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Field Efficiency Determination Using Traffic Pattern Indices

R. D. Grisso, M. F. Kocher, V. I. Adamchuk, P. J. Jasa, M. A. Schroeder

Abstract. *Field efficiency is an important criterion for determining field capacity during field operations and, indirectly, for making important machinery management decisions. Geographic location data gathered with a yield monitor during harvest and a data logger during planting were used to provide time−motion studies of equipment and operator productivity. This study used these spatial and temporal data to quantify field performance of a combine and a planter. Seven Nebraska fields were used to compare results from soybean and corn production systems. Fields that were relatively flat with straight rows were contrasted with contoured fields with slopes of 3% to 5%. Two unique traffic patterns in fields with a center pivot were compared. Four traffic pattern indices were developed and averaged across each field to indicate the steering behavior (or adjustments) made during field operations. Geo−referenced data were used to predict field efficiency for various traffic patterns. Of the four indices compared, the average steering angle (θ) and its standard deviation had the strongest association with field efficiency with Pearson correlation coefficients of −0.654 and −0.664, respectively. The average steering angle for contoured traffic patterns were two to four times in magnitude that of straight− and gently curved−row traffic patterns. The steering angle index gave valuable information about field operating conditions but differences in data recording methods and operational characteristics imposed limitations on statistically appropriate comparison analyses.*

Keywords. *Field efficiency, Machinery management, Traffic patterns, Geo−referenced data.*

Machine capacity information is an important component of machinery management decisions. Machine capacity determines timeliness of field operations, which greatly affect the economics of a production system. Machinery performance studies have traditionally required the use of stopwatches with observations recorded on a clipboard (Renoll, 1972; 1981). These field studies were tedious, time consuming, and required the researcher to be on−site during the operation. The advent of real−time geo−referenced data logging has made data collection easier, and often the data can be reviewed off−site to examine traffic patterns, field practices, and other operational issues. One such method uses a GPS (Global Positioning System) receiver on a yield monitor that is installed on a combine to map yields.

Currently, relatively low−cost digital equipment, accurate navigational (GPS−based) systems, and various real−time controllers and sensors have been combined to provide the necessary technology to make site−specific crop management a reality. The knowledge gained from site−specific crop management equips producers to make better management decisions that result in potential environmental benefits and potential improvements in productivity and profitability. Geo−referenced data can play an important role in the management and operation of farm equipment.

Literature Review

According to Hunt (1995), time efficiency (percentage) is a ratio of the time a machine is effectively operating to the total time the machine is committed to the operation. Time when the operator is in the machine and not actually working the field is counted as lost time. Specifically, field efficiency (*ASAE Standards*, 1999a) is the "ratio between the productivity of a machine under field conditions and the theoretical maximum productivity." The factors considered appropriate for calculating field efficiency were described in Grisso et al. (2002).

Several factors affecting field efficiency have been studied intensively. Renoll (1965; 1970; 1972) used time studies and system analysis to evaluate field operations while considering the interactions between machinery use and the physical and geometric characteristics of the field. He also examined the influence of implement width and travel speed on productivity. His work showed that field capacity (as related to row length, field size, and terracing) varied greatly from field to field. Renoll (1972) provided adjustment factors

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for additions to planters such as fertilizer and spray attachments. Renoll (1981) used 14 field variables to develop estimates of field capacity for planting, plowing, spraying, and cultivating in operating widths ranging from 2.04 to 20.4 m. These predicted values were compared against actual field measurements and had a range less than 5% error.

Grisso et al. (2002) used geo−referenced data gathered during field operations (planting and harvesting) to determine field efficiency. They demonstrated a strategy that compared field efficiency for machinery operations between flat, straight−rows and contoured traffic patterns. The methodology described by Grisso et al. (2002) has several potential applications. First, the *ASAE Standards* (1999b) could be updated to provide additional information about selecting values for specific field operating conditions. Results of the analysis are similar to other time−motion studies used in industrial applications, where the inefficiencies of a given process can be identified and quantified, and economic impacts can be assessed. Management strategies can be implemented to minimize inefficiencies and solutions verified. The analysis could be used to compare various machinery operation techniques and practices. Producers could compare different methods (Reichenberger, 2001) such as the time saved by using bulk seed versus bags during planting. During harvest, producers could assess time saved due to unloading on−the−go versus keeping the grain cart out of the field. Finally, assessment of machinery and operator costs could be estimated for each field or subsection instead of using whole farm enterprise averages.

One drawback of using field efficiency is that it is a composite of machine, operator, and landscape features. Currently, users select a value from a wide range of field efficiencies. An index is proposed to better estimate field efficiency. The index could provide users of the *ASAE Standard's* (1999b) information a means of selecting a field efficiency that would better match the conditions experienced by the user. It is hoped that distinctions can be made between flat, straight planted fields and contoured planted fields. It is proposed that the traffic patterns be used to characterize these differences.

OBJECTIVES

The objective of this study was to evaluate the estimation of field efficiency from four indices of traffic pattern that were determined from geo−referenced data for planting and harvesting field operations.

TRAFFIC PATTERN INDICES

Selection of the traffic pattern indices will provide information that integrates the influences of field geometry, complexity of traffic patterns, and issues that deal with operational characteristics such as refilling, unloading, maintenance of field equipment, and other non−productive activities. The definitions of the indices are based on three consecutive geo−referenced points determined during field operation. Three consecutive points, as shown in figure 1, are defined as points A, B, and C. As a vehicle traverses the field from point A to C, the first traffic pattern index is defined as steering angle (θ).

The steering angle (θ) was considered negative if a clockwise adjustment was made and positive if a counter clockwise adjustment was made. The interval timing of the GPS receiver and speed of the vehicle could influence the steering adjustment, thus two steering rates were compared. The steering angle per distance traveled (θ_d, deg/m) and a steering rate (θ_r, deg−m/s) were defined as:

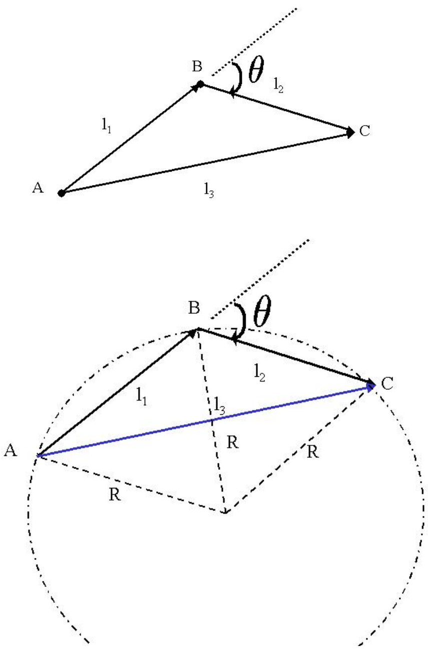

Figure 1. Relative position of three consecutive points (A, B, and C) of the travel path of equipment during a field operation. The points were determined by a DGPS unit and the distances and angles used to calculate the traffic pattern indices.

$$\theta_d = \frac{\theta}{(l_1 + l_2)} \quad (1)$$

$$\theta_r = \frac{\theta\,(l_1 + l_2)}{t_{A-C}} \quad (2)$$

where l_1 and l_2 are the distances between points A and B, and B and C, respectively (see fig. 1), and t_{A-C} – is the total time spent traveling from A to C.

Three consecutive points can be described by a radius of curvature (R), defined as:

$$R = \frac{l_1\ l_2\ l_3}{4\sqrt{(S)(S-l_1)(S-l_2)(S-l_3)}} \quad (3)$$

where l_3 is the distance between points A and C (see fig. 1), and $l_3$can be defined as:

$$l_3 = \sqrt{l_1^2 + l_2^2 - 2\,l_1 l_2\ \cos\ (180^o - \theta)} \quad (4)$$

Parameter S is defined as:

$$S = (1/2)(l_1 + l_2 + l_3) \quad (5)$$

Three consecutive points in different locations were needed to compute the four traffic pattern indices (θ, θ_d, θ_r, and R). The first three points (points A, B, C, as shown in fig. 1) were used to determine the values of the traffic pattern indices at point B. Next, points B, C, and D (D is the next sequential point) were used to determine the set of values for the traffic pattern indices at point C. In this manner, a moving window of three consecutive points was used to obtain the values of the four traffic pattern indices for all workable points in the data. If either of the distances calculated (l_1, l_2) were zero, the traffic pattern indices were null and the equipment was assumed stationary. If the vehicle continued on the same path with no steering adjustment and the steering angle didn't change (θ = 0 degrees), then the radius of curvature approached infinity.

The absolute values of these four traffic pattern indices (θ, θ_d, θ_r, and R) were compared in seven fields. For each field the average and the standard deviation of each of the traffic pattern indices were determined.

EXPERIMENTAL PROCEDURES

Data were gathered from seven fields near Ashland and Ithaca, Nebraska (tables 1 and 2). Ashland farming practices were based on 76−cm (30−in.) rows in a corn−soybean rotation. A John Deere 9500 series combine was equipped with an AgLeader yield monitor and GPS using the U.S. Coast Guard (USCG) radio beacon signal for differential correction (DGPS). The combine used a 6−row corn head to harvest corn and an 8−row platform head for soybeans. Data collection was stopped while the combine head was lifted during turns and when grain was unloaded from the combine. During the planting season, the DGPS equipment was mounted on a 12−row John Deere MaxEmerge tractor/planter unit. Data were recorded continuously and collection of data was not stopped while the planter was turning and performing other non−working activities. The recording rate for both operations was set at 1/3 Hz (location recorded every 3 s).

The fields on the Ithaca farm were very similar to the Ashland fields and were based on 76−cm (30−in.) rows in a corn−soybean rotation. During planting, the PF3000 (AgLeader Technologies, Inc., Ames, Iowa) yield monitor using a Ag132 GPS (Trimble Navigation Limited, Sunnyvale, Calif.) with USCG DGPS correction was mounted on an 8−row Case−IH 955 three−point mounted planter (no lift assist) pulled with a John Deere 7810 112−kW (150−hp) PowerShift MFWD tractor with rear duals. As with the

Table 1. Field characteristics, average travel speed, and field efficiency during planting.

Field Identifier	Traffic Pattern	Production System	Planting No. of Points (Points used)	Field Size ha (acres)	Average Speed km/h (mph)	Theoretical Time (h)	Actual Field Time (h)	Field Efficiency (%)
Field 1	Straight, constant length rows	Soybean	4,525 (4,190)	28.2 (69.6)	10.19 (6.33)	3.02	4.57	66.1
Field 2	Contour, varying length rows	Soybean	5,825 (5,689)	30.5 (75.3)	9.43 (5.86)	3.53	5.74	61.5
Field 3	Straight, constant length rows	Corn	5,163 (4,240)	27.9 (69.0)	8.85 (5.50)	3.45	5.97	57.8
Field 4	Straight, varying length rows	Corn	7,592 (6,263)	37.1 (91.7)	9.45 (5.87)	4.30	6.33	67.9
Field 5	Contour, varying length rows	Corn	9,490 (8,230)	37.6 (92.8)	8.74 (5.43)	4.70	9.31	50.5
Field 6	Straight & curved, varying length rows	Soybean	6,195 (4,157)	18.9 (46.7)	8.93 (5.55)	3.47	5.33	65.1
Field 6a	Straight, varying length rows	Soybean	918 (915)	3.9 (9.7)	8.14 (5.06)	0.79	1.27	62.4
Field 6b	Curved, varying length rows	Soybean	5,277 (3,242)	15.0 (36.9)	9.08 (5.64)	2.70	4.06	66.5
Field 7	Straight & curved, varying length rows	Soybean	4,587 (4,582)	24.0 (59.4)	10.27 (6.38)	3.84	5.68	67.6
Field 7a	Straight, varying length rows	Soybean	2,133 (2,130)	11.2 (27.8)	10.33 (6.42)	1.78	2.81	63.5
Field 7b	Curved, varying length rows	Soybean	2,454 (2,452)	12.8 (31.6)	10.22 (6.35)	2.05	2.80	73.3
Field 8	Straight, varying length rows	Corn	8,725 (8,447)	23.3 (57.6)	8.14 (5.06)	4.70	5.92	79.3
Field 9	Straight, varying length rows	Corn	8,081 (7,934)	22.0 (54.3)	8.18 (5.08)	4.41	6.24	70.6

Table 2. Field characteristics, average travel speed, and field efficiency during harvest.

Field Identifier	Traffic Pattern	Production System	Harvesting No. of Points (Points Used)	Field Size ha (acres)	Average Speed km/h (mph)	Theoretical Time (h)	Actual Field Time (h)	Field Efficiency (%)
Field 1	Straight, constant length rows	Soybean	6,410 (6,408)	28.2 (69.6)	9.25 (5.75)	4.99	7.47	66.9
Field 2	Contour, varying length rows	Soybean	10,294 (10,292)	30.5 (75.3)	6.44 (4.00)	7.77	13.06	59.5
Field 3	Straight, constant length rows	Corn	8,253 (8,250)	27.9 (69.0)	9.30 (5.78)	6.57	12.34	53.2
Field 4	Straight, varying length rows	Corn	10,980 (10,977)	37.1 (91.7)	8.93 (5.55)	9.09	14.72	61.7
Field 5	Contour, varying length rows	Corn	12,141 (12,139)	37.6 (92.8)	7.92 (4.92)	10.37	19.36	53.6

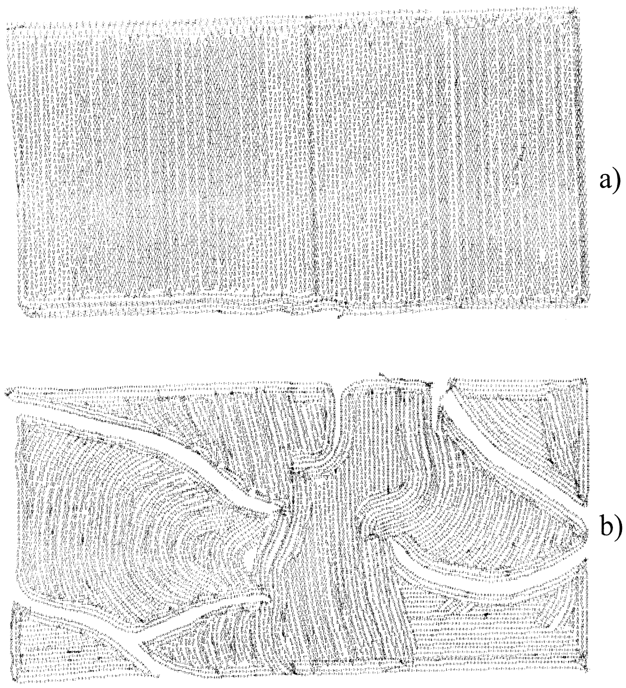

Figure 2. The traffic pattern of two Ashland fields for the soybean crop production system. The fields are identified as: (a) Field 1 straight, constant length rows, and (b) Field 2 with contour, varying length rows.

harvest data, the header height switch was mounted on the three−point hitch so that when the planter was raised, no data were collected. The recording rate was 1/3 Hz for planting soybean and 1/2 Hz for planting corn.

Ashland fields were selected to represent both contour and straight traffic patterns under corn and soybeans production systems. Two fields (identified as Fields 1 and 2) were selected for soybeans and two fields (identified as Fields 3 and 5) were selected for corn production. An additional cornfield (Field 4) with straight rows of varying length (a circular, center−pivot irrigated field) was selected. A summary of the field information and the number of geo−referenced data points is shown in tables 1 and 2. The traffic patterns during harvest for these fields are shown in figures 2 to 5.

Ithaca fields were relatively flat and were selected to represent different traffic patterns under a center pivot irrigation system. Two fields (identified as Fields 6 and 7 in figs. 6 and 7) were selected for soybeans and in a portion of the field the planter followed the pivot tracks. The section following the pivot tracks was referred to as “curved” traffic patterns (referred to Field 6a and 7a). The straight planted portion of the field was designated as Fields 6b and 7b. Field 6 had several passes planted in 38−cm (15−in.) row corn by using a double planting of the area and a plot with high population rates was planted. These two areas were removed from the analysis, hence the reason for the gaps in the curved section (fig. 6).

Two similar fields (identified as Fields 8 and 9 in figs. 8 and 9) were planted in corn with straight rows of various lengths. Fields 8 and 9 were similar to Field 4 except only half the pivot area was planted. These fields do have a common element. Fields 6 and 8 were the same field but planted with different crops in different years. Similarly, Fields 7 and 9 were the same field, but planted with different crops in different years. Table 1 shows a summary of the field information and the number of geo−referenced data points.

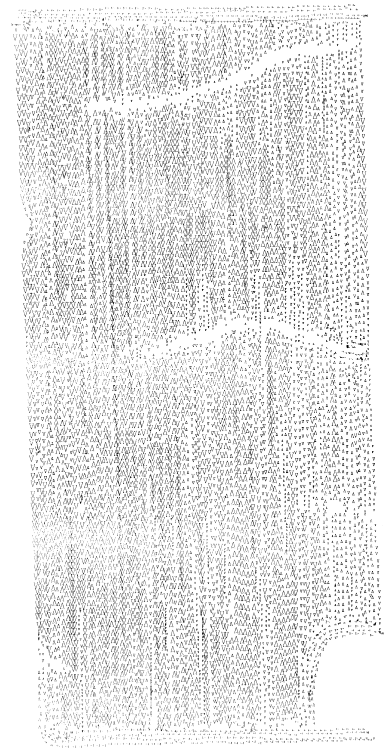

Figure 3. The traffic pattern of Field 3 (Ashland) with straight, constant length rows used in the corn crop production system.

The data from the monitor were compiled by the yield monitor manufacturer’s mapping program and exported as a text file (advanced text export format). Then the exported file was analyzed with a spreadsheet and a GIS package was used to view the graphical data. Travel speed was calculated with

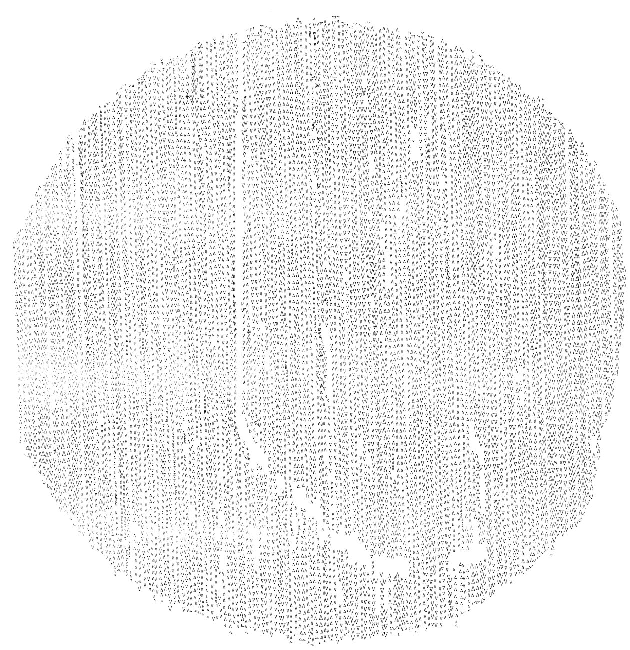

Figure 4. The traffic pattern of Field 4 (Ashland) with straight, varying length rows used in the corn crop production system.

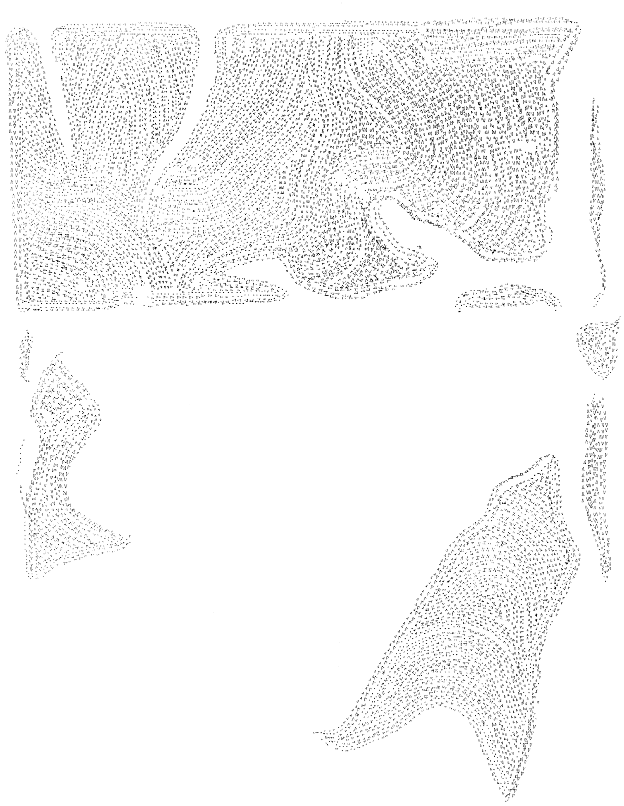

Figure 5. The traffic pattern of Field 5 (Ashland) with contour, varying length rows used in the corn crop production system.

the distance between consecutive points as reported by the DGPS unit and divided by the time interval recorded by the monitor (3 or 2 s depending on the field). The actual UTC time between data records was obtained from the DGPS receiver. UTC time was used to confirm the sequence of field operations. Coordinates of latitude and longitude were used to develop traffic patterns, travel lengths and steering angles.

The field efficiency for each field was calculated based on the ratio of theoretical time to complete the operation to the measured time required to complete that operation. To calculate the theoretical time, the field area was divided by the theoretical field capacity (Grisso et al., 2002). Field size was determined from the harvest data (yield monitor). Theoretical capacities for planting and harvesting were calculated based on average travel speed (excluding turns) for each field and the following operational widths. For planting Fields 1−5, a planter width of 9.1 m (30 ft) was assumed. For harvesting Fields 1−5, a combine width of 4.6 m (15 ft) for corn and a 6.1−m (20−ft) platform header for soybeans was assumed. For planting Fields 6−9, a planter width of 6.1 m (20 ft) was used. The average travel speeds for each field are given in tables 1 and 2.

Results and Discussion

Field Efficiency

Field efficiencies were calculated as described by Grisso et al. (2002) and are reported in tables 1 and 2. The average planting field efficiency (68.8%) for the seven fields with straight rows (Fields 1, 3, 4, 6a, 7a, 8, and 9) was higher than the average (59.5%) for the fields with contour and curved row patterns (Fields 2, 5, 6b, and 7b). The average harvesting field efficiencies for the three fields (Fields 1, 3, and 4) with straight rows (60.6%) was higher than for the two fields (Fields 2 and 5) with contour patterns (56.6%). Comparing the planting operations of Fields 1 and 2 (soybean production), the contour pattern had a field efficiency 4.5 percentage points lower than for the field with the straight rows, and the harvest field efficiency on contours was more than 7.4 percentage points lower for the same fields. Comparing Fields 3 and 4 to Field 5 (corn production), the contour pattern planting field efficiency was 7.3 to 17 percentage points less than for the fields with straight rows, while with the contour pattern of Field 5, the harvesting field

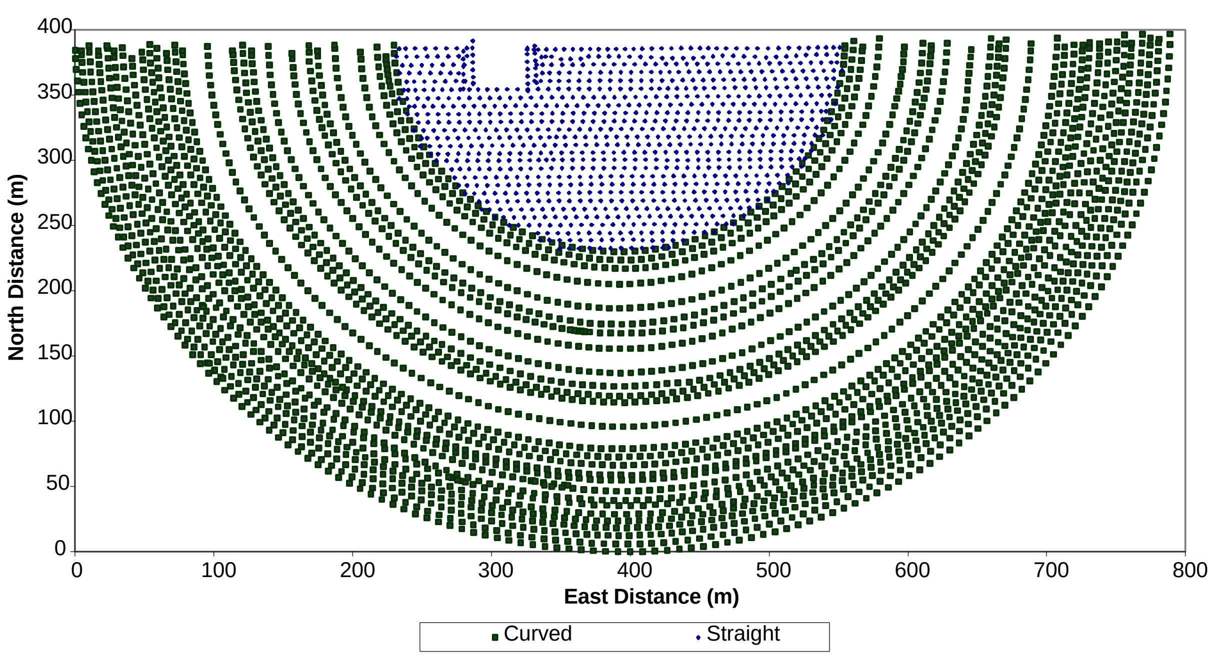

Figure 6. The traffic pattern of Field 6 (Ithaca) with straight and curved, varying length rows used in the soybean crop production system.

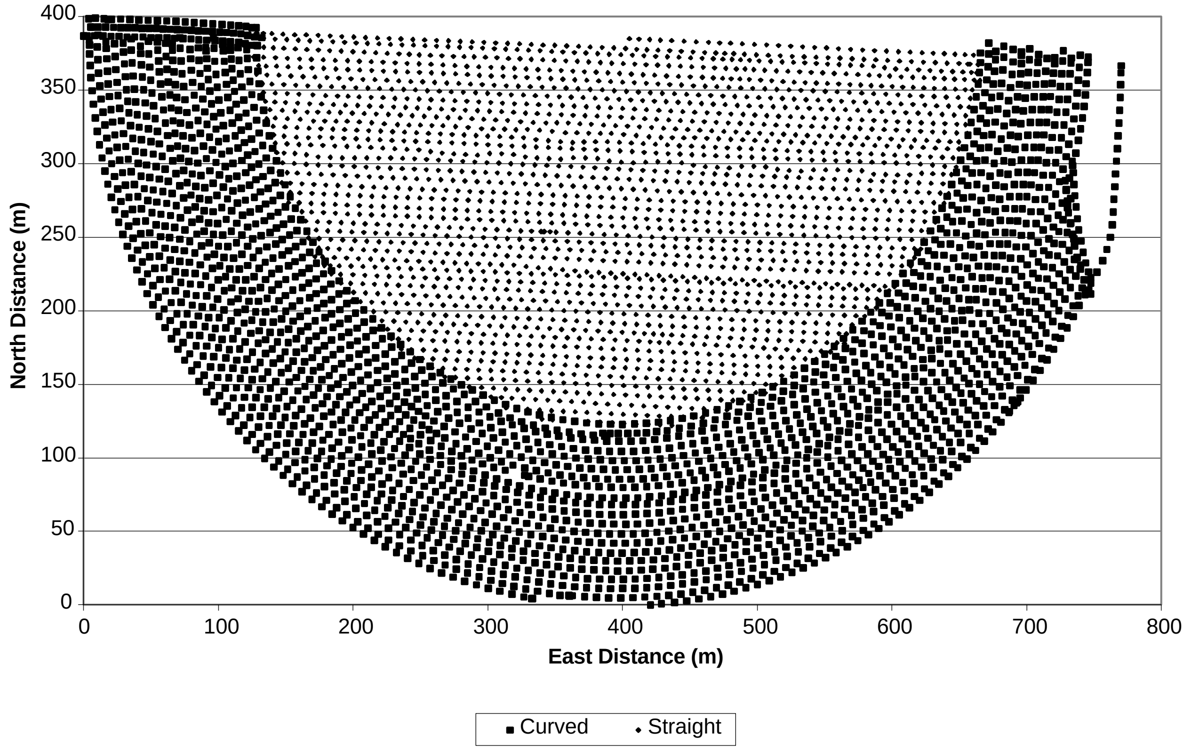

Figure 7. The traffic pattern of Field 7 (Ithaca) with straight and curved, varying length rows used in the soybean crop production system.

efficiency was 8 percentage points less than for Field 4. The planting field efficiency for Fields 6−9 ranged from 62% to 79%.

The comparisons among Fields 6−9 show some interesting contrasts. The field efficiency was a little lower in Field 6 than expected. Comparing the straight−planted to the curved−planted portions of Fields 6 and 7, the curved sections had higher field efficiency but the row lengths for the curved sections were significantly longer than those in the straight−planted sections. Along with that, the field efficiency for the straight rows on Field 7 (Field 7a) was higher than for the straight rows on Field 6 (Field 6a) and the length of the straight rows in Field 7 (Field 7a) were greater than those of Field 6 (Field 6a). The difference in field efficiency between Fields 7 and 9 was minimal despite the difference in traffic pattern and crops. While times for refilling the planter were

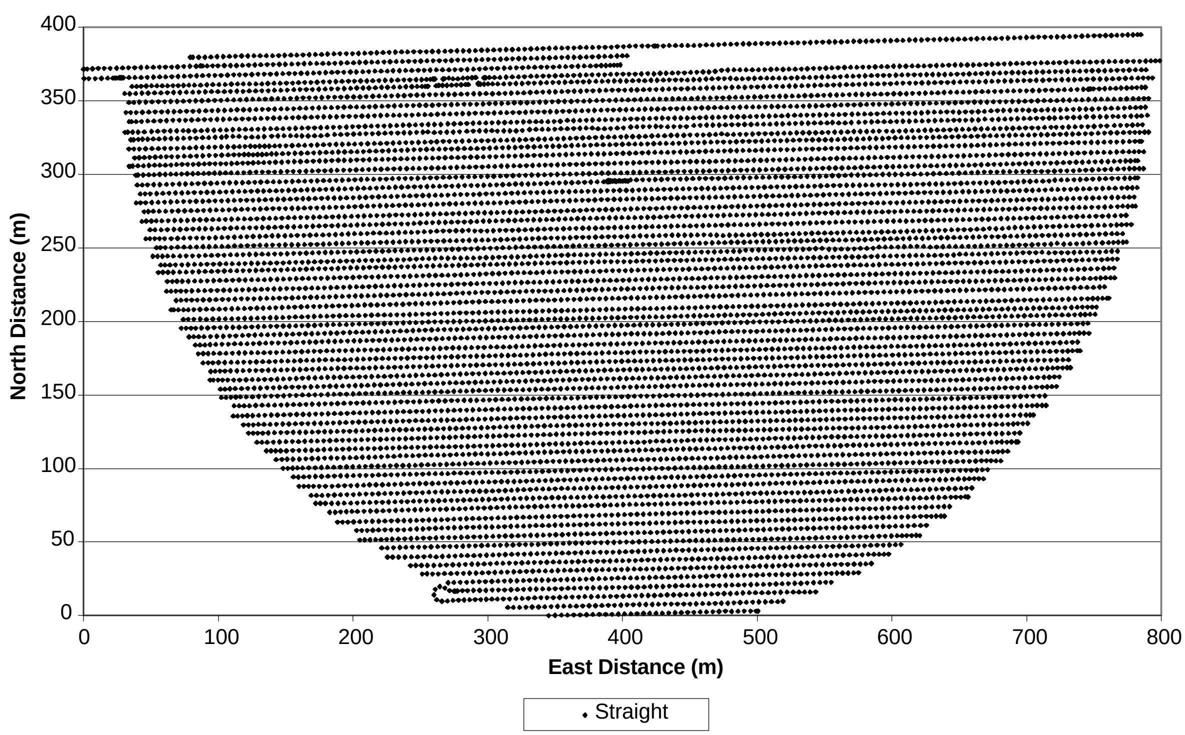

Figure 8. The traffic pattern of Field 8 (Ithaca) with straight, varying length rows used in the corn crop production system.

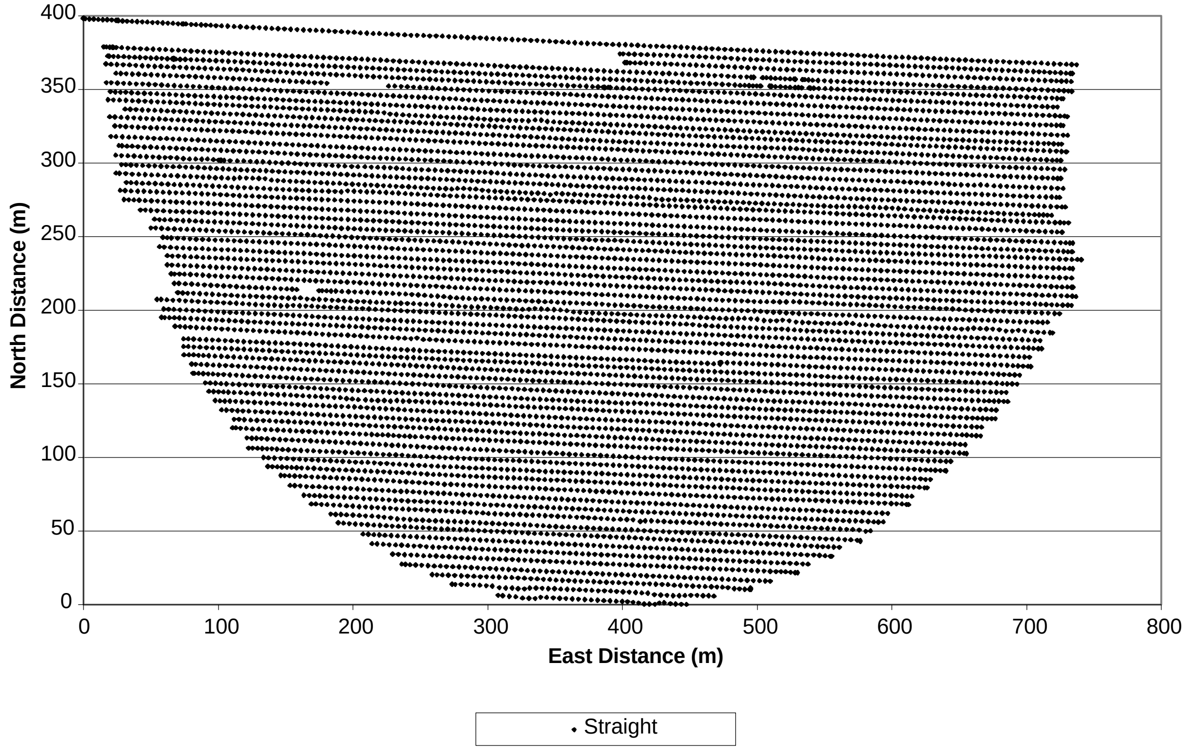

Figure 9. The traffic pattern of Field 9 (Ithaca) with straight, varying length rows used in the corn crop production system.

not calculated separately, it required two refills of seed corn to plant the same field area as compared to five refills of soybean seed. Due to less time for seed filling, field efficiency for planting corn would be expected to be about 8 percentage points higher than for soybean. The traffic patterns in Fields 7 and 9 had the same number of passes. Because, the non−productive time spent turning was about the same, the traffic pattern used following the conventional straight paths had no advantage in field efficiency over the curved traffic pattern.

To obtain higher field efficiencies in studied fields, the producer could reduce the number of turns. For example, there were about 66 passes planted in Fields 7 and 9 and there would need to be more than a 20% to 25% reduction in pass turns (reduction of 12 turns) to show improvement in field efficiency. Even though Fields 7a and 7b were about the same size in area, the curved planted portion (7b) had an improved field efficiency of about 10 percentage points over the portion following the straight rows (7a); probably because the curved rows were longer than the straight rows (fewer turnarounds) and the curves were gentle, not requiring a speed reduction.

Traffic Pattern Indices

The four traffic pattern indices were defined at most locations in the field (where possible) and the indices were analyzed by frequency distributions. Figure 10 shows example distributions of steering angle (θ) for Fields 1 and 2 with both planting and harvesting operations. More than 80% of the steering adjustments for Field 1 (straight rows, constant length) were made in the 0−5 degree range. The minimal steering angle was not the case for Field 2 (contoured rows, varying length). Field 2 had only 50% to 60% of the steering adjustment between 0−5 degrees. To accumulate 80% of the occurrences in Field 2, the steering range had to extend 0−20 degrees and 0−10 degrees for planting and harvesting, respectively. These high steering angle ranges indicated that the complex traffic pattern of contouring in Field 2 was correctly represented in the steering angle. Figure 10 also indicates some percentage of steering angle greater than 140 degrees. Most of these high steering angles occurred when the operator pulled up to the row and reversed to align the machine or had a running start at the row.

Tables 3 and 4 show the average and standard deviation of the absolute values from the four traffic pattern indices for the seven fields. Fields 6 and 7 have different traffic patterns within each field and the results were separated and presented in table 3.

Note in table 3 that Fields 5, 6b, and 7b had small values of radius of curvature but Fields 2 and 5 had large differences in the magnitude of the average steering angle compared to the straight traffic patterns. Fields 2 and 5 (contour traffic pattern) had many turns, and tighter turns, so the average steering angle turned out to be some of the highest. Fields 6b and 7b have long, curved rows with gradual turns, so the average steering angles were not much different than for fields with straight rows. This lack of differences shows that using many larger steering angles (as on a contoured field) was best reflected in the average steering angle, while continuously using small steering angles (as on curved rows) was best reflected in the radius of curvature. The radius of curvature showed a strong indication of separating the contoured traffic patterns from the straight row and gently curved traffic patterns, but was not strongly associated with field efficiency.

The average values of each of the four traffic pattern indices for each field were correlated with the corresponding field efficiencies. Using a Pearson correlation coefficient, the steering angle (θ) showed the strongest association (−0.654) with field efficiency unlike the other three indices. The Pearson correlation coefficients for θ_r, θ_d, and R were −0.224,

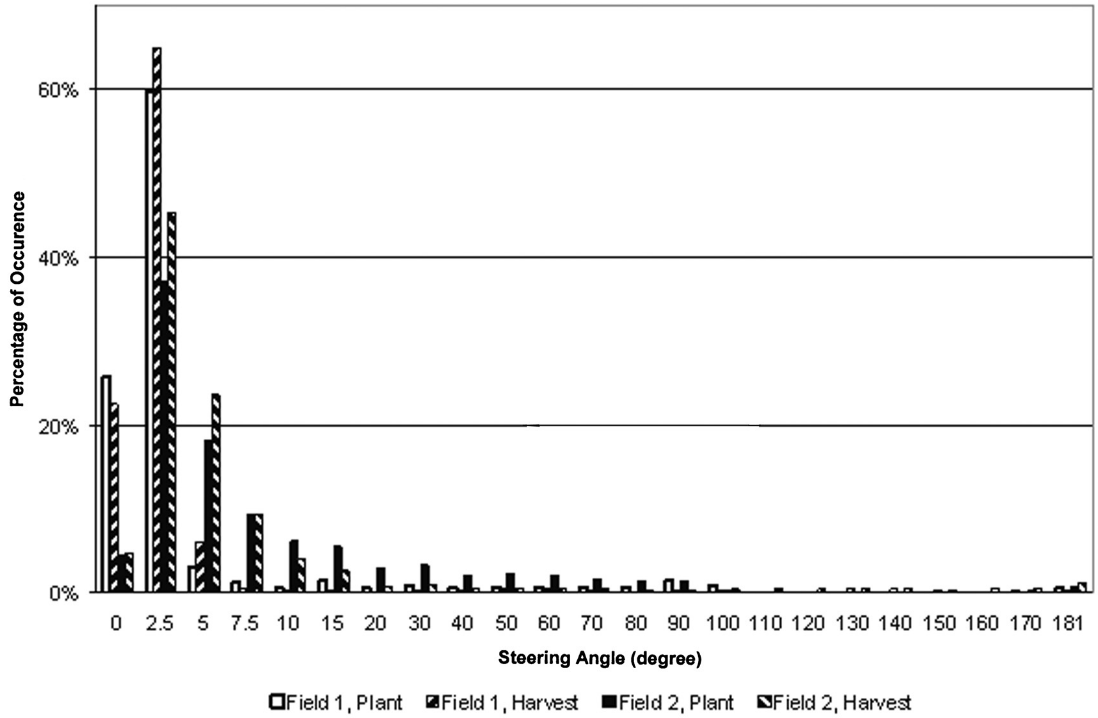

Figure 10. The frequency distribution of the absolute value of steering angle made during planting and harvest (soybean production). Field 1 has straight, constant length rows while Field 2 has contoured, varying length rows patterns.

−0.196, and −0.076, respectively. There was a negative correlation between field efficiency and steering angle (fig. 11). If the traffic pattern is complex, the expected standard deviation should also be large. The standard deviation of the steering angle was strongly associated with field efficiency and had a Pearson correlation coefficient of −0.664 (fig. 12).

The information from the four traffic pattern indices was useful to characterize different field operations. However, differences in recording the geo−referenced data between the planting and harvesting operations created some discrepancies in the traffic pattern indices that may have resulted in lower coefficients of correlation with field efficiency. For example, Fields 1−5 had inconsistent data logging protocol. As mentioned before, during harvesting, data were not recorded while the header was up during turns and other non−productive activities. During the planting operation on the other hand, data were recorded continuously; even through the turns and other non−productive activities. When recorded continuously, the turns at the end of the rows for planting had several data points and the steering angle changed gradually. Unlike harvest operations which had data

Table 3. Field average and standard deviation of the absolute values of four traffic pattern indices during planting.

Field Identifier		θ (degree)		θ_d (degree/m)		θ_r (degree−m/s)		Radius of Curvature (R), m	
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Field 1[a]	Soybeans	7.30	23.6	6.08	72.1	14.8	45.7	95,900	3,430,000
Field 2[b]	Soybeans	13.1	25.6	3.15	36.8	29.1	63.4	30,300	2,070,000
Field 3[a]	Corn	6.10	21.7	16.4	104.9	7.00	59.8	32,300	46,200
Field 4[c]	Corn	6.33	21.3	15.3	119.9	5.15	215	44,600	1,730,000
Field 5[b]	Corn	14.3	27.0	13.3	97.7	26.1	48.2	2,340	14,000
Field 6[d]	Soybeans	4.38	18.0	0.28	1.32	35.8	457	4,630	18,500
Field 6a[c]	Soybeans	7.90	28.2	0.47	1.71	37.8	295	17,900	35,000
Field 6b[e]	Soybeans	3.39	13.7	0.22	1.18	35.2	495	881	5,470
Field 7[d]	Soybeans	4.19	18.3	0.30	1.75	13.5	133	67,900	3,110,000
Field 7a[c]	Soybeans	4.55	20.6	0.29	1.45	15.9	179	145,000	4,560,000
Field 7b[e]	Soybeans	3.87	16.1	0.30	1.97	11.3	71.6	843	5,230
Field 8[c]	Corn	2.81	14.7	3.50	65.7	2.81	14.7	5,620	17,500
Field 9[c]	Corn	3.00	14.9	2.63	59.5	7.58	49.6	92,100	2,810,000

[a] Straight rows, constant length.
[b] Contoured rows, varying length.
[c] Straight rows, varying length.
[d] Curved and straight rows, varying length.
[e] Curved rows, varying length.

Table 4. Field average and standard deviation of the absolute values of four traffic pattern indices during harvest.

Field Identifier		θ (degree)		θ_d (degree/m)		θ_r (degree−m/s)		Radius of Curvature (R), m	
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Field 1[a]	Soybeans	5.74	22.6	0.42	2.32	1.58	14.2	47,800	1,960,000
Field 2[b]	Soybeans	12.3	33.0	1.37	12.3	3.19	19.9	42,100	1,900,000
Field 3[a]	Corn	4.27	20.3	0.63	12.5	4.44	40.4	44,200	1,180,000
Field 4[c]	Corn	4.15	19.1	0.21	1.40	7.69	101	23,700	41,700
Field 5[b]	Corn	13.7	33.5	1.42	17.7	17.9	73.2	16,400	1,580,000

[a] Straight rows, constant length.
[b] Contoured rows, varying length.
[c] Straight rows, varying length.

points that stopped at the end of the row and then resumed at the beginning of the next row, resulting in a pair of large steering angle values. Even though these values were from the same fields with similar traffic patterns (planting versus harvest), the changes in average steering angle between the two operations were not great While the changes in the other traffic pattern indices were on the order of 2 to 20 times.

Another factor that affected the traffic pattern indices was the recording interval. Data in all the fields were taken at 1/3 Hz except for Fields 8 and 9, which were at 1/2 Hz. This closer interval likely meant that the steering angles were not as great as those with a longer time interval. Again, the impact was not seen in the average steering angle but did show a larger difference in the steering angle per distance traveled and steering rate indices.

CONCLUSIONS

Results demonstrated that geo−referenced data gathered during field operations were useful for developing time−motion studies and observing machine and operator patterns for machinery management decisions. Seven fields were used to compare results from soybean and corn production systems. Fields that were relatively flat with straight−rows were contrasted with contoured fields with slopes up to 5%. Two unique traffic patterns in fields with a center pivot were compared as well. Geo−referenced data were used to determine field efficiency and four traffic pattern indices were developed to indicate the steering behavior observed during field operations. Of the four indices compared, the average steering angle (θ) and its standard deviation had the strongest correlation with field efficiency (r = −0.654 and r = −0.664, respectively). The average steering angle for contoured traffic patterns were two to four times in magnitude that of straight− or gently curved−row traffic patterns. The steering angle index gave reliable quantification of field operation conditions but differences in data recording methods and operational characteristics likely imposed limitations on the strength of the correlations.

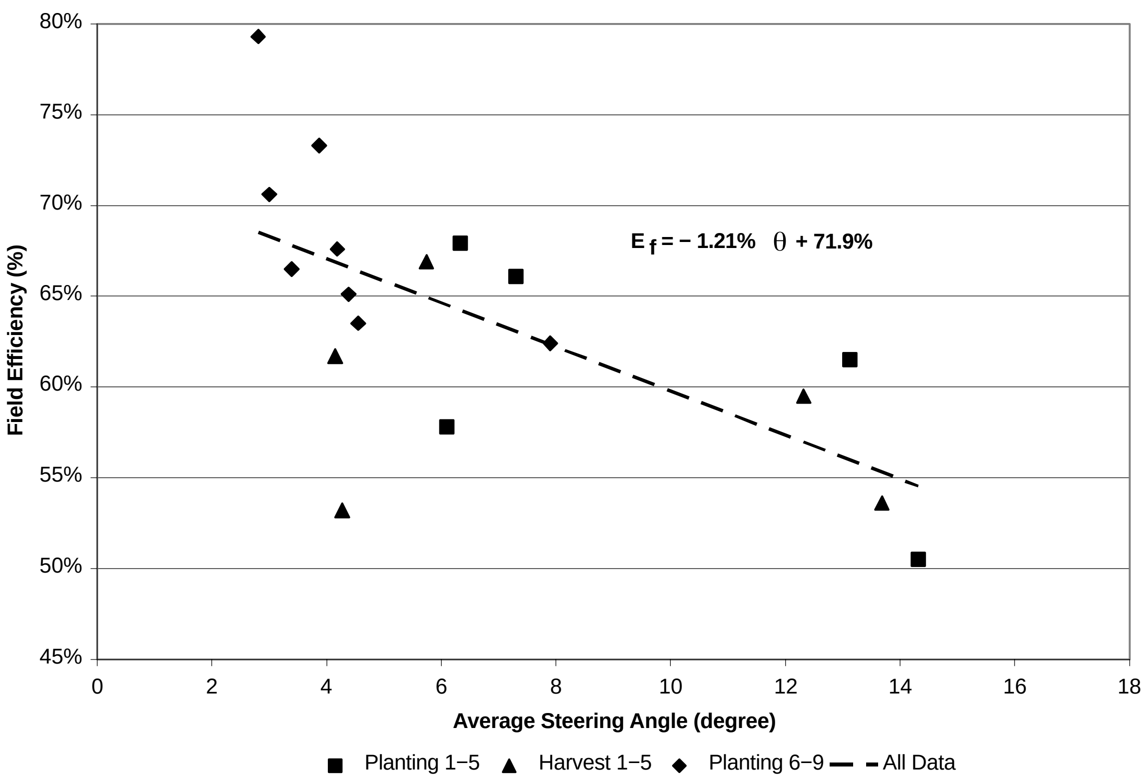

Figure 11. The relationship between average steering angle and field efficiency made during planting and harvest (soybean and corn production systems). "Planting 1−5" represents planting operations in Fields 1−5, "Planting 6−9" represents planting operations in Fields 6−9, and "Harvest 1−5" represents harvest operation in Fields 1−5. Also shown is the linear regression for all data.

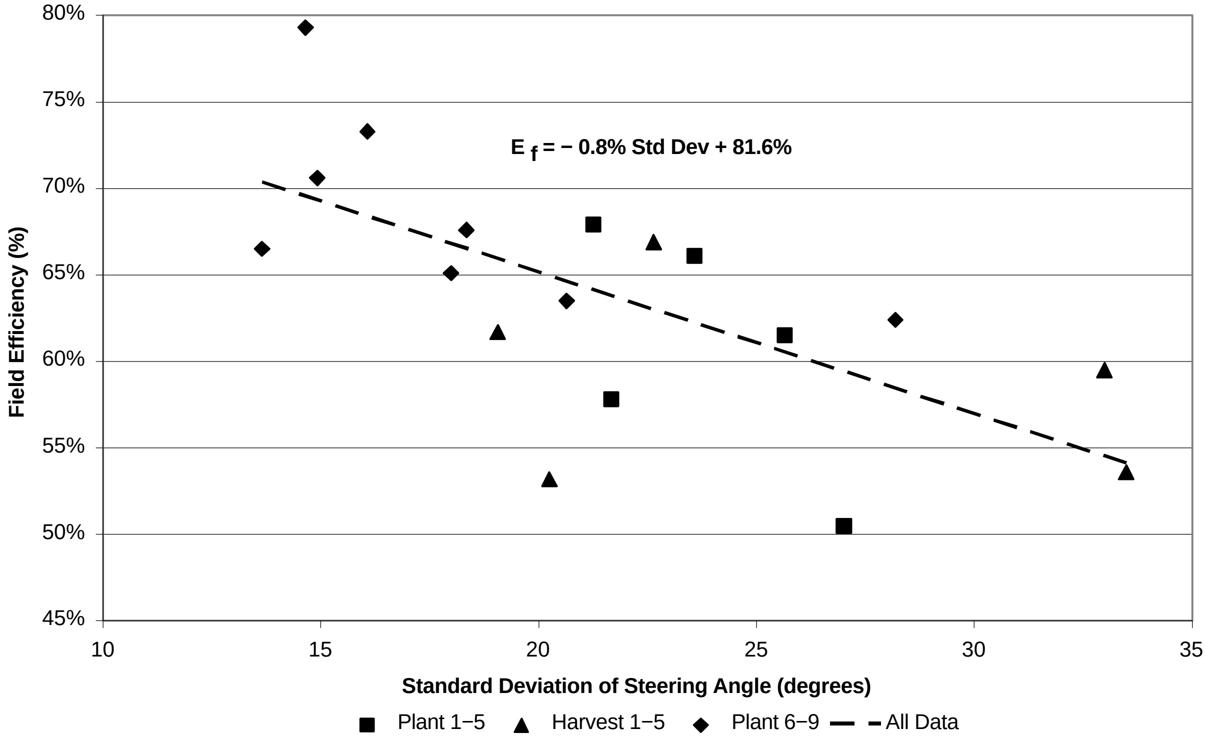

Figure 12. The relationship between the standard deviation of steering angle and field efficiency made during planting and harvest (soybean and corn production systems). "Plant 1−5" represents planting operations in Fields 1−5, "Plant 6−9" represents planting operations in Fields 6−9, and "Harvest 1−5" represents harvest operation in Fields 1−5. Also shown is the linear regression for all data.

The following general conclusions can be drawn from the results obtained:

- Use of geo−referenced data obtained while planting and harvesting corn and soybean allowed for off−site analysis of traffic patterns and a possible method to determine field efficiency.
- The assessment of traffic pattern complexity through average steering angle index (θ) was correlated with field efficiency.
- To achieve stronger relationships between field efficiency and other traffic pattern quantifiers, the same protocol of recording the geo−referenced data and operational characteristics have to be followed.

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