2000

Performance Tests of Three-Point Mounted Implement Guidance Systems: II. Results

Michael F. Kocher
University of Nebraska-Lincoln, mkocher1@unl.edu

Michael B. Smith
University of Nebraska-Lincoln

Robert D. Grisso
Virginia Tech

Linda J. Young
University of Nebraska-Lincoln

PERFORMANCE TESTS OF THREE-POINT MOUNTED IMPLEMENT GUIDANCE SYSTEMS: II. RESULTS

M. F. Kocher, M. B. Smith, R. D. Grisso, L. J. Young

ABSTRACT. *Side-shift and disk-steer implement guidance systems were tested for differences in performance during cultivation on fields with 0 and 5% side slope. Test speeds were slow (4.8 km/h, 3 mph) and medium (8.0 km/h, 5 mph). Test path shapes included a tractor ramp, implement ramp, sine and curve. Performance measures included tractor positional error, implement positional error, torque from side forces on the cultivator non-swiveling coulters, and travel speed. Relatively few significant differences between guidance systems were detected, and most of those involved interaction with path shape. Therefore, no clear conclusion could be reached indicating one guidance system was better than the other. There were no differences between the effects of the two travel speeds on the performance measures directly related to the implement guidance (implement positional error and the torque on either coulter) indicating that for future experiments only one of the travel speeds need be included. The implement positional error distributions indicated the side-shift system kept a higher percentage of errors within the ±3 cm (±1.2 in.) and ±5 cm (±2.0 in.) acceptable error bands in the test situations where the rows were mostly straight (tractor ramp, implement ramp and sine path shapes), while the disk-steer system performed better with the ±3 cm (±1.2 in.) acceptable error band in the test situations were the rows were mostly curved. Both implement guidance systems performed well in keeping the implement centered between the crop rows, as at least 80% of the implement positional errors were within the ±5 cm (±2.0 in.) acceptable error band. The torque from side forces on the non-swiveling, residue-cutting coulters of the side-shift system were less than or equal to, not greater than the torque for the disk-steer system.*

Keywords. *Automated guidance, Guidance systems, Implements, Performance.*

Automatic guidance of agricultural equipment can reduce stress on the operator due to the demands of steering. This permits the operator to focus on the functioning of the equipment and improving performance.

In the past 10 to 15 years, several manufacturers have developed automatic guidance systems to control the position of three-point mounted implements. The main use for these guidance systems has been in controlling cultivator position so the cultivating tools travel down the center of the furrows between the crop rows. Other uses have included planting row crops (by following marker furrows) and precision post-emergence spraying.

The automatic implement guidance systems from the different manufacturers are based on different operating principles. This has raised questions regarding which operating principle, or which type of system, is best for the many situations in which producers operate. Producers and consultants alike have not had independent, objective information on which to base their decisions for selecting a type of system. The results presented in this article provide performance information to aid in making this decision.

The development of the test procedure has been outlined by Kocher et al. (2000). The research reported in this article involved many details that cannot be included in this article. Additional details on all aspects of this work have been described by Smith (1993).

OBJECTIVES

The primary objective of this research was to evaluate the performance of side-shift and disk-steer guidance systems that sense and control the location of three-point mounted implements relative to the crop rows. The procedure developed simulated field operating conditions as closely as possible (Kocher et al., 2000; Smith, 1993). Specific objectives were to:

1. Determine if there were differences in performance measures between the slow and medium travel speeds.
2. Determine if there were differences between the implement guidance systems in their effects on the tractor.
3. For each implement guidance system, determine if there were differences in performance measures between the tractor ramp and the implement ramp.
4. Determine if there were differences in cultivator positional errors for similar runs among the implement guidance systems.

Article was submitted for publication in September 1999; reviewed and approved for publication by the Power & Machinery Division of ASAE in August 2000. Presented as ASAE Paper No. 94-3574.

Published as Journal Series No. 12792, Agricultural Research Division, University of Nebraska-Lincoln, Lincoln, Nebraska. Mention of trade and company names is for descriptive purposes only and does not imply endorsement or preferential treatment by the authors or the University of Nebraska.

The authors are **Michael F. Kocher**, ***ASAE Member Engineer***, Associate Professor, **Michael B. Smith**, former Graduate Assistant, and **Robert D. Grisso**, ***ASAE Member Engineer***, Professor, Department of Biological Systems Engineering, and **Linda J. Young**, Professor, Department of Biometry, University of Nebraska-Lincoln, Lincoln, Nebraska. **Corresponding author:** Michael F. Kocher, University of Nebraska-Lincoln, Department of Biological Systems Engineering, 205 L. W. Chase Hall, Lincoln, NE 68583-0726, phone: 402.472.3949, fax: 402.472.6338, e-mail: <mkocher1@unl.edu>.

5. Determine if there were differences in torque from side forces on the cultivator (implement) non-swiveling, residue-cutting coulters for similar runs among the implement guidance systems.

Equipment and Procedures

The location for this research was at the University of Nebraska-Lincoln Rogers Memorial Farm east of Lincoln, Nebraska. A field with 0% side slope was used to represent furrow irrigated row crop land. Fields with 5% side slope (slope perpendicular to the direction of travel) were used to represent operation on side slopes as is normally done with row crops planted on contour. A track with path features including a tractor ramp, implement ramp, sine wave, and curve was used to give consistent desired travel paths for the tractor and cultivator in each test. The term ramp in this article is used to describe a linear sideways displacement of the tractor or implement, not an incline in elevation. An automatic steering device (model Agtronics Electronic Steering Pilot, Sigmanetics, Inc., Concord, California), on loan from the manufacturer, was used to steer the tractor down the desired tractor path. A side-shift implement guidance system (model Navigator, HR Manufacturing Company, Pender, Nebraska) and a disk-steer implement guidance system (model MP III Tracker, Orthman Manufacturing, Inc., Lexington, Nebraska) were available on loan from their respective companies for this research. The total length of the track used on the field with 0% side slope was 136.2 m (447 ft) over which 895 data collection events occurred. The curve was not used on the field with 5% side slope as a curve going uphill or downhill did not simulate contour farming. The total length of the track used on the field with 5% side slope was 90.2 m (296 ft) over which 593 data collection events occurred. A six-row cultivator (model Buffalo® 4630, Fleischer Manufacturing, Inc., Columbus, Nebraska) with 76 cm (30 in.) row spacing, a pair of barring-off disks, a non-swiveling residue-cutting coulter, and a sweep at the back for each furrow was used as the implement pulled behind the tractor. The sweep was the widest soil engaging tool so the positional error of the implement was measured at the outside point on the sweeps. These positional errors indicated how far the sweeps were cutting into row area reserved for the crop. Speeds of 4.8 and 8.0 km/h (3 and 5 mph) were used for the tests representing slow and medium speeds typical of cultivation with implement guidance systems. The instrumentation system was designed to measure positional errors for the tractor and implement, torque from side forces on two of the non-swiveling residue cutting coulters, and travel speed at each 15.2 cm (6 in.) increment along the track. The positional errors measured were the sideways displacement between the desired location of the tractor or implement (indicated by the track) and the actual location of the tractor or implement. Additional detail on the procedures used is given in Kocher et al., (2000) and Smith (1993).

Analyses

The experiment was set up as a split, split, split plot experiment. The main unit treatments were land with 0% and 5% side slope, each having three replications. The sub-unit treatments were guidance systems. Each guidance system was run at the low speed (4.8 km/h, 3.0 mph), and at the medium speed (8.0 km/h, 5.0 mph). Thus, the sub-sub-unit treatments were speeds. Each test run had several path shapes so the sub-sub-sub-unit treatments were path shapes.

Only one machine of each type of implement guidance system was used in this experiment. This means that statistical inference from the results of this experiment to other machines of the same type is not possible. It was expected that variation among machines of the same type would be small in comparison to differences among the different types of implement guidance systems.

The General Linear Models Procedure (SAS, 1989) was used to calculate the analyses of variance and the least squares means. The Type III sums of squares were used to test the hypotheses as the data were unbalanced and some data were missing. ANOVAs were used to determine which treatment effects were significant, and the method of least significant differences ($\alpha < 0.05$) was used to determine significant differences among the treatment means.

Results and Discussion

Testing for rep 1 was conducted during the summer of 1992. Testing for reps 2 and 3 was conducted during the summer and fall of 1993. A summary of soil moisture content and cone penetrometer information is given in table 1.

Sample tractor positional error and implement positional error data illustrated in figure 1 are from rep 1 for the side-shift and disk-steer guidance systems operating through the sine wave path shape at 4.8 km/h (3.0 mph) on the field with 0% side slope. The side-shift guidance system had implement positional errors with magnitudes less than 2.3 cm (0.9 in.). The disk-steer guidance system had

Table 1. Soil cone penetrometer and moisture content information for each test run

Guidance System	Rep	Side Slope (%)	Speed km/h (mph)	Cone Index kPa (psi)* Depth 0-7.6 cm (0-3.0 in.)	Depth 7.6-15.2 cm (3.0-6.0 in.)	Depth 15.2-22.9 cm (6.0-9.0 in.)	Moisture Content (%, DB)
Disk-steer	1	0	4.8 (3.0)	274 (40)	579 (84)	615 (89)	†
			8.0 (5.0)	364 (53)	628 (91)	600 (87)	25.2
		5	4.8 (3.0)	446 (65)	1,189 (172)	1,489 (216)	21.3
			8.0 (5.0)	380 (55)	1,180 (171)	1,536 (223)	22.8
	2	0	4.8 (3.0)	520 (75)	557 (81)	695 (101)	27.7
			8.0 (5.0)	677 (98)	620 (90)	696 (101)	27.0
		5	4.8 (3.0)	545 (79)	857 (124)	1120 (162)	27.9
			8.0 (5.0)	718 (104)	832 (121)	1074 (156)	28.6
	3	0	4.8 (3.0)	729 (106)	654 (95)	596 (86)	27.6
			8.0 (5.0)	759 (110)	613 (89)	638 (93)	26.8
		5	4.8 (3.0)	1,338 (194)	1,427 (207)	1496 (217)	26.7
			8.0 (5.0)	†	†	†	26.8
Side-shift	1	0	4.8 (3.0)	587 (85)	859 (125)	788 (114)	22.5
			8.0 (5.0)	414 (60)	744 (108)	696 (101)	23.8
		5	4.8 (3.0)	579 (84)	1,217 (177)	1,444 (209)	23.0
			8.0 (5.0)	654 (95)	1,329 (193)	1,579 (229)	22.3
	2	0	4.8 (3.0)	619 (90)	578 (84)	779 (113)	28.1
			8.0 (5.0)	659 (96)	752 (109)	881 (128)	26.3
		5	4.8 (3.0)	749 (109)	981 (142)	1,250 (181)	25.1
			8.0 (5.0)	771 (112)	948 (137)	1,083 (157)	28.8
	3	0	4.8 (3.0)	918 (133)	876 (127)	977 (142)	25.3
			8.0 (5.0)	1,168 (169)	1,056 (153)	885 (128)	26.1
		5	4.8 (3.0)	1,237 (179)	1,553 (225)	1,724 (250)	28.6
			8.0 (5.0)	1,265 (183)	1,529 (222)	1,711 (248)	27.4

* Average from 20 penetrometer punches.
† Missing data.

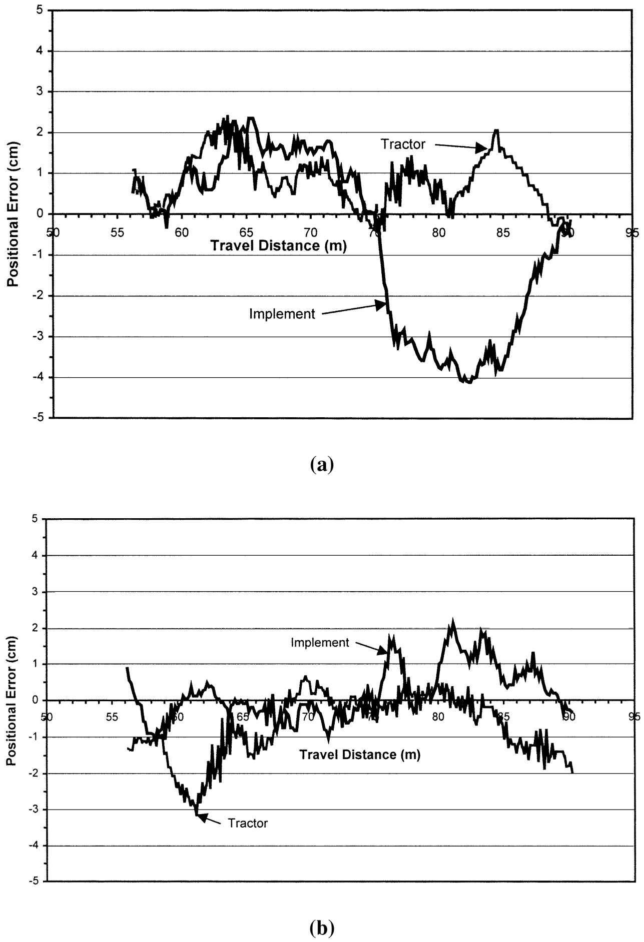

Figure 1–Sample tractor positional error and implement positional error data for rep 1 with the disk-steer (top) and side-shift (bottom) implement guidance systems at 4.8 km/h (3.0 mph) on the field with 0% side slope in the sine path shape.

implement positional errors with magnitudes less than 4.0 cm (1.6 in.).

The ANOVA for tractor positional error showed significant effects from path shapes with the presence of implement guidance system by path shape interaction, and speed by path shape interaction. The ANOVA for implement positional error showed significant effects from guidance systems and path shapes with the presence of guidance system by path shape interaction. The ANOVAs for the torque on Coulter 1 (in the furrow behind the left rear tractor wheel) showed significant effects from path shapes with the presence of guidance system by path shape interaction. The ANOVAs for the torque on Coulter 2 (in the uncompacted furrow to the right of the right rear tractor wheel) showed significant effects from path shapes only. The ANOVA for the speed deviation indicated no significant effects. This indicates there were no significant differences among the means of speed deviation for any of the treatments or treatment combinations. Hence the differences between travel speed and desired speed were similar for all test runs.

Comparison Between Speeds

The only performance measure that included significant effects from speed was the tractor positional error, and that was with the presence of speed by path shape interaction. The only significant difference was in the curve on the field with 0% side slope. The mean tractor positional error in the curve on the field with 0% side slope at the slow speed (4.69 cm, 1.85 in.) was significantly greater than at the medium speed (3.19 cm, 1.26 in.). There were no effects on the performance measures directly related to the implement guidance (implement positional error and the torque on either coulter). That leads to the conclusion that for future experiments interested only in implement performance with disk-steer and side-shift implement guidance systems, only one of the travel speeds (slow = 4.8 km/h, 3.0 mph, or medium = 8.0 km/h, 5.0 mph) needs to be included.

Comparison Between Implement Guidance Systems for Tractor Positional Error

If no differences existed in tractor positional error for similar runs with the different implement guidance systems, then the tractor guidance system performed equally well with both implement guidance systems. If differences did exist, then the implement guidance systems could have caused different effects on tractor position. All implement guidance systems exert some force on the tractor while exerting the force on the implement needed to move it to the correct position. Because of the different operating methods, there may be differences among implement guidance systems in the amount of force they exert on the tractor to obtain the same movement of the implement.

The results from the ANOVAs and the least significant difference analyses indicated only one significant difference in tractor positional error between the side-shift and disk-steer implement guidance systems. The average tractor positional error on the field with 0% side slope over the curve path with the disk-steer system (3.25 cm, 1.28 in.) was significantly smaller (P = 0.0001) than with the side-shift system (4.62 cm, 1.82 in.).

The difference in tractor positional error on the curve is most likely related to the different method of operation (or operating principles) for the different implement guidance systems. The natural tendency for towed equipment or trailers is to travel to the inside of curves. With the side-shift system the implement must be pushed toward the outside of the curve (to the right in this experiment, negative positional error) by the side-shift system. In order for the side-shift system to develop the force needed to push the implement to the outside of the curve, it must exert a force of approximately equal magnitude pushing the tractor to the inside of the curve (to the left in this experiment, positive positional error). With the disk-steer guidance system the implement must also be pushed to the outside of the curve, but the steering disks push against the soil to provide that side force while the tractor is pulling the implement. As a result, the component of force on the tractor directed to the inside of the curve is likely smaller for the disk-steer system than for the side-shift system. Thus, the significant difference in tractor positional error on the curve is likely related to the difference in methods of operation for the two implement guidance systems.

In summary, the only difference in tractor positional error between the side-shift and disk-steer implement guidance systems occurred on the curve and was likely caused by the difference in operating methods. The side-shift guidance system pushed the tractor farther to the inside of the curve than the disk-steer system.

Comparison Between the Tractor Ramp and the Implement Ramp

The next question was to determine whether any differences existed between the performance of the implement guidance systems in the tractor ramp path compared to the implement ramp path. If no significant differences existed, one of these two paths could be eliminated from future tests with no loss of useful information.

There were no significant differences between the tractor ramp and implement ramp paths for the performance measures of tractor positional error, Coulter 1 torque and Coulter 2 torque. Specifically, the average tractor positional error with either guidance system over the tractor ramp path was not significantly different than with the same guidance system over the implement ramp path. Similarly, the average torque for either coulter with either guidance system over the tractor ramp was not significantly different than for the same coulter with the same guidance system over the implement ramp.

There was one significant difference between the tractor ramp and implement ramp paths. The average implement positional error with the disk-steer system over the tractor ramp (–0.26 cm, –0.10 in.) was significantly different ($P = 0.0001$) from the same system over the implement ramp (2.77 cm, 1.09 in.).

The reason for the difference is not clear. In the tractor ramp, while the tractor moved to the right, the implement guidance systems had to keep the implement going straight, which resulted in the implement being farther and farther to the left of the tractor. The relative lateral locations of the tractor and implement at the end of the tractor ramp were maintained in the settling section between the tractor ramp and the implement ramp. In the implement ramp, while the tractor went straight ahead, the implement guidance systems had to move the implement to the right, back in line with the tractor. The disk-steer system may not have reacted as aggressively in moving the implement back in line with the tractor (implement ramp) as it did in the moving the implement out of line with the tractor (tractor ramp). Whatever the reason, the average implement positional errors were to the right (negative) when the disk steer system was moving the implement to the left relative to the tractor (tractor ramp), and implement positional errors were to the left (positive) when the disk-steer system was moving the implement to the right relative to the tractor (implement ramp). Additional research with tractor and implement ramps going both to the left and the right may determine whether these functions really are different, and the reasons for any differences.

Comparison Between Implement Guidance Systems for Implement Positional Error

The next question was to determine whether the cultivator positional error was the same for similar runs with the different guidance systems. The different implement guidance systems have different methods of operation. The different methods of operation could result in differences in performance among the implement guidance systems in different situations. For example, one implement guidance system may work best with straight crop rows in fields with no side slope. Another may work best with straight rows in fields with a side slope. Another may work best in fields with rows that are curved because of irregular field shape or fields farmed on the contour because of rolling terrain.

The results indicated there were some significant differences in implement positional error between systems (table 2). The average implement positional errors for the side-shift system were significantly different from the disk-steer system over the implement ramp, sine, and curve paths. When comparing the magnitude of the average implement positional errors, the side-shift system performed better than the disk-steer system on the implement ramp, performance was about equal on the sine path, and the disk-steer system performed better than the side-shift system on the curve.

Implement positional error differences on the curve are most likely related to differences in the method of operation for the two implement guidance systems, and the distance between the location of the implement guidance system position sensor and the location of the implement positional error transducer. With the side-shift implement guidance system the three-point hitch sway stops keep the implement tool bar perpendicular to the tractor line of travel. The implement and the implement positional error transducer then become a straight line trying to travel through a curve (fig. 2). The negative average positional error means the implement was to the right of where it should have been. This right positional error was a result of the natural left rotation of the implement positional error transducer as it followed the curve to the left. This error would have been smaller if the location of the implement

Table 2. Average implement positional errors for the disk-steer and side-shift implement guidance systems over each travel path shape on fields with 0 and 5% side-slope

Path Shape	Average Implement Positional Errors, cm (in.) Side-shift	Disk-steer	P-value*
Tractor ramp	–1.21 (–0.48)	–0.26 (–0.10)	0.1655
Implement ramp	0.09 (0.04)	2.77 (1.09)	0.0002
Sine	–0.36 (–0.14)	0.36 (0.14)	0.0492
Curve†	–1.70 (–0.67)	0.23 (0.09)	0.0001

* P-value associated with the protected LSD test of equality of means for the guidance systems by path shape combinations.

† Note that the curve path shape was only used on the fields with 0% side-slope, so the averages for the curve do not include data from the fields with 5% side-slope.

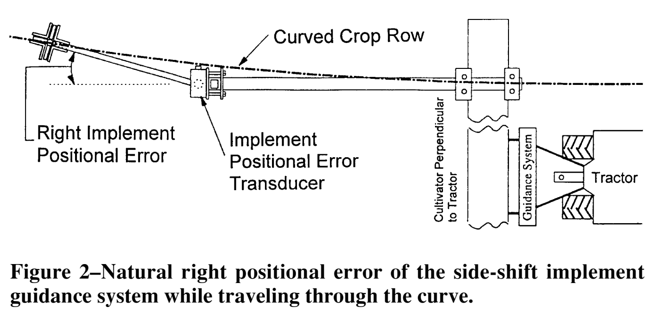

Figure 2–Natural right positional error of the side-shift implement guidance system while traveling through the curve.

guidance system position sensor unit had not been in front of the implement, but closer to the rear of the cultivator sweeps where the implement positional errors were measured.

The disk-steer guidance system did not keep the cultivator tool bar perpendicular to the tractor like the side-shift system. The disk-steer system allowed the cultivator to articulate in a clockwise direction (as viewed from above), reducing the length of straight line trying to travel through a curve and reducing the natural right error (fig. 3).

The important differences between the implement guidance systems for implement positional errors have been discussed above. The lack of a significant difference on the tractor ramp path and the size of the significant differences are also important, however. The average implement positional errors were less than 1 cm (0.4 in.) for five of the eight path shape by guidance system combinations (table 2), less than 2 cm (0.8 in.) for seven of the eight combinations, and less than 3 cm (1.2 in.) for all eight combinations.

Kocher et al. (2000) discussed an example illustrating that positional error distributions may be more meaningful to producers than means, ranges and standard deviations. The percent of implement positional errors within ±3 cm (±1.2 in.) and ±5 cm (±2.0 in.) error bands were determined for each implement guidance system by path shape combination. For each implement guidance system, there were more than 600 implement positional error data points over the tractor ramp, and more than 600 over the implement ramp. Similarly, for each implement guidance system, there were more than 2,000 and 1,600 data points over the sine and curve paths, respectively.

Figure 4 shows the disk-steer system kept about 70% of the implement positional errors within a ±3 cm (±1.2 in.) error band on the tractor ramp, implement ramp, and sine wave functions, and 99.8% of the errors on the curve. When the error band was widened to ±5 cm (±2.0 in.), the disk-steer system did slightly better, keeping about 87%, 81%, 85%, and 100% of the implement positional errors within the allowable error band on the tractor ramp, implement ramp, sine and curve functions, respectively.

Figure 5 shows the side-shift system kept about 83% and 80% of the implement positional errors within a ±3 cm (±1.2 in.) error band on the sine and curve functions, and 93% and 95% of the errors within that error band on the tractor ramp and implement ramp, respectively. When the error band was widened to ±5 cm (±2.0 in.), the side-shift system kept the implement position within the allowable error band at least 97% of the time. These implement positional error distributions showed the side-shift system kept a higher percentage of errors within the ±3 cm (±1.2 in.) and ±5 cm (±2.0 in.) acceptable error bands on the tractor ramp, implement ramp, and sine path functions. The disk-steer system kept a higher percentage of errors within the ±3 cm (±1.2 in.) acceptable error band on the curve.

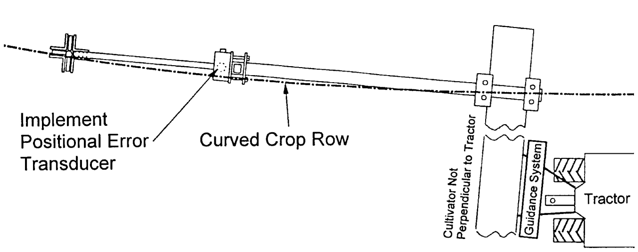

Figure 3–Positional error transducer with the disk-steer implement guidance system while traveling through the curve.

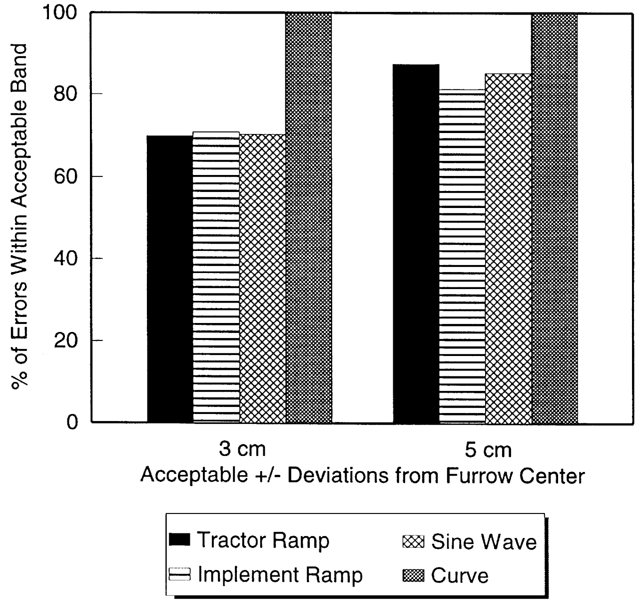

Figure 4–Percent of implement positional errors within ±3 cm (±1.2 in.) and ±5 cm (±2.0 in.) of the furrow center for the disk-steer implement guidance system over the tractor ramp, implement ramp, sine, and curve path shapes.

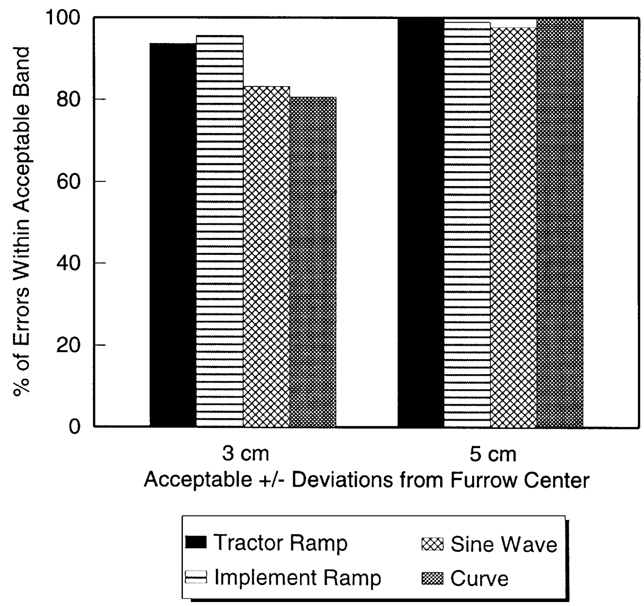

Figure 5–Percent of implement positional errors within ±3 cm (±1.2 in.) and ±5 cm (±2.0 in.) of the furrow center for the side-shift implement guidance system over the tractor ramp, implement ramp, sine and curve path shapes.

This indicates the side-shift implement guidance system did a slightly better job than the disk-steer system of positioning the implement properly between the crop rows for test situations where the rows were mostly straight. The disk-steer implement guidance system did a slightly better job than the side-shift system of positioning the implement properly between the crop rows for the test situation where the rows were mostly curved, as in fields with irregular shapes, or where farming on the contour. However, both implement guidance systems did well in keeping the implement centered between the crop rows, as at least 80% of the implement positional errors were within the ±5 cm (±2.0 in.) acceptable error band.

Comparison Between Implement Guidance Systems for Torque on the Non-swiveling Coulters

The last question was to determine whether the torque from the side forces on the cultivator (implement) non-swiveling coulters was the same for similar runs with the different guidance systems. Claims had been made that the side-shift implement guidance system places more side force on the cultivator coulters than the other systems. Swiveling coulters are generally recommended with disk-steer implement guidance systems. The steering disks for this guidance system provide the major portion of the side force to move the cultivator to the correct position, and use of swiveling coulters avoids placing unnecessary side forces on the coulters. The question has been raised whether swiveling coulters are necessary with side-shift guidance systems to avoid placing excessive side force on these coulters, contributing to high failure rates for these coulters or their bearings.

The results showed significant differences in the torque on Coulter 1 between the guidance systems. The average torque values are given in table 3. The average torque from Coulter 1 for the side-shift system over the tractor ramp was significantly lower than for the disk-steer system. The average torque from Coulter 1 for the disk-steer system over the curve was significantly lower than for the side-shift system. The results for the average torque from Coulter 2 indicated there were no significant differences between the side-shift and disk-steer systems. The average torque from Coulter 2 ranged from 160 to 185 N·m (118 to 136 lb·ft) over all four path shapes.

The highest average torque from these analyses was for the disk-steer system in the tractor ramp. This result contradicted the claims that the side-shift implement guidance system places more side force on cultivator coulters than the other systems. The reason for this is most likely related to the different methods of operation for the two guidance systems. The side-shift system moves the implement into the proper position by forcing it sideways (perpendicular to the direction of travel), which could cause significant side forces on non-swiveling coulters aligned with the direction of travel. However, the speed of forward travel was so much greater than the speed of side-shift travel (ratio of 53:1 for the slow forward travel speed and the fastest side-shift speed) that the forward travel of the coulters allowed them to roll and cut into new soil fast enough to minimize the side forces from the sideways travel.

The high torque that occurred with the disk-steer system in the tractor ramp is also likely a result of its method of operation. When the steering disks for the disk-steer system disks rotated counterclockwise (about a vertical axis) to move the implement to the left (relative to the tractor), the lower links of the three-point arms moved to the left, causing the implement to rotate clockwise (about a vertical axis). So when the steering disks turned left, and the implement moved to the left, the non-swiveling coulters actually pointed to the right, resulting in a side force pushing the non-swiveling coulters to the right. The non-swiveling coulters on the cultivator actually worked against the steering disks in this situation. This makes it reasonable for the side forces on the non-swiveling coulters of the disk-steer system to be greater than the side forces on the non-swiveling coulters of the side-shift system in the tractor ramp path shape. Thus, the recommendation from the disk-steer implement guidance system manufacturers that swiveling coulters, not non-swiveling coulters, should be used with their product, is wise advice.

Information about the average torque is helpful, and additional information on the distribution of the torque is useful for developing design criteria. The maximum torques for Coulter 2 were higher than for Coulter 1, so the distributions of the magnitudes of the torque measurements for Coulter 2 were determined. The cumulative frequency (in percent of the total number) of the torque magnitudes over each path shape were determined for each guidance system. These results are illustrated in figure 6 for the side-shift system and figure 7 for the disk-steer system. From figure 6, note that for the side-shift system at least 80% of the torque magnitudes were less than 200 N·m (150 lb·ft), at least 93% were less than 300 N·m (220 lb·ft), and 100% were less than 600 N·m (440 lb·ft). From figure 7 for the disk-steer system, however, the torque magnitude had to be at least 300 N·m (220 lb·ft) before 80% of the torque magnitudes were less than that, and at least 400 N·m

Table 3. Average torque values from Coulter 1 (wheel track furrow) for the disk-steer and side-shift implement guidance systems over each path shape

	Average Torque Values, N·m (lb·ft)		
Travel Path Function	Side-shift	Disk-steer	P-value*
Tractor ramp	128 (94)	226 (167)	0.0040
Implement ramp	123 (91)	169 (125)	0.1440
Sine	122 (90)	147 (108)	0.1456
Curve†	103 (76)	48 (35)	0.0082

* P-value associated with the protected LSD test of equality of means for the guidance system by path shape combinations.

† Note that the curve path shape was only used on the fields with 0% side-slope, so the averages for the curve do not include data from the fields with 5% side-slope.

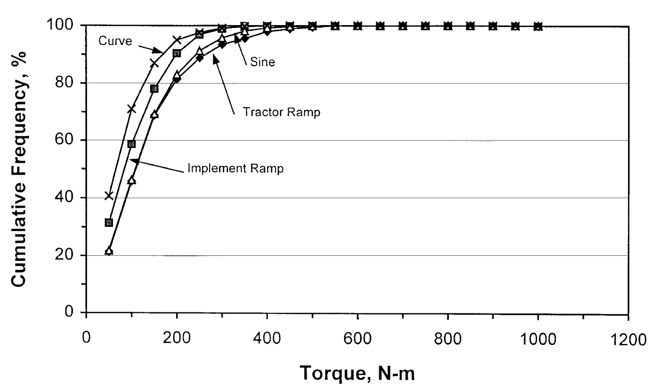

Figure 6–Percentage of torques of lesser magnitude for each path shape for the non-swiveling, residue-cutting coulter operating in the furrow to the right of the right rear tractor wheel (Coulter 2) in the performance test for the three-point mounted side-shift implement guidance system.

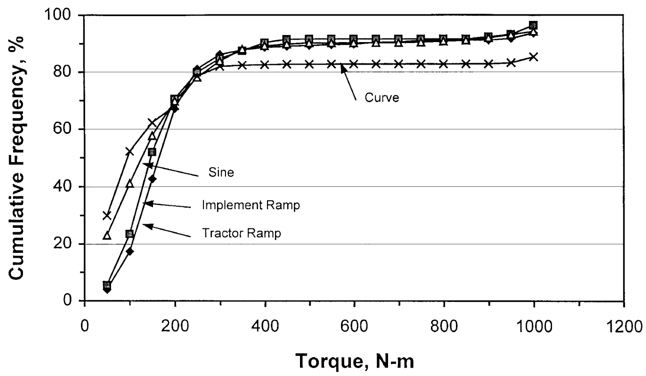

Figure 7–Percentage of torques of lesser magnitude for each path shape for the non-swiveling, residue-cutting coulter operating in the furrow to the right of the right rear tractor wheel (Coulter 2) in the performance test for the three-point mounted disk-steer implement guidance system.

(300 lb·ft) for the implement ramp, 500 N·m (370 lb·ft) for the sine, 650 N·m (480 lb·ft) for the tractor ramp, and over 1000 N·m (740 lb·ft) for the curve before 90% of the torque magnitudes were less than that. All of the torque magnitudes were less than 600 N·m (440 lb·ft) for the side-shift system (fig. 6), while about 5 to 15% of the torque values for the disk-steer system were greater than 1000 N·m (740 lb·ft) (fig. 7). This illustrates that the torque values in the high end of the distribution for the disk-steer system were greater than the torque values in the high end of the distribution for the side-shift system.

Conclusions

Relatively few significant differences between guidance systems were detected, and most of those involved interaction with path function. Therefore, no clear conclusion could be reached indicating one guidance system was better than the other. Specific conclusions were as follows:

1. There were no differences between the effects of the two travel speeds on the performance measures directly related to the implement guidance (implement positional error and the torque on either coulter). That leads to the conclusion that for future experiments interested only in the implement performance with disk-steer and side-shift implement guidance systems, only one of the travel speeds (slow = 4.8 km/h, 3.0 mph, or medium = 8.0 km/h, 5.0 mph) needs to be included.
2. The only difference in tractor positional error between the side-shift and disk-steer implement guidance systems occurred on the curve and was likely caused by the difference in operating methods. The side-shift guidance system pushed the tractor farther to the inside of the curve than the disk-steer system.
3. The only significant difference in the performance measures between the tractor ramp and the implement ramp was for the implement positional error. Additional research with tractor and implement ramps going both to the left and the right may determine whether these functions are really different and the reasons for any differences.
4. The implement positional error distributions indicated the side-shift system kept a higher percentage of errors within the ±3 cm (±1.2 in.) and ±5 cm (±2.0 in.) acceptable error bands in the test situations where the rows were mostly straight (tractor ramp, implement ramp and sine path shapes), while the disk-steer system performed better with the ±3 cm (±1.20 cm) acceptable error band in the test situations where the rows were mostly curved. Both implement guidance systems performed well in keeping the implement centered between the crop rows, as at least 80% of the implement positional errors were within the ±5 cm (±2.0 in.) acceptable error band.
5. The highest average torque from Coulter 1 (in the furrow behind the left rear tractor wheel) was 226 N·m (167 lb·ft) for the disk-steer system in the tractor ramp compared to 128 N·m (94 lb·ft) for the side-shift system. Also, the torque values in the high end of the distribution for the disk-steer system were greater than the torque values in the high end of the distribution for the side-shift system. These results contradict claims that the side-shift implement guidance system places more side force on cultivator coulters than the other systems.

Acknowledgments. The authors would like to gratefully acknowledge the loan of equipment and donation of funding for this research from HR Manufacturing Company, Pender, Nebraska; Orthman Manufacturing, Inc., Lexington, Nebraska; and Fleischer Manufacturing, Inc., Columbus, Nebraska. The authors would also like to thank Sigmanetics, Inc. at Concord, California, for the loan of equipment and assistance in getting it properly adjusted for this research. The gracious assistance of these manufacturers made this work possible.

The authors would also like to gratefully acknowledge the assistance of Mr. Mark A. Schroeder, Research Farm Manager for the Department of Biological Systems Engineering. His assistance in determining field test sites and field preparation was greatly appreciated.

References

Kocher, M. F., M. B. Smith, R. D. Grisso, and L. L. Bashford. 2000. Performance tests of three-point mounted implement guidance systems: I. Procedure. *Applied Engineering in Agriculture* 16(6): 595-603.

SAS Institute, Inc. 1989. 5th Ed. *SAS/STAT User's Guide*, Version 6, Vols. 1 and 2. Cary, N.C.: SAS Institute, Inc.

Smith, M. B. 1993. Performance evaluation procedure for three-point mounted guidance systems. Unpub. M.S. thesis. Lincoln, Nebr.: University of Nebraska-Lincoln Libraries.