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FIELD SLOPE EFFECTS ON UNIFORMITY OF CORN SEED SPACING FOR THREE PRECISION PLANTER METERING SYSTEMS

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Field Slope Effects on Uniformity of Corn Seed Spacing for Three Precision Planter Metering Systems

C. L. Searle, M. F. Kocher, J. A. Smith, E. E. Blankenship

Abstract. *The effects of field slope on planter seed spacing uniformity were evaluated for three different seed metering units (cell plate, finger pick-up, and flat plate) operating with medium round corn seed in a laboratory using the University of Nebraska planter test stand with an opto-electronic seed spacing sensor system. The metering units included a John Deere MaxEmerge ™ Plus VacuMeter row unit with the standard cell corn plate, a John Deere MaxEmerge ™ Plus VacuMeter row unit with the flat plate, and a John Deere MaxEmerge ™ Plus row unit with the finger pick-up metering system. Planter seed spacing uniformity was measured using three parameters: ISO Miss index, ISO Multiples index, and Coefficient of Precision (CP3). Six replications for nine field slope treatments were conducted for each metering unit. The field slope treatments included: front-up (front of planter unit), front-down, right-up (right side of planter unit), and left-up (left side of the planter unit) each at field slope levels of 10% and 20%, and level.*

Slope and travel pattern had significant effects on the seed spacing uniformity for each of the three metering units tested. The finger pick-up was the least affected by slope as only the treatment of front-up at 20% slope had significantly worse seed spacing uniformity than the level treatment. For the cell plate metering unit, seed spacing uniformity was best with the planter on a level surface, or with the uphill-downhill travel pattern on a 10% slope, and on a 20% slope the uphill-downhill travel pattern had better seed spacing uniformity than the on-the-contour travel pattern. The finger pick-up metering unit had equally good seed spacing uniformity on a level surface and with either travel pattern on the 10% slope. On a 20% slope, the finger pick-up metering unit had better seed spacing uniformity with the on-the-contour travel pattern than with the uphill-downhill travel pattern. The flat plate metering unit had its best seed spacing uniformity with the front up on a 10% slope, followed by equivalent seed spacing uniformity between right up on a 10% slope and on a level surface. The flat plate metering unit had equivalent seed spacing uniformity between the travel patterns on a 10% slope, while on a 20% slope the uphill-downhill travel pattern had better seed spacing uniformity than the on-the-contour travel pattern.

Keywords. *Planters, Field slope, Precision planters, Seed spacing, Uniformity, Corn.*

Non-uniform spacing of corn plants has been shown to reduce yields by 5% to 10%. In 2005 approximately 33.1 million ha (81.8 million acres) of corn was planted in the United States (United States Department of Agriculture; National Agricultural Statistics Service, 2005). Using the 2005 average price of $2.00 per bushel, a 5% yield increase translates to an income increase of $111 million.

Glenn and Daynard (1974) demonstrated that uniform seed spacing increased corn yield up to 5.5%. Krall et al. (1977) showed that corn yield increased by 219 kg·ha^{-1} (3.5 bu/acre^{-1}) to 1211 kg·ha^{-1} (19.3 bu/acre^{-1}) from having uniform plant spacing compared to non-uniform plant spacing.

Several researchers have quantified change in corn yield as a function of change in standard deviation of seed spacing. Nafziger (1996) predicted that 10% plant skips would decrease corn yield by 180 kg·ha^{-1} per cm (7.4 bu/acre^{-1} per in.) increase in standard deviation of seed spacing and 10% doubles would increase yield by 130 kg·ha^{-1} per cm (12.9 bu/acre^{-1} per in.) increase in standard deviation of seed spacing with a population of 74,100 seeds per ha (30,000 seeds per acre). Doerge and Hall (2000) demonstrated that testing and adjusting metering units increased yield an average of 100 kg·ha^{-1} per cm (4.1 bu/acre^{-1} per in.) decrease in standard deviation of seed spacing uniformity. Nielsen (2001) determined a yield increase of 62 kg·ha^{-1} per cm (2.5 bu/acre^{-1} per in.) decrease in standard deviation of seed spacing uniformity. Doerge et al. (2002) suggested that yield can be increased an average of 84 kg·ha^{-1} per cm (3.4 bu/acre^{-1} per in.) decrease in standard deviation of within-row spacing. They concluded that poorly spaced and missing

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plants decreased yield while an occasional extra plant increased yield.

Panning et al. (2000) tested planters in the field and in the laboratory. Field tests consisted of planting sugarbeet seed in the field and then carefully uncovering each seed. Seed spacing measurements were taken and compared to seed spacing measurements obtained in the laboratory using the opto-electronic system developed by Kocher et al. (1998). Panning et al. (2000) found that seed spacing uniformity in the laboratory was better than or equal to the seed spacing uniformity found in field testing. Differences in seed spacing uniformity were attributed to seed bounce and roll, which occurred in the furrow but not in the laboratory test method.

The operator's manual for the John Deere 1700 and 1730 MaxEmerge™ Plus planters (Deere & Company, 2003) notes that special care should be taken to ensure that the planter be "leveled" on a level surface for optimum operation and performance of the planter units. Deere recommends that when planting on hillsides a flat seed disk with a doubles eliminator or a smaller cell plate be used with their 1700 and 1730 MaxEmerge™ Plus Integral Planters (Deere & Company, 2003). This suggested that field slope could affect the seed spacing accuracy of planters.

Quick and Buchelle (1978) reported that in 1977, 45% of the U.S. land in production agriculture was on slopes ranging from 6% to 18%, including some prime corn and soybean growing regions. The ISO Standard 7256/1 (International Organization for Standardization, 1984) for evaluation of precision planter performance states that planter units should be tested on a 20% slope. Searle (2006) analyzed field slope data (U.S. Department of Agriculture; Natural Resource Conservation Service, 2005) for the top five corn producing states in the United States in 2004 (Iowa, Illinois, Nebraska, Minnesota, and Indiana). The results showed that about 83% of the land considered had slopes of 10% or less, only about 9% had slopes between 10% and 18%, and about 8% had slopes greater than 18%. Nebraska was somewhat different from the other four states in the study as only about 66% of the Nebraska land considered had slopes of 10% or less, about 14% had slopes between 10% and 18%, and about 20% had slopes greater than 18%. This indicates Nebraska has a higher percentage of crop land on which corn is grown with higher field slope than the other four states in the study.

Objectives

The overall objective of this study was to determine the effects of field slope and travel direction on corn seed spacing uniformity for three seed metering units (cell plate, flat plate, and finger pick-up).

Procedure

This experiment was conducted in a laboratory setting using the University of Nebraska Planter Test Stand with opto-electronic system to measure seed spacing (Kocher et al., 1998; Lan et al., 1999). Three metering units were tested: a John Deere MaxEmerge™ Plus VacuMeter using the standard corn cell plate (John Deere part number A50617), a John Deere flat plate (John Deere part number A52904), and a John Deere finger pick-up metering unit (John Deere part number AA60535). The metering units were comparable to the commonly used units in the Midwest for planting corn and soybeans. Each of the metering units was in used and well maintained condition, and was tested using the curved seed tube (part number A56784) manufactured with a ramp above the sensor hole.

Treatment levels for slope were: level, 10%, and 20% (6 and 11 degree angles). Treatment levels for travel direction of uphill (front-up), downhill (front-down), left-side-up, and right-side-up were each used on both the 10% and 20% slopes. Due to safety constraints when tilting the test stand the maximum slope used for the front-up and front-down orientations was limited to 17% (9 degree angle).

The seed spacing descriptive parameters used in the analysis were Coefficient of Precision (CP3), ISO Miss index, and ISO Multiples index. The Coefficient of Precision rating (CP3) is the percent of actual spacings that were within ±1.5 cm of the theoretical spacing (Smith et al., 1991; L'Institut Technique Français de la Betterave Industrielle, 1994; Searle, 2006). A miss is defined as "the absence of a seed where there should be a seed" (International Organization for Standardization, 1984; Searle, 2006). For the ISO Miss index, the ISO Standard classifies "all spaces larger than 1.5 times the theoretical spacing" as a miss. A multiple is defined as "the presence of two seeds where there should be one" (International Organization for Standardization, 1984; Searle, 2006). For the ISO Multiples index, the ISO Standard classifies "all spacings less than one-half times the theoretical seed spacing" as multiples. The ISO Miss and Multiples indices are both expressed as percentages of the theoretical number (rather than the actual number) of seed spacings. Note that better seed spacing uniformity is indicated by larger CP3 values and smaller values for both the ISO Miss index and the ISO Multiples index.

Medium round corn seed was used throughout the experiment to minimize variation due to the size and shape of the seed (Coleman, 2004). The seed used was Jirdon Agri hybrid seed corn, variety JA2100, with 87,950 seeds per 22.7-kg (50-lb) bag, lot number RJA 6/05GC, and grade of medium round. Seed was only used once for a test run, and not reused during the test. Talc was used with the seed for the cell and flat plate metering units at the recommended rate of 118 cm^3 of talc to 40.7 kg (1/2 cup of talc to 1.6 bushel) of seed . Graphite was used in the finger pick-up metering unit at the recommended rate of 14.8 cm^3 per 40.7 kg (1 tablespoon per 1.6 bushel) of seed (Deere & Company, 2003).

An equivalent field speed (rotational speed of the metering unit mechanism) of 6.5 $km \cdot h^{-1}$ (4.0 $mile \cdot h^{-1}$) was selected for all tests. While this field speed is at the low end of typical field speeds used by producers, it allowed for increased ability to discern differences in seed spacing uniformity among slope and travel direction treatments, when differences did occur.

The target seed spacing for all treatments with all metering units was 17.8 cm (7.0 in.), based on a typical seed population of 74,100 seeds per ha (30,000 seeds per acre) with 76-cm (30-in.) row spacing. The mechanical drive system for each metering unit mounted on the test stand used discrete combinations of sprockets. Because of the drive sprocket combinations available, the actual theoretical seed spacings were 17.7, 17.2, and 15.9 cm (6.97, 6.78, and 6.27 in.) for the cell plate, finger pick-up, and flat plate metering units, respectively.

The respective planter operator's manual was consulted for recommended initial settings of vacuum pressure for the flat plate and cell plate metering units, and adjustment for the doubles eliminator (kit, John Deere part number AA61046) for the flat plate metering unit, with the particular seed and field speed used in this study. These settings were fine-tuned with each metering unit operating on a level surface, as recommended by the operator's manuals. This fine-tuning was done by examining the seed spacing results of a series of test runs at settings above and below the recommended initial adjustments. Final vacuum pressures chosen were 20.3 and 38.1 cm (8.0 and 15.0 in.) H_2O for the cell and flat plate metering units, respectively. The doubles eliminator was set to cover 25% of the seed hole for the flat plate metering unit. The finger clearance adjustment for the finger pick-up metering unit was adjusted according to the operator's manual. These final adjustments were maintained throughout the experiment as the focus of the experiment was on determining differences in seed spacing uniformity among the slope and travel direction treatment combinations within the individual metering units.

Transient start-up effects for each test run were avoided by starting the test stand and allowing the planter to meter seed for about 10 s before data collection was initiated. The spacings for 800 seeds (799 spacings) were recorded during each test run.

Statistical Analysis

The experimental design was a split-plot design in which the whole plot experimental units were arranged in randomized complete blocks. The main treatment factor was the seed metering units. There were six complete blocks of main plot experimental units and the block effect was time. The subplot treatment was the slope on which the planter was operated. The order in which the slope treatments were applied was randomized separately for each metering unit in each block. All field slope treatments for a seed metering unit were conducted consecutively before switching to the next metering unit.

The data were analyzed using a split-plot analysis of variance, implemented in SAS PROC GLIMMIX (SAS, 2004). To account for multiple comparisons among the treatments, the simulate option in PROC GLIMMIX was used to calculate adjusted p-values. For all of the tests conducted a level of 5% was used to determine significance. Least Square Means were used for comparisons to adjust for the random effect introduced by the split-plot design.

An arcsine square root transformation is recommended when working with data consisting of percentages to stabilize variances in binomial distributions. The residuals were graphed and the graphs did not display a problem with non-constant variance which indicated it was not necessary to use the arcsine square root transformation for this study.

When considering travel patterns, farmers commonly plant traveling in one direction, turn around, and plant coming back in the opposite direction. This results in two possible travel patterns to consider on sloped fields. In many Nebraska fields with slopes, the preferred travel pattern is on-the-contour, going one direction (e.g. left side up) and coming back the other direction (right side up). When circumstances warrant, Nebraska farmers may plant with an uphill (front up) and downhill (front down) travel pattern. This made it logical to compare seed spacing uniformity of each of the three metering units with an uphill-downhill (front up-front down) travel pattern against an on-the-contour (left up-right up) travel pattern.

Three sets of comparisons were made. The first comparisons determined for each metering unit, which combinations of slope and travel direction had significantly different seed spacing uniformity from that on level ground. Second, the seed spacing uniformity was compared among travel patterns for each metering unit at each slope. Third, the seed spacing uniformity was compared among metering units for each travel pattern at each slope. As only one of each metering unit was used in the experiment the third comparisons are valid for the specific metering units tested.

Results and Discussion

For the Deere metering units used, the seeds were on the left side of the seed plates. With the geometry of the seed drop tube below the metering unit, operating on side slopes (left up or right up) greater than about 4% means that seeds will contact the inside of the tube side wall before exiting the seed tube (e.g. with right up slope, seeds contact left side wall). Contact of the seed with the walls of the seed tube increases the chances of affecting the time of the seed drop event, leading to variation in spacing. With 10% front up slopes, the seeds will likely fall freely inside the tube for the longest distance before contacting the inside front surface, so this treatment has the potential to have good seed spacing uniformity. As the steepness of the front up slope increases above about 18%, the seed will much more likely contact the inside *back* surface of the seed tube, causing more seed bounce in the tube, degrading the seed spacing uniformity.

Performance on Slopes Compared to Level

The seed spacing uniformity of each metering unit on the slopes in all travel directions was compared to its uniformity on a level surface, with the significant differences noted in table 1. The finger pick-up metering unit was least sensitive to slope, as only one of the eight slope-travel direction treatment combinations had seed spacing uniformity different (all three seed spacing uniformity parameters) than on a level surface. The cell plate metering unit had four of the eight slope-travel direction treatment combinations with seed spacing uniformity different from on a level surface for all three seed spacing uniformity parameters, and another treatment combination with CP3 different from on a level surface. For the flat plate metering unit seven of the eight slope-travel direction treatment combinations had at least one seed spacing uniformity parameter different from on a level surface.

Cell Plate

For the cell plate metering system, seed spacing uniformity was best with the treatments of the planter level, or at a 10% slope with the front up and front down travel directions (table 1). With slopes of 20%, the cell plate metering system was able to maintain its highest seed spacing uniformity only with the front down travel direction.

The averages of the LS Mean values for the uphill-downhill and on-the-contour travel patterns are given in table 2, with significant differences noted in the table. The

Table 1. LS Mean values for Coefficient of Precision (CP3), ISO Miss index, and ISO Multiples index for the three types of planter metering units operated on the level, and with field slope treatments.

Meter	Treatment: Slope	Treatment: Direction	LS Mean for CP3 (%)[a]	LS Mean for ISO Miss Index (%)	LS Mean for ISO Multiples Index (%)
Cell	0%	Level	57.3	0.67	1.05
	10%	Front up	61.6	0.42	1.16
		Front down	58.6	0.71	1.05
		Left up	29.2**[b]	2.00**	3.06**
		Right up	41.6**	1.21	1.49
	20%	Front up	45.5**	2.79**	3.42**
		Front down	56.1	0.86	1.28
		Left up	32.6**	2.08**	3.89**
		Right up	37.7**	1.86**	2.11**
Finger	0%	Level	53.9	1.92	0.41
	10%	Front up	55.7	1.83	0.42
		Front down	52.9	1.87	0.47
		Left up	56.7	2.17	0.58
		Right up	53.0	1.65	0.64
	20%	Front up	40.1**	3.29**	1.96**
		Front down	52.5	2.22	0.72
		Left up	52.5	2.04	0.89
		Right up	54.6	2.20	1.01
Flat	0%	Level	46.4	1.01	2.26
	10%	Front up	57.0**	1.18	2.48
		Front down	44.0	1.64	3.70**
		Left up	42.2	2.03**	4.56**
		Right up	51.0	0.59	2.31
	20%	Front up	38.6**	1.43	3.89**
		Front down	39.4**	2.04**	4.25**
		Left up	40.3**	3.26**	5.77**
		Right up	38.5**	1.66	2.68

[a] Standard errors for CP3, ISO Miss index, and ISO Multiples index were 1.63%, 0.21%, and 0.23%, respectively.
[b] ** Indicates the mean for this treatment was significantly different at the 0.05 level from the value for the same parameter with the level treatment within the same metering unit.

cell plate metering system with the uphill-downhill travel pattern had better seed spacing uniformity than the on-the-contour travel pattern for all three seed spacing uniformity parameters with the 10% slope treatment, and for the CP3 parameter with the 20% slope.

Finger Pick-Up

The finger pick-up metering unit maintained its seed spacing uniformity performance on all slope conditions compared to level, except for planting uphill on a 20% slope (table 1). On a 20% slope, the finger pick-up metering unit planting with the on-the-contour travel pattern had seed spacing uniformity not significantly different from planting on the level, and the CP3 value for planting with the on-the-contour travel pattern was better than for planting with the uphill-downhill travel pattern (tables 1 and 2).

Flat Plate

For the flat plate metering unit on a 10% slope, the best seed spacing uniformity was obtained with the front up treatment, followed by equivalent seed spacing uniformity between the level treatment and the right up treatment.

Table 2. Average LS Mean values of the seed spacing uniformity parameters for each of the travel pattern combination treatments with each planter metering unit operated at each slope level.

Meter	Treatment: Slope	Treatment: Travel Pattern	Coefficient of Precision (CP3) (%)[a]	ISO Miss Index (%)	ISO Multiples Index (%)
Cell	10%	Front up-front down	60.1**[b]	0.6**	1.1**
		Left up-right up	35.4**	1.6**	2.3**
	20%	Front up-front down	50.8**	1.8	2.4
		Left up-right up	35.2**	2.0	3.0
Finger	10%	Front up-front down	54.3	1.8	0.4
		Left up-right up	54.8	1.9	0.6
	20%	Front up-front down	46.3**	2.8	1.3
		Left up-right up	53.5**	2.1	0.9
Flat	10%	Front up-front down	50.5	1.4	3.1
		Left up-right up	46.6	1.3	3.4
	20%	Front up-front down	39.0	1.7**	4.1
		Left up-right up	39.4	2.5**	4.2

[a] Standard errors for CP3, ISO Miss index, and ISO Multiples index were 1.36%, 0.161%, and 0.163% respectively.
[b] ** Indicates a significant difference at the 0.05 level for this parameter between the means of the front up-front down and left up-right up travel patterns at the same slope and with the same metering unit.

The comparison between the uphill-downhill and on-the-contour travel patterns for the flat plate metering system at 10% slope showed no significant differences in seed spacing uniformity (table 2).

For the flat plate metering unit with the 20% slope treatments, table 1 shows that the CP3 was worse for all four of these treatments, the ISO Miss index was worse for two of these four treatments, and the ISO Multiples index was worse for three of these four treatments than on a level surface. Table 2 indicates that for the flat plate metering unit with the 20% slope treatment, the uphill-downhill travel pattern had better seed spacing uniformity (lower ISO Miss index) than for the on-the-contour travel pattern.

Comparisons Among Metering Units

The LS Means for each of the specific metering units tested are given in table 3 with significant differences noted. On a level surface, the cell plate metering unit had better seed spacing uniformity (lower ISO Miss index) than the finger pick-up metering unit, which had better seed spacing uniformity (lower ISO Multiples index) than the flat plate metering unit.

On a 10% slope with the uphill-downhill travel pattern, the cell plate metering unit had better seed spacing uniformity (lower ISO Miss index) than the finger pick-up metering unit, which had better seed spacing uniformity (lower ISO Multiples index) than the flat plate metering unit (table 3). On a 10% slope with the on-the-contour travel pattern, the finger pick-up metering unit had better seed spacing uniformity (larger CP3 and smaller ISO Multiples index) than both the cell plate and flat plate metering units. On a 10% slope with the on-the-contour pattern, it is not clear which of the flat plate and cell plate metering units had better seed spacing uniformity as the flat plate metering unit had a higher CP3, while the cell plate metering unit had the lower ISO Multiples index.

Table 3. LS Mean values for Coefficient of Precision (CP3), ISO Miss index, and ISO Multiples index noting significant differences among the three types of planter metering units operated at each slope level.

Slope	Travel Pattern	Metering Unit	Coefficient of Precision (CP3) (%)[a]	ISO Miss Index (%)	ISO Multiples Index (%)
0%	Level	Cell	57.3 a	0.67 a	1.05 a
		Finger	53.9 ab	1.92 b	0.41 a
		Flat	46.4 b	1.01 ab	2.26 b
10%	Front up-front down	Cell	60.1 a	0.6 a	1.1 a
		Finger	54.3 ab	1.8 b	0.4 a
		Flat	50.5 b	1.4 b	3.1 b
	Left up-right up	Cell	35.4 c	1.6 a	2.3 b
		Finger	54.8 a	1.9 a	0.6 a
		Flat	46.6 b	1.3 a	3.4 c
20%	Front up-front down	Cell	50.8 a	1.8 a	2.4 b
		Finger	46.3 a	2.8 b	1.3 a
		Flat	39.0 b	1.7 a	4.1 c
	Left up-right up	Cell	35.2 b	2.0 a	3.0 b
		Finger	53.5 a	2.1 a	0.9 a
		Flat	39.4 b	2.5 a	4.2 c

[a] For comparisons between metering units at the same slope level, means for a seed spacing parameter followed by the same letter were not significantly different at the 0.05 level.

On a 20% slope with the uphill-downhill travel pattern, the cell plate metering unit and the finger pick-up metering unit appear to have similar seed spacing uniformity as their CP3 values are not different, and while the cell plate metering unit has the lower ISO Miss index, the finger pick-up metering unit has the lower ISO Multiples index (table 3). On a 20% slope with the uphill-downhill travel pattern, both the finger pick-up and cell plate metering units appear to have better seed spacing uniformity than the flat plate metering unit, as they have higher CP3 and lower ISO Multiples index values, although the flat plate metering unit has an ISO Miss index value as low as the cell plate metering unit, and lower than the finger pick-up metering unit.

On a 20% slope with the on-the-contour travel pattern, the finger pick-up had better seed spacing uniformity (higher CP3 and lower ISO Multiples index) than the cell plate and flat plate metering units, while the cell plate metering unit had better seed spacing uniformity (lower ISO Multiples index) than the flat plate metering unit.

When considering the seed spacing uniformity of the three metering units overall, the cell plate had the best seed spacing uniformity on a level surface. On a 10% slope, the cell plate had the best seed spacing uniformity for the uphill-downhill travel pattern, while the finger pick-up had the best seed spacing uniformity for the on-the-contour travel pattern. On a 20% slope, the finger pick-up had the best seed spacing uniformity for the on-the-contour travel pattern, while for the uphill-downhill travel pattern, the cell plate and finger pick-up metering units had approximately equal seed spacing uniformity, and better seed spacing uniformity than the flat plate metering unit.

Summary and Conclusions

For the three metering units tested (cell plate, flat plate, and finger pick-up) with a speed of 6.44 $km \cdot h^{-1}$ (4.0 $mile \cdot h^{-1}$) with medium round corn seed, slope and travel direction did have significant effects on seed spacing uniformity. The finger pick-up metering unit was least sensitive to slope and travel direction in that only one of eight treatments involving operation on slopes of 10% and 20% had significantly worse seed spacing uniformity than the treatment involving operation on the level. For the flat plate and cell plate metering systems, seven of eight treatments for operation on a slope of 20%, and four of eight treatments for operation on a slope of 10% had significantly worse seed spacing uniformity for at least one of the three seed spacing uniformity parameters than operation on the level.

For the cell plate metering unit, seed spacing uniformity was best with the planter operating on the level, or with the uphill-downhill travel pattern on a 10% slope. The cell plate metering unit had significantly better seed spacing uniformity with the uphill-downhill travel pattern for slopes of 10% and 20% than with the on-the-contour travel pattern.

The finger pick-up metering unit did not have a significant change in seed spacing uniformity in all travel directions on the 10% slope compared to level. On the 20% slope, the finger pick-up unit had better seed spacing uniformity with the on-the-contour travel pattern than with the uphill-downhill travel pattern.

For the flat plate metering unit, the best seed spacing uniformity was obtained with the front up on a 10% slope. The next best seed spacing uniformity was with the level treatment or the right up on a 10% slope. There were no significant differences in seed spacing uniformity between the travel patterns with the flat plate on a 10% slope. The uphill-downhill travel pattern with the flat plate metering unit on a 20% slope had better seed spacing uniformity than with the on-the-contour travel pattern.

Comparisons among the metering units were made and showed that on the level surface the cell plate metering unit tested had better seed spacing uniformity than either the flat plate or finger pick-up metering units. On a 10% slope, the cell plate had the best seed spacing uniformity for the uphill-downhill travel pattern, while the finger pick-up had the best seed spacing uniformity for the on-the-contour travel pattern. On a 20% slope, the finger pick-up had the best seed spacing uniformity for the on-the-contour pattern, while for the uphill-downhill travel pattern, the cell plate and finger pick-up metering units had approximately equal seed spacing uniformity, and better seed spacing uniformity than the flat plate metering unit.

References

Coleman, J. M. 2004. Corn seed spacing as influenced by seed shape and seed tube condition. Unpublished M.S. thesis. Lincoln, Nebr.: University of Nebraska Libraries.

Deere & Company. 2003. Operator's manual 1700 and 1730 MaxEmerge™ Plus Integral Planters (North American Edition) OMA77209 Issue E3 (English). Moline, Ill.: Deere & Co.

Doerge, T., and T. Hall. 2000. The value of planter calibration using the MeterMax* system. *Crop Insights* 10(23): 1-4.

Doerge, T., T. Hall, and D. Gardner. 2002. New research confirms benefits of improved plant spacing in corn. *Crop Insights* 12(2): 1-5.

Glenn, F. B., and T. B. Daynard. 1974. Effects of genotype, planting pattern and plant density on plant-to-plant variability and grain yield of corn. *Canadian Journal of Plant Science* 54: 323-330.

International Organization for Standardization. 1984. Sowing Equipment - Test Methods - Part one. Single seed drills (precision drills). 7256/1. Geneva, Switzerland: ISO

Kocher, M. F., Y. Lan, C. Chen, and J. A. Smith. 1998. Opto-electronic sensor system for rapid evaluation of planter seed spacing uniformity. *Transactions of the ASAE* 41(1): 237-245.

Krall, J. M., H. A. Esechie, R. J. Raney, S. Clark, G. TenEyeck, M. Lundquist, N. E. Humburg, L. S. Axthelm, A. D. Dayton, and R. L. Vanderlip. 1977. Influence of within-row variability in plant spacing on corn grain yield. *Agronomy Journal* 69(5): 797-799.

Lan, Y., M. F. Kocher, and J. A. Smith. 1999. Opto-electronic sensor system for laboratory measurement of planter seed spacing with small seeds. *J. Agric. Engng. Res.* 72(2): 119-127.

L'Institut Technique Français de la Betterave Industrielle. 1994. Compte rendu des travaus effectuès en 1994. Semoirs, Essai comparatif de semoirs à Marcelcave (Somme). L'Institut Technique Français de la Betterave Industrielle, 45 Rue de Naples, 75008 Paris, France. pp. 22-59. (language: French).

Nafziger, E. D. 1996. Effects of missing and two-plant hills on corn grain yield. *J. of Production Agriculture* 9(2): 238-240.

Nielsen, R. L. 2001. Stand establishment variability in corn. AGRY - 91 - 1 (rev. Nov. -01). Department of Agronomy. W. Lafayette, Ind.: Purdue Univ.

Panning, J. W., M. F. Kocher, J. A. Smith, and S. D. Kachman. 2000. Laboratory and field testing of seed spacing uniformity for sugarbeet planters. *Applied Engineering in Agriculture* 16(1): 7-13.

Quick, G. R., and W. F. Buchele. 1978. *The Grain Harvesters*. St. Joseph Mich.: ASAE.

SAS Institute Inc. 2004. SAS 9.1.3 Help and Documentation, Cary, N.C.: SAS Institute Inc.

Smith, J. A., K. L. Palm, C. D. Yonts, and R. G. Wilson. 1991. Seed spacing accuracy of sugarbeet planters. ASAE Paper No. 911551. St. Joseph, Mich.: ASAE.

Searle, C. L. 2006. Field slope effects on uniformity of corn seed spacing for three precision planter metering systems. Unpublished M.S. thesis. Lincoln, Nebr.: University of Nebraska Libraries.

United States Department of Agriculture; National Agricultural Statistics Service. 2005. Acreage. Available at http://www.nass.usda.gov:8080/QuickStats/index2.jsp. Accessed on 20 May 2006.

United States Department of Agriculture; Natural Resources Conservation Service. 2005. Soil data mart. Available at http://soildatamart.nrcs.usda.gov/. Accessed on 9 September 2005.