2011

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Kocher, Michael F.; Coleman, John M.; Smith, John A.; and Kachman, Stephen D., "Corn Seed Spacing Uniformity as Affected by Seed Tube Condition" (2011). *Biological Systems Engineering: Papers and Publications*. 194.
https://digitalcommons.unl.edu/biosysengfacpub/194

CORN SEED SPACING UNIFORMITY AS AFFECTED BY SEED TUBE CONDITION

M. F. Kocher, J. M. Coleman, J. A. Smith, S. D. Kachman

ABSTRACT. *Variation in corn seed spacing from a John Deere MaxEmerge ™ Plus Vacumeter planter was evaluated on the University of Nebraska Planter Test Stand in a laboratory setting for two seed tube conditions (new or worn) with two examples of corn seed shape (round or flat). Seed spacing uniformity was measured using three seed spacing uniformity parameters: Coefficient of Precision (CP3), ISO Multiples index, and ISO Miss index.*

Differences were detected in all three seed spacing uniformity parameters due to the seed tube condition. The new seed tubes had better seed spacing uniformity than the worn seed tubes, within each example of the seed shapes (round or flat) used in this experiment. For the seed used in this experiment, the round corn seed had better seed spacing uniformity than the flat corn seed, within each of the seed tube conditions (new or worn).

A recommended schedule for seed tube replacement to maintain seed spacing uniformity has not been developed, and more research in this area is needed. Currently, sugarbeet growers in western Nebraska use one of three options: a) test one of their seed tubes on a good planter test stand every year before sugarbeet planting season and replace all tubes when results indicate it will improve seed spacing uniformity to the desired level; b) feel the inside front surface of the seed tube every year before sugarbeet planting season and change seed tubes when the feel of the surface changes from a slick plastic to a very fine sandpaper; or c) replace seed tubes before sugarbeet planting season when they have planted over approximately 150 acres of corn per planter row with their current seed tubes.

Keywords. *Corn, Planters, Seed drop tube, Seed shape, Seed spacing, Uniformity.*

In 2003 in the United States, 31.6 million ha (78.1 million acres) of corn were planted for grain (USDA National Agricultural Statistics Service, 2003). Improving yields has been an important issue since the beginning of corn production. In recent years some research has focused on the uniformity of seed spacing as a way of improving yields. Nielsen (1996) indicated that improperly adjusted or malfunctioning planter mechanisms are the most frequent cause of uneven stand establishments in corn.

RELATIONSHIP OF CORN YIELDS TO SEED SPACING UNIFORMITY

Hoff and Mederski (1960) determined that adequate soil moisture was the most important factor for obtaining high corn yields. Other factors proven to affect yields include plant population, the amount of sunlight the crop receives, and the amount of nutrients provided by the soil. Uniform seed spacing plays an important role in ensuring a crop receives adequate amounts of sunlight, nutrients, and moisture.

Staggenborg et al. (2004) determined that increased corn planting speed adversely affected plant spacing uniformity performance as measured by miss, multiple, quality of feed, and precision indices, and standard deviation of plant spacing in northeast Kansas. Despite the degradation in uniformity of plant spacing, corn yield remained unchanged for three of four location-years, and decreased by 0.094 $t{\cdot}ha^{-1}$ per $km \cdot h^{-1}$(2.4 $bu{\cdot}acre^{-1}$ per $mile{\cdot}h^{-1}$) as speed increased from approximately 7.2 to 11.3 $km{\cdot}h^{-1}$ (4.5 to 7 $mile{\cdot}h^{-1}$) in only one of four location-years of the experiment.

Krall et al. (1977) studied effects of within-row plant spacing variability on corn yield utilizing a planter to obtain nonuniform seed spacing and hand-planted seed to obtain uniform seed spacing. They also surveyed plant spacing variability in farmers' fields and determined the standard deviation of plant spacings ranged from 6.6 to 18.4 cm (2.6 to 7.2 in.). They selected a spacing standard deviation of 4 cm (1.6 in.) as a maximum spacing uniformity obtainable with mechanical planting. Using a regression line from the combined trials at St. John and Rossville over 1973-1974, they projected a yield increase of 0.22 $t{\cdot}ha^{-1}$ (3.5 $bu{\cdot}acre^{-1}$) for corn planted with a spacing standard deviation of 4 cm (1.6 in.) rather than 6.6 cm, and 1.20 $t{\cdot}ha^{-1}$ (19.3 $bu{\cdot}acre^{-1}$) for corn planted with a spacing standard deviation of 4 cm (1.6 in.) rather than 18.4 cm (7.2 in.). Nielsen (1996)

Submitted for review in June 2009 as manuscript number PM 8086; approved for publication by the Power & Machinery Division of ASABE in September 2010.

A contribution of the University of Nebraska Agricultural Research Division, supported in part by funds provided through the Hatch Act. Mention of a trade name, proprietary products, or company name is for presentation clarity only and does not imply endorsement by the authors or the University of Nebraska.

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Applied Engineering in Agriculture

Vol. 27(2): 177-183 ISSN 0883-8542

determined uneven stand establishment in corn decreased yields between 0.44 and 0.94 t·ha^{-1} (7 and 15 bu·acre^{-1}).

IMPROVING SEED SPACING UNIFORMITY

Nielsen (1995) planted corn at speeds of 6.4, 8.0, 9.7, and 11.3 km·h^{-1} (4, 5, 6, and 7 mile·h^{-1}). Machine harvesting showed yield losses of at least 0.08 t·ha^{-1} per km·h^{-1} (2 bu·acre^{-1} per mile·h^{-1}) increase in planting speed. Moody et al. (2003) used a John Deere MaxEmerge™ Plus row unit without furrow closing wheels to plant cotton seed. Measurements taken within the furrow indicated a direct correlation between the increase in standard deviation from 2.8 to 6.1 cm (1.1 to 2.4 in.) and the increase in travel speed from 4.8 to 9.7 km·h^{-1} (3.0 to 6.0 mile·h^{-1}). Mowitz (1993) evaluated the effects of planting speed on corn seed spacing with John Deere 71 Flexi (plate), John Deere MaxEmerge™ 2, Kinze 2000, and White 6000 planter row units on a grease belt test stand. The results indicated a 10% to 13% increase in spacing error as speed increased from 6.4 to 11.3 km·h^{-1} (3 to 7 mile·h^{-1}).

Jasa and Dickey (1982) investigated the effects of different tillage practices (plow-disk-disk, chisel-disk, disk-disk, and no-till) on corn seed spacing uniformity. Plant and seed spacing uniformity were measured two to four weeks after planting. On six of eight sites there were no differences among the coefficients of variation of seed spacing among the tillage systems (coefficients of variation of seed spacing ranged from 0.28 to 0.61 over these sites). On two of the eight sites, the coefficients of variation of seed spacing for the no-till tillage treatment (0.35 for site 4 and 0.62 for site 7) were significantly less than for the other tillage treatments (averages of 0.48 for site 4 and 0.67 for site 7). Mowitz (1993) reported that corn seed size (large or small) did not affect seed spacing uniformity, provided the correct plates and disks were used. Erbach et al. (1972) compared corn seed spacing uniformity from V-type runner and double-disk furrow openers with and without a seed tube. The standard deviation of plant spacing with the seed tube [4.4 cm (1.7 in.) with V-type runner, 4.7 cm (1.9 in.) with double disk opener] was significantly smaller than without the seed tube [(6.0 cm (2.4 in.) with V-type runner, 6.5 cm (2.6 in.) with double disk opener]. Moody et al. (2003) found that the largest component of spacing variability was induced by the metering unit, and/or bounce of the seed in the upper half of the seed tube, above the OEM seed sensor.

COMPARISON OF LABORATORY AND FIELD SEED SPACING RESULTS

Panning et al. (2000) compared sugarbeet seed spacing uniformity for three planters (Franz Kleine Unicorn-3, John Deere 71 Flexi (plate), and John Deere MaxEmerge™ 2) measured with an opto-electronic system in laboratory tests and by carefully removing the soil to locate seeds in field tests. Seed spacing uniformity was reported using "CP3" or coefficient of precision, determined as the percent of actual seed spacings that were within ±1.5 cm of the spacing for which the planter was mechanically set. Their results indicated CP3 values determined in laboratory tests [e.g. 78.5 for Franz Kleine Unicorn-3, and 68.3 for John Deere MaxEmerge™ 2 with an experimental metal seed tube, both at 5.6 km·h^{-1} (3.5 mile·h^{-1})] were better than, or equal to, CP3 values determined in field tests [e.g. 68.4 for Franz Kleine Unicorn-3 and 40.8 for John Deere MaxEmerge™ 2 with an experimental metal seed tube, both at 5.6 km·h^{-1} (3.5 mile·h^{-1})]. They concluded that laboratory testing allowed determination of the maximum capability of the planter metering unit and seed tube combination to space seeds uniformly.

PLANTER MAINTENANCE AND ADJUSTMENTS

Planter maintenance and adjustments are extremely important in achieving seed spacing uniformity. Nielsen (1995), the Iowa Grain Quality Initiative (2003), and Deere and Company (2003) document typical problems in planter maintenance and adjustment.

The condition of the inside surface of the seed tube has received little research attention, but may also affect corn seed spacing uniformity. New seed tubes generally have a shiny inside surface (contacted by the seeds as they pass through the tubes) which feels smooth and slick to the touch. Worn tubes generally have a dull inside surface with many fine scratches that feels slightly rough, like a very fine sandpaper surface. In addition, different conditions of the inside surface of the seed tube (smooth or rough) may have different effects on the seed spacing uniformity for different seed shapes, such as round or flat.

OBJECTIVE

The objective of this study was to determine the effects of planter seed drop tube condition (new or worn) on seed spacing uniformity of a John Deere MaxEmerge™ Plus VacuMeter planter with the pneumatic option. Corn seed with round and flat shapes were used to obtain an indication of whether any effects from seed tube condition applied to both shapes.

PROCEDURE

Several decisions were made to limit the scope of the experiment to keep it to a reasonable level. Only one planter row unit was used and was of a planter model commonly used for planting row crops in the Midwestern United States. The planter row unit was in a used and well-maintained condition. The one seed plate used was the one recommended in the planter operator's manual for both of the corn seed shapes, sizes, and number of seeds per unit weight. The vacuum setting for the pneumatic metering option on the planter unit was evaluated just before the experiment was conducted and the setting determined to be most effective (lowest numbers of multiples and misses) for both seed shapes was 31.8-cm H_2O (12.5-in. H_2O). This vacuum setting was within the manufacturer's recommended vacuum range of 11- to 34-cm H_2O (4.2-to 13.5-in. H_2O) for the seed disk, depending on seed size. Several seed tube versions were used so inferences from the results would apply to more than one tube version. However, no comparisons among the seed tube versions were planned. Only one example of each of the two most commonly planted corn seed shapes (round and flat) were used, both of medium size, so the results of the study should not be inferred to apply to all round or flat corn seed of medium size.

The experimental design was a split plot design with the main plots arranged in a completely randomized design. The main plot treatment was the condition of the seed tube, new or worn, with 14 replications for each of these two treatments. The subplot treatment was the shape of corn seed (round or flat). A total of 56 experimental test runs were performed using 1000 seeds per run (999 spacings), nominally. The sequence in which the seed tubes were tested was randomized. Round corn seed and flat corn seed were run through each tube in consecutive experimental test runs. For each tube, the sequence in which the seed shapes were tested with that tube was also randomized. 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 laboratory research was completed in a shop building with doors closed during test runs (to ensure that ambient light did not interfere with the optoelectronic seed spacing measurement system) at the University of Nebraska Panhandle Research and Extension Center located near Scottsbluff, Nebraska, in August 2003. Coleman (2004) can be consulted for additional details concerning this experiment.

TEST STAND SYSTEM AND PLANTER

The experiment was conducted using the University of Nebraska Planter Test Stand with an optoelectronic system to measure seed spacing (Kocher et al., 1998; Lan et al., 1999). The test stand held the planter row unit stationary over a horizontal conveyor grease-belt which was powered to move at the travel speed desired for the test run, thereby simulating normal forward travel of the planter. A sprocket-and-chain transmission between the grease-belt drive and the planter metering unit ensured the proper speed relationship was maintained between the planter metering unit and the grease-belt so the planter unit delivered the desired target seed spacing. Seeds falling onto the grease-belt stuck to the top belt surface for subjective visual confirmation that the desired target seed spacing was achieved.

All seed spacing data and results for this experiment were obtained using the optoelectronic system described by Lan et al. (1999) which consisted of a seed detection sensor with 24 “electric eyes” spaced 4 mm apart in a horizontal plane located below the bottom of the seed tube where the bottom of the furrow would be in a normal sugarbeet planting situation, and aimed from side-to-side, perpendicular to the direction of planter travel. Seeds passing through the seed detection sensor blocked one (or possibly two consecutive) electric eyes, indicating to the computer the front-to-back location where the seed dropped through the sensor and the time at which the seed dropped through the sensor. The computer used the time interval between consecutive seeds and the measured belt speed (simulated planter travel speed) to calculate the spacing between the seeds, and corrected that spacing based on the relative locations of where those seeds passed through the seed detection sensor.

The planter unit used was a Deere and Company MaxEmerge™ Plus VacuMeter (VacuMeter refers to the pneumatic metering option). The planter unit consisted of a seed box, a frame, the metering unit, and seed tube. No disc opener, furrow closer, or packer was installed on the planter row unit during the tests. The planter metering unit was in a used, well-maintained condition.

The seed tubes were classified as new (purchased from a local John Deere dealer) or worn (used by a farmer while planting). Some of the worn seed tubes were donated by a John Deere dealer who had replaced seed tubes for farmers. The remaining worn seed tubes were obtained by contacting farmers and trading them two new tubes for two of their worn tubes.

Four different seed tube versions were used in the experiment. The first and oldest seed tube version was manufactured before planter monitors with seed tube sensors became popular. The length by width dimensions of the opening at the top of the tube where the seed enters the tube were 5.5 × 4 cm (2.17 × 1.57 in.) (John Deere Part No. A74932). Two of the new tubes and two of the worn tubes were of this version. The second seed tube version was manufactured with holes appropriate for installation of a seed tube sensor. The length by width dimensions of the opening at the top of the tube where the seed enters the tube were 5.5 × 3.6 cm (2.17 × 1.42 in.) (John Deere part No. A26183), smaller in width than the first tube version. Four of the new tubes and four of the worn tubes were of this version. The third and fourth seed tube versions tested were the largest versions used in these experiments. The length by width dimensions of the opening at the top of the tubes where the seed enters the tube were 7.5 × 5 cm (2.95 × 1.97 in.). Version three seed tubes were manufactured with a ramp above the top of the hole for the seed sensor in order to eliminate contact of the seed with the seed tube sensor (John Deere part No. A56784). This version of seed tube was the only one manufactured with a ramp. Eight of the new tubes and six of the worn tubes were version three tubes. The only difference between versions three and four was that version four did not have a ramp (John Deere part No. A54773). Two worn seed tubes were of this version. No new tubes of this version were used in the experiment as we only discovered that these two tubes did not have the ramp after testing was completed. During testing, seed tube sensors were inserted on all seed tubes that accommodated them. The sensor was used simply to fill the holes in the front and back of the seed tube at about mid-height of the tube and was not used to measure seed spacings for the experiment.

A standard corn seed disk (John Deere Part No. A50617) was used for the entire experiment with both the round and flat corn seeds as recommended by Deere and Company (2003). There were 30 cells in this disk with 3.6-mm diameter holes, allowing for a capacity of 1980 to 4410 seeds·kg^{-1} (900 to 2000 seeds·lb^{-1}).

SEED

Two examples of corn seed shape (round and flat) were used to limit the scope of the experiment, and still obtain an indication of whether any effects from seed tube condition applies to spacing uniformity of seeds with different shapes. The two seed shapes and size were chosen to represent the size and shapes believed to be most commonly planted in the midwestern U.S. Jirdon Agri Chemicals, Incorporated (Morrill, Nebr.) processed the medium, round corn seed (variety JA2103 and lot number RJA – 6/05GC) with a seed count of 3590 seeds·kg^{-1} (1630 seeds·lb^{-1}). High Cycle Seed Systems (Livingston, Wis.) processed the medium, flat corn seed (variety 7194RR and lot number JBA – 1/03FC) with a seed count of 4230 seeds·kg^{-1} (1920 seeds·lb^{-1}). Seed that passed through the planter during one test run was not put back in the planter hopper for any other test run. Talc powder was not mixed with the seed for this experiment.

PLANTER TRAVEL SPEED AND SPACING DISTANCE

The travel speed selected for the experiment was 8.0 km·h^{-1} (5.0 mile·h^{-1}). This speed was comparable to the average travel speed of a row crop planter suggested by *ASAE Standards* (2000), 9.0 km·h^{-1} (5.5 mile·h^{-1}). Travel speed (grease-belt speed on the test stand) measured in the experimental test runs ranged from 8.1 to 8.35 km·h^{-1} (5.03 to 5.35 mile·h^{-1}) with an average speed of 8.22 km·h^{-1} (5.11 mile·h^{-1}).

Seed spacing was selected based on a population of 74,100 seeds·ha^{-1} (30,000 seeds·acre^{-1}) with 76-cm (30-in.) row spacing. This resulted in a theoretical seed spacing of 17.70 cm (6.97 in.), and the sprocket selections available in the planter transmission allowed the target seed spacing to be set at 17.7 cm (6.97 in.).

METHOD OF ANALYSIS

Kachman and Smith (1995) determined the mean and standard deviation of seed spacings are not good descriptors of seed spacing uniformity. The three parameters used in this experiment to describe seed spacing uniformity were Coefficient of Precision (CP3), ISO Miss index, and ISO Multiples index. The Coefficient of Precision (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; Coleman, 2004). The International Organization for Standardization (1984) Standard 7256/1 was the basis for the ISO Miss index and the ISO Multiples index. These parameters are defined relative to the theoretical spacing of the seed. Theoretical spacing is defined as the "spacing set on the control mechanism and stated by the manufacturer" (ISO, 1984). Spacing is defined as, "the distance between two successive seeds in the row" (ISO, 1984). A multiple is defined as "the presence of two seeds or more where there should only be one" (ISO, 1984). The ISO Standard counts all spacings less than one-half the theoretical spacing as multiples. A miss is defined as "the absence of a seed where there should be one theoretically" (ISO, 1984). The ISO Standard counts all spacings greater than 1.5 times the theoretical spacing as a miss. The ISO Multiples and Miss indices are expressed as percentages of the theoretical number (rather than the actual number) of seed spacings. Note that an improvement in seed spacing uniformity is indicated by larger numbers for CP3 and smaller numbers for the ISO Multiples and Miss indices.

DESCRIPTION OF STATISTICAL ANALYSIS

Analysis of variance was used to determine the significance level of each treatment factor combination. The three seed spacing uniformity parameters used were measured on a percentage scale and were analyzed using the untransformed scores and using an arcsine square root transformation. This transformation is recommended to stabilize variances in binomial distributions. The results from both analyses were similar. For simplicity only the results from the untransformed analysis are reported. For all tests conducted, a level of 5% was used to determine significant differences.

Table 1. Analysis of variance results, Type 3 Tests of Fixed Effects for the seed spacing uniformity parameters from a John Deere MaxEmerge™ Plus Vacumeter planter with new or worn seed tubes, and round or flat corn seed.

Source	Degrees of Freedom	CP3, F-Value (PR>F)	ISO Multiples Index, F-Value (PR>F)	ISO Miss Index, F-Value (PR>F)
Seed tube condition	1	45.28 (<0.0001)	18.57 (0.0002)	15.55 (0.0006)
Tube (Cond)	25			
Seed shape	1	236.57 (<0.0001)	717.13 (<0.0001)	13.20 (0.0013)
Seed tube condition *Seed shape	1	4.46 (0.0445)	0.33 (0.5734)	0.28 (0.6028)
Error	25			

Table 2. Least Square Means with standard errors for the seed spacing uniformity parameters of ISO Multiples index and ISO Miss index from a John Deere MaxEmerge™ Plus Vacumeter planter with new or worn seed tubes, and round or flat corn seed.

	New Seed Tubes	Worn Seed Tubes	Round Corn Seed	Flat Corn Seed
ISO Multiples index (%)	8.17 (0.545)	11.56 (0.566)	3.65 (0.456)	16.08 (0.456)
ISO Miss index (%)	2.11 (0.517)	5.05 (0.537)	2.93 (0.413)	4.23 (0.413)

Table 3. Least Square Means with standard errors for the CP3 seed spacing uniformity parameter from a John Deere MaxEmerge™ Plus Vacumeter planter with new or worn seed tubes, and round or flat corn seed.

Seed Tube Condition	Round Seed	Flat Seed
New	49.6 (1.13)	35.3 (1.13)
Worn	38.7 (1.13)	27.8 (1.13)

RESULTS AND DISCUSSION

The results of the analysis of variance are displayed in tables 1 through 3. These tables include the "Type 3 Test of Fixed Effects" and "Least Square Means" results. The Type 3 Tests of Fixed Effects tests the significance of the three effects of tube condition, seed shape, and the tube condition by seed shape interaction (SAS Institute, Incorporated, 1999). "Least Square Means are predicted population margins; that is, they estimate the marginal means over a balanced population" (SAS Institute, Incorporated, 1999).

As shown in table 1, both seed tube condition and seed shape had significant effect on all three seed spacing uniformity parameters. The analysis of variance showed the seed tube condition by seed shape interaction was significant only for the CP3.

The Least Square Means of the seed spacing uniformity parameters of ISO Multiples index and ISO Miss index for the treatments of new seed tubes and worn seed tubes, and round and flat seed are given in table 2. The results in table 2 show that seed spacing uniformity was better (lower ISO Multiples index and lower ISO Miss index) with the new seed tubes than with the worn seed tubes. Seed spacing uniformity was also better with the round corn seed used in the experiment than with the flat seed.

Table 3 gives the effects of each treatment combination of seed tube condition and seed shape on the Least Square

Means and standard errors of the CP3 seed spacing uniformity parameter. The combination of new seed tubes with the round seed had the best seed spacing uniformity in terms of the highest CP3 value of 49.6%. The combination of worn seed tubes with the flat seed had the worst seed spacing uniformity in terms of the lowest CP3 value of 27.8%. The results in table 3 show CP3 decreased by more than 20% (from 49.6 to 38.7 for the round seed, and from 35.3 to 27.8 for the flat seed) when changing from new seed tubes to worn seed tubes, within each seed shape. Similarly, table 3 shows that the round seed used in this experiment had better seed spacing uniformity (higher CP3) than the flat seed, within each seed tube condition.

DISCUSSION OF INTERACTION

Interaction between seed tube condition and seed shape occurred for the CP3 parameter of seed spacing uniformity in the analysis of variance (table 1). Additional tests for interaction were conducted, with the results from the analysis of variance illustrated in table 4. Three factors were utilized in calculating the interaction. Two factors included the seed tube condition and the seed shape with the third factor, experimental run, as a covariate. Each of the combinations was tested as well as the individual factors. The results showed that the three-way interaction (experimental run by seed tube condition by seed type) was significant. The reasons for the interaction of the experimental run with seed tube condition and seed shape treatment for the CP3 measure are not clear. One possible reason is a change in ambient air conditions during the time the test runs were conducted. Test runs were conducted from 1:00 P.M. to 5:00 P.M., and then resumed at 9:00 P.M. and continued until midnight. The building in which the tests were conducted was not heated or cooled during this time of year and had a large overhead door that was opened and closed to move equipment in and out of the shop during the day, and a regular door that was open and closed for people to access the building. Consequently, the air conditions inside the building were very similar to the outside air conditions. During the afternoon hours, the average air temperature was 30.6°C (87.1°F) and the average relative humidity was 36.9%, as reported by the Scottsbluff, Nebraska station of the National Weather Service. During the evening hours the average air temperature was 19.8°C (67.7°F) and the average relative humidity was 73.5%. These changes in air conditions from warmer, drier air to cooler air

Table 4. Analysis of variance results, Type 3 tests of fixed effects for CP3, testing for interaction with new or worn seed tubes, and corn with round or flat seed.

Source	Degrees of Freedom	F-Value (PR>F)
Seed tube condition	1	82.43 (<0.0001)
Seed shape	1	529.89 (<0.0001)
Seed tube condition*Seed shape	1	13.91 (0.0010)
Experimental run	1	19.91 (0.0002)
Experimental run*Seed tube condition	1	3.08 (0.0921)
Experimental run*Seed shape	1	35.70 (<0.0001)
Experimental run*Seed tube condition*Seed shape	1	9.72 (0.0047)
Error	23	

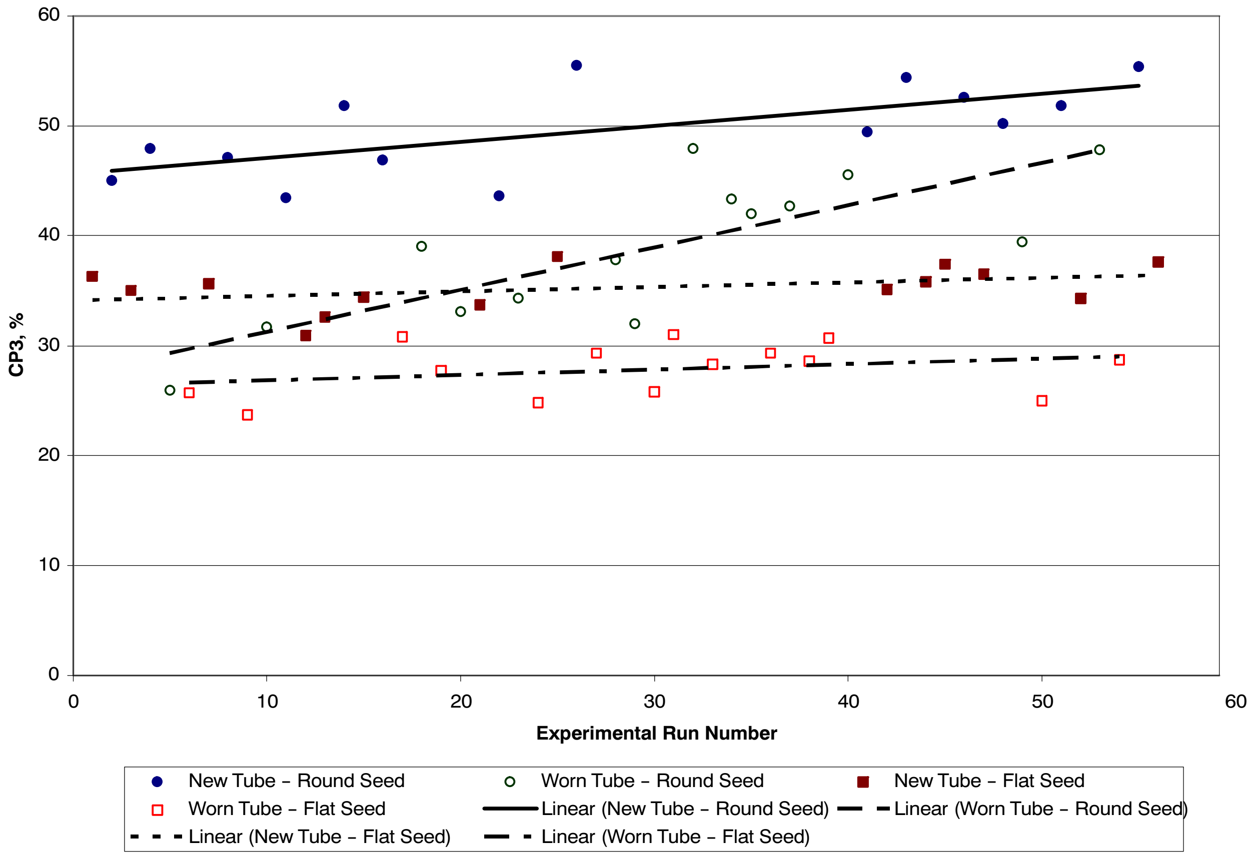

Figure 1. Interaction of coefficient of precision (CP3) and experimental run for a John Deere MaxEmerge™ Plus VacuMeter planter with new or worn seed tubes and round or flat corn seed.

with a higher moisture content may have resulted in the seed having a higher moisture content during the evening test runs (Equilibrium Moisture Content on a wet basis, $EMC_{wb} \approx 14\%$) than during the afternoon test runs ($EMC_{wb} \approx 9\%$), which may have affected seed properties related to bouncing or sliding of the seed on the inside surface of the seed tube. More research on this topic is needed.

For an additional investigation into the interaction, CP3 was plotted as a function of experimental test run number (order in which the experimental runs were conducted) for all four treatment combinations (fig.1).

Statistical testing showed the slopes of the lines for the treatment combinations with the round seed (new tube with round seed, and worn tube with round seed) were significantly different than zero, while the slopes of the lines for the treatment combinations with the flat seed were not. This means that the treatment combinations with round seed were the only ones that had significant interaction between CP3 and run number. Despite this interaction, it is clear that when making comparisons within each seed shape, new seed tubes had better seed spacing uniformity (higher CP3 value) than worn seed tubes. Likewise, within each seed tube condition, round seed had better seed spacing uniformity than flat seed.

Overall, and despite the interaction, the results showed that seed spacing was more uniform (higher CP3, lower ISO Multiples, and lower ISO Miss indices) with new seed tubes than with worn seed tubes for each of the two seed types used in this experiment (round and flat corn seed). Similarly, seed spacing was more uniform for the round corn seed than the flat corn seed used in this experiment for each of the seed tube conditions (new and worn).

This research has shown that in addition to the traditional pre-season planter maintenance and adjustment items, condition of the seed tube must be considered to achieve top seed spacing uniformity. At present, the only way to determine if the seed tubes on a producer's planter will give acceptable seed spacing uniformity is to conduct seed spacing testing with those seed tubes.

Recommended schedules for seed tube replacement to maintain top seed spacing uniformity are not currently available. Research is needed to determine the factors causing wear of seed tubes that affects seed spacing uniformity, and the rate of decline in seed spacing uniformity with these factors. Factors that should be investigated include: seed type (corn, soybeans, and sugarbeets), type of material used for the inside front surface of the seed tube, impact and abrasion of the seed on the front inside surface of the seed tube, and chemical reaction(s) between the seed coating(s) and the inside front surface of the seed tube.

Currently, sugarbeet growers in western Nebraska use one of three options to determine when to replace their planter seed tubes to maintain desired seed spacing uniformity. Some will test a seed tube along with their metering units every year before the start of the sugarbeet planting season. Others will feel the inside front surface of some of their seed tubes with their fingers every year before the start of the sugarbeet planting season and replace all their seed tubes when the surface starts feeling like very fine sandpaper instead of like a slick plastic surface. The remainder will replace seed tubes before the sugarbeet planting season after they have planted approximately 150 acres or more of corn per planter row with their current seed tubes.

SUMMARY AND CONCLUSIONS

Uniform seed spacing distribution is an important factor in corn production systems. A previously-undocumented factor affecting corn seed spacing uniformity is the condition of the inside surface of the seed tube that the seeds contact as they travel through the seed tube, whether new (shiny and smooth) or worn (dull and slightly rough like a very fine sandpaper surface).

Seed spacing uniformity as represented by all three seed spacing uniformity parameters (CP3, ISO Multiples index and ISO Miss index) was better with the new seed tubes than with the worn seed tubes for a John Deere Max Emerge™ Plus VacuMeter planter row unit with the four versions of seed tubes tested in the laboratory with the University of Nebraska Planter Test Stand. All three seed spacing parameters also showed that the round seed used in this experiment had better seed spacing uniformity than the flat seed, within the same seed tube condition (new or worn).

A recommended schedule for seed tube replacement to maintain seed spacing uniformity has not been developed, and more research in this area is needed. Currently, sugarbeet growers in western Nebraska use one of three options: a) test one of their seed tubes on a good planter test stand every year before sugarbeet planting season and replace all tubes when results indicate it will improve seed spacing uniformity to the desired level; b) feel the inside front surface of the seed tube every year before sugarbeet planting season and change seed tubes when the feel of the surface changes from a slick plastic to a very fine sandpaper; or c) replace seed tubes before sugarbeet planting season when they have planted over approximately 150 acres of corn per planter row with their current seed tubes.

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