ns}

Active downforce setting influenced the average plant spacing (Table 3) and ground speed influenced its standard deviation (Table 4). Average spacing was statistically different between the high and low setting. Higher incidence of missed seeds as shown by the significantly higher values of miss index for the low downforce setting resulted in a significantly lower quality of feed index. No significant differences was observed on the multiple index together with precision. Although average spacing are not statistically different across speed levels, planting speed of 16.1 kph (10 mph) revealed a significantly higher standard deviation compared to the other speed treatments. Spacing variability due to faster planting speed caused a higher incidence of misses and doubles as shown by highest values of miss and multiple indices, respectively. Such variation in spacing resulted in a significantly lower quality of feed index and precision when ground speed was increased. These results suggests that the set target gauge wheel load at low setting may have been inadequate to stabilize the row units thus minimizing vibration. These may have caused the seeds to bounce and roll as they exit the seed tube which resulted in uneven seed spacing. Applied gauge wheel load at high setting may have been enough to reduce row unit bounce resulting in a lower frequency of misses and doubles. As such, a quality of feed index of 82% was achieved, which shows the percentage of measured plant-to-plant spacings that were within the target spacing of 17.8 cm (7 inches). Planting within the range of 7.2 kph (4.5 mph) to 9.6 kph (6 mph) may have kept minimum row unit vibrations which allowed seeds to be dropped directly to the trench without too much contact along the seed tube and caused the low incidence of doubles. Planting at faster ground speed even with an active downforce control may have not prevented row unit vibration reducing the ride quality which may have caused ricocheting effect on metered seeds as they travel along the seed tube before dropping on the seed trench. These resulted in an increased number of misses and doubles which lowered the precision and fewer plant spaces within the target spacing.

Table 3. Average plant spacing measurements and uniformity indices as for the active downforce influenced by the downforce settings.

Setting	Average spacing (cm)	SD (cm)	Multiple index (%)	Miss index (%)	Quality of feed index (%)	Precision (%)	Live population (%)
Low	18.2 [a]	9.0 [ns]	6.9 [ns]	17.1 [a]	73.0 [a]	19.9 [ns]	93.6 [ns]
High	19.5 [b]	8.6 [ns]	6.4 [ns]	11.3 [b]	81.4 [b]	20.5 [ns]	95.4 [ns]

Table 4. Average plant spacing measurements and uniformity indices as for the active downforce influenced by the speed of planting.

Speed, kph	Average spacing (cm)	SD (cm)	Multiple index (%)	Miss index (%)	Quality of feed index (%)	Precision (%)	Live population (%)
7.2	18.8 [ns]	7.8 [e]	1.6 [a]	16.0 [eg]	78.5 [e]	17.1 [a]	93.4 [ns]
9.6	18.2 [ns]	8.6 [e]	1.6 [a]	12.2 [eg]	84.1 [e]	18.7 [ab]	94.5 [ns]
12	19.1 [ns]	8.3 [e]	8.0 [b]	10.8 [f]	80.2 [e]	21.2 [bc]	97.3 [ns]
16	19.3 [ns]	10.4 [f]	15.4 [c]	17.8 [e]	66.1 [f]	23.8 [c]	92.9 [ns]

[e-g]: similar letter notations indicates no significant differences at $\alpha = 0.1$.

Seeding depth

Target seeding depth was set at 5.08 cm (2 in) and a range of ±0.635 cm (0.25 in) of the target was selected to account for variability due to crop residue. Variability in the measured planting depth was influenced by ground speed when downforce is set at low setting (Figure 4). Ground speed of 7.2 kph (4.5 mph) was able to keep the average measured seeding depth within the range of the target but increasing the ground speed resulted in a shallower seeding depth. Effects observed suggests the fixed downforce low setting applied insufficient load to be able to maintain ground contact of row units at faster planting speed. This situation may have caused the opening discs to create a trench shallower than the desired depth. Medium and high fixed downforce setting was able to keep the average seeding depth within the range of the target across all speed treatments. This indicates that even with a fixed load set which could result in insufficient or excessive application of load across the field, these settings still were capable of keeping the row units on the ground most of the time which resulted in a uniform seeding depth even at faster ground speed. Selected load for medium and high settings, nonetheless, is still inadequate to achieve the target seeding depth of 2 5.08 cm (2inches).

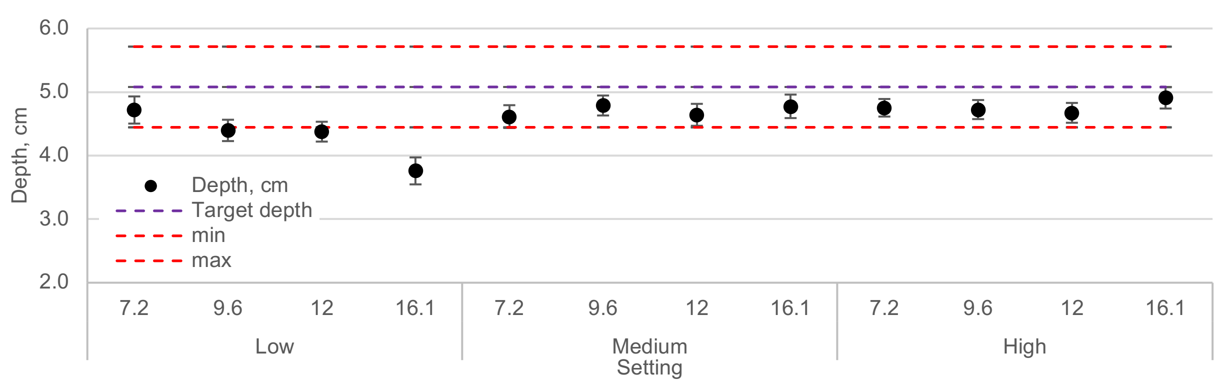

Figure 4. Average seeding depth for the fixed downforce setting at different ground speed

Interestingly, increasing the depth of planting to 6.35 cm (2.5 in) resulted in average measured seeding depth outside of the target range across all downforce settings and ground speed (Figure 5). Planting at faster ground speed resulted in a significantly shallow seeding depth at medium and high settings while high downforce setting achieved a seeding depths closer to the target. Such results suggests that different settings of downforce are required when target seeding depth varies during planting. Increasing the seeding depth by half an inch would require additional load for the opening discs for creating the soil furrow. Thus, implementing the settings for the 2 inch target depth when planting at 2.5 inches depth resulted in a shallower seeding depths.

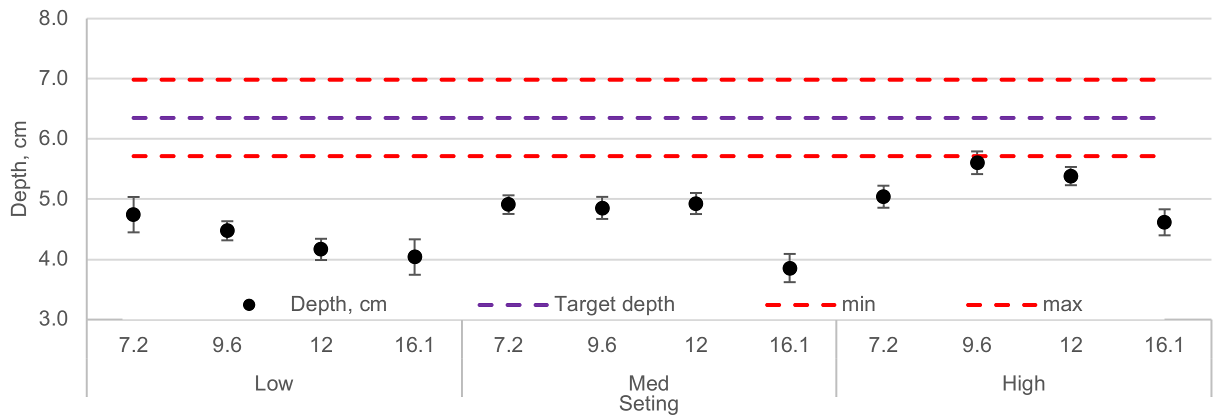

Figure 5. Average seeding depth for the fixed downforce setting across different ground speeds at 6.35 cm (2.5 in) target seeding depth

Figure 6 shows the influence of active downforce settings and speed on the average measured seeding depth. Active low setting was able to keep the average seeding depth within the range of the target across all speed treatments except at 16.1 kph (10 mph). Observed effects indicates that the target gauge wheel load was not able to stabilize the row units when planting at faster ground speed which may have reduced rolling resistance of gauge wheels due to row unit bounce thus it was not able to maintain the desired seeding depth. Planting at active high downforce setting achieved an average seeding depth that is within the range across all planting speed treatments. Planting at gound speed of 7.2 kph (4.5 mph) achieved an average measured seeding depth close to the target of 5.08 cm (2 inches). Such results indicates that active high setting was able to apply the desired load to keep the gauge wheel in ground contact and minimized row unit vibration which kept the depth within the target even at faster planting speed.

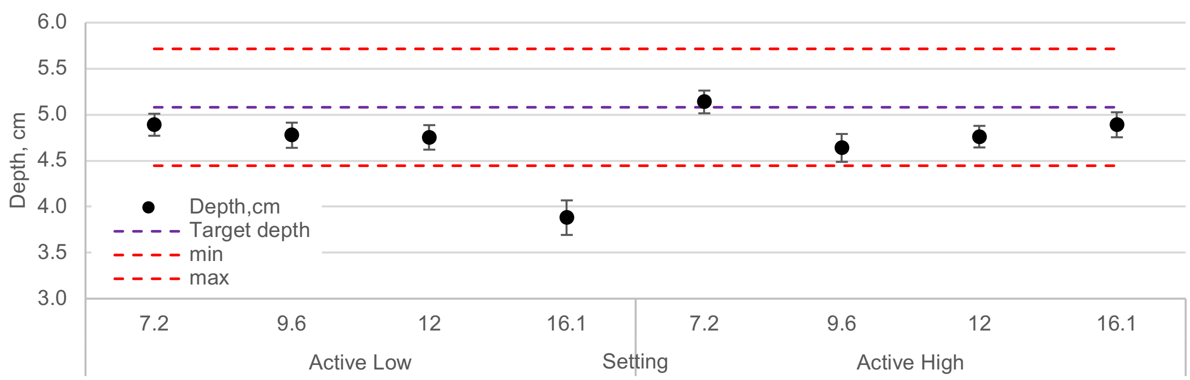

Figure 6. Average seeding depth for the active downforce setting at different ground speed

Row unit vibration and gauge wheel load

Row unit vibration was monitored using an accelerometer which provides the magnitude of row unit movements as shown by acceleration readings measured in g-force. Row unit bounce for the fixed downforce control increases with speed across all treatments of downforce setting (Figure 7). Average gauge wheel load is reduced at faster ground speed due to the increase in vibration of the row units as shown by the higher variability of the average gauge wheel load. Such vibrations implies that the downforce settings were not enough to apply the optimum amount of downforce at faster planting speed resulting in increased incidence of misses and doubles and the inability to achieve the desired target depth.

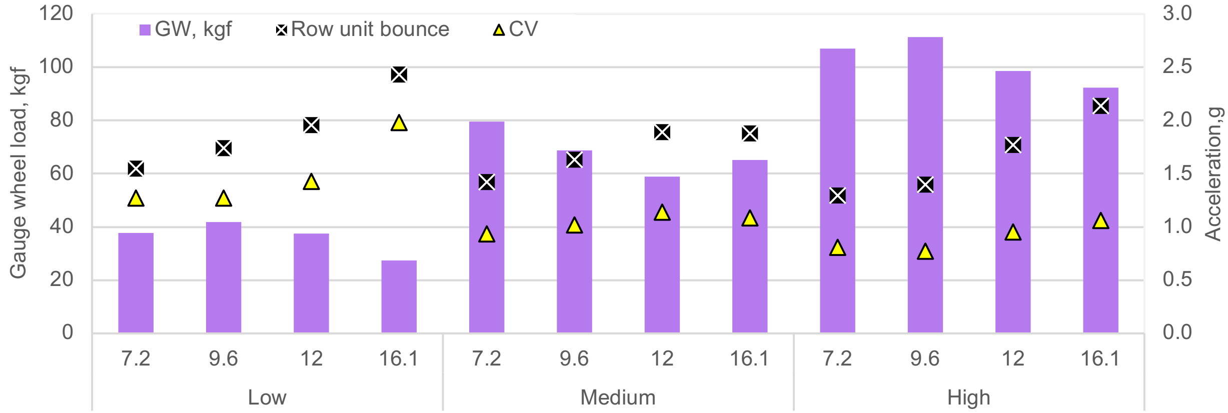

Figure 7. The response of row unit bounce at fixed downforce setting with increasing ground speed

Average gauge wheel load was significantly reduced when the target planting depth is increased by half an inch (Figure 8). Results suggested that load requirement for soil penetration was significantly higher at deeper seeding depth. Applied load across the downforce settings was not sufficient to minimize row unit bounce as the ride quality decreases with speed. High variability on the applied gauge wheel load may have influenced the ride quality which may have resulted in shallower seeding depth. High downforce setting across all ground speed resulted in a more uniform average gauge wheel load which corresponds to the measured seeding depth closer to the target (Figure 5). On the other hand, low downforce setting resulted in a more variable average gauge wheel load which may have caused a shallower measured seeding depth across all ground speed treatments.

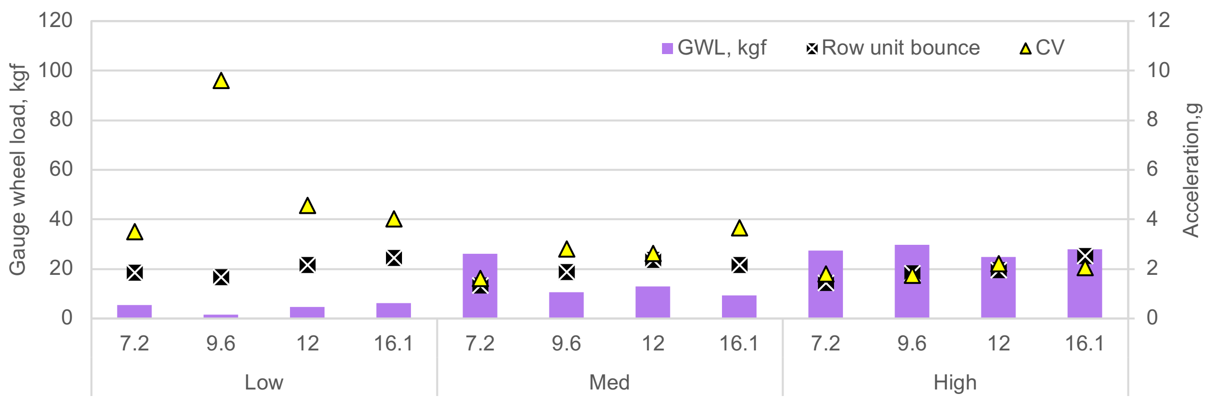

Figure 8. The response of row unit bounce at fixed downforce setting with increasing ground speed at 6.35 cm (2in) target seeding depth

Similar results can be observed on the row unit bounce for the active downforce control wherein ride quality decreases with speed (Figure 9). As expected, the active downforce control was able to keep the gauge wheel load within target for both active low (~70 kgf) and active high (~110 kgf) settings. Even with the target load being applied at higher ground speed, low setting was not able to maintain a seeding depth within the range of the target when planting at 16.1 kph (10 mph). Aside from ground speed, such result can be attributed to differences in soil conditions. Nevertheless, with almost 50% reduction in variability on the gauge wheel load compared to the fixed downforce control, lower variability of the average gauge wheel load may have caused the row units to maintain optimum ground contact most of the time. This caused the opening discs to create a uniform depth and allowed the seeds to be dropped uniformly in the trench with minimal bounce effects which caused a more uniform plant spacing and seeding depth closer to the target.

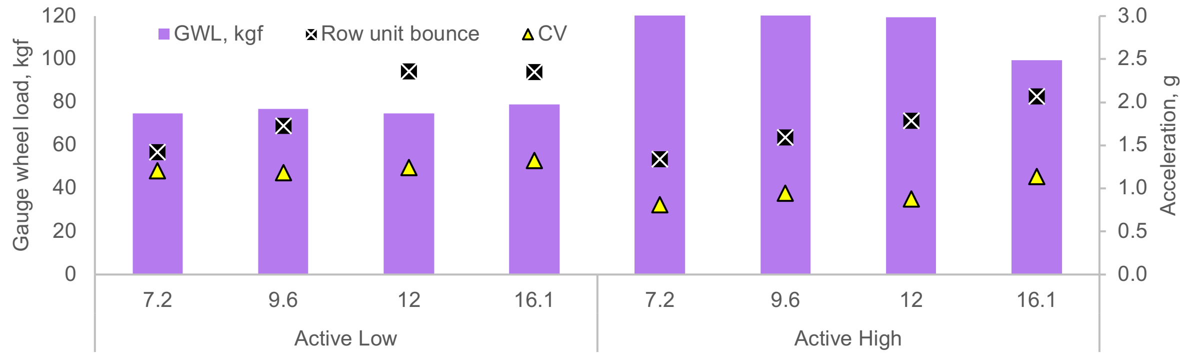

Figure 9. The response of row unit bounce at fixed downforce setting with increasing ground speed

Conclusion

Results revealed that the medium setting for fixed downforce control and high setting for the active downforce control achieved the lowest values for the multiple and miss indices. Such frequency of doubles and misses resulted in a quality of feed index of greater than 81% and precision of less than 21%. Planting at slower ground speeds ranging from 7.2 kph (4.5 mph) to 9.6 kph (6 mph) resulted in a higher quality of feed index for both fixed and active downforce controls which ranges from 78% to 87% and precision of 17% to 19%, respectively. Observed effects suggests that medium setting for fixed downforce control and high setting for the active downforce control along with slower ground speeds ranging from 7.2 kph (4.5 mph) to 9.6 kph (6 mph) could minimize row unit bounce which could result in a uniform seed placement. Medium and high setting for the fixed downforce control achieved an average seeding depth of 4.6 cm (1.8 in) to 4.9 cm (1.9 in) which is within the range of the target depth of 5.08 cm (2 in). Low setting indicates insufficient load to minimize row unit bounce at faster ground speed which resulted in a shallower seeding depth. Low and high setting for the active downforce control exhibited an average seeding depth of within the range of the target except when planting at a ground speed of 16.1 kph (10 mph) at low setting. Planting at 7.2 kph (4.5 mph) ground speed for the active high setting achieved the desired seeding depth. Increasing the target seeding depth by 0.5 inch resulted in an average seeding depth outside the range of the target across all downforce settings and ground speeds. Average gauge wheel load was insufficient to achieve the desired seeding depth. Row unit bounce increases with speed for both fixed and active downforce control. Such vibrations may have resulted in higher variability in the gauge wheel load for the fixed downforce control which might have caused more incidence of misses and doubles and the inability to achieve the target seeding depth. Smaller gauge wheel load variability was expected for the active downforce control which resulted in a fewer occurrence of misses and doubles and capability to achieve the desired seeding depth at slower speed

Acknowledgements

The authors would like to extend their great appreciation to Horsch LLC, USA for supporting this research; Kansas State University Biological and Agricultural Engineering Department for the supportive funding, data acquisition hardware and software and guidance system; and to Central Luzon State University (CLSU) and the Philippines' Department of Science and Technology-Engineering Research and Development for Technology (DOST-ERDT) for the scholarship of the primary author.

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