# SPATIO-TEMPORAL ANALYSIS OF YIELD VARIABILITY FOR A CORN-SOYBEAN FIELD IN IOWA

A. Bakhsh, D. B. Jaynes, T. S. Colvin, R. S. Kanwar

**ABSTRACT.** *Spatio-temporal analyses of yield variability are required to delineate areas of stable yield patterns for application of precision farming techniques. Spatial structure and temporal stability patterns were studied using 1995-1997 yield data for a 25-ha field located near Story City, Iowa. Corn was grown during 1995-1996, and soybean in 1997. The yield data were collected on nine east-west transects, consisting of 25 yield blocks per transect. The two components of yield variability, i.e., large-scale variation (trend) and small-scale variation, were studied using median polishing technique and variography, respectively. The trend surface, obtained from median polishing, accounted for the large-scale deterministic structure induced by treatments and landscape effects. After removal of trend from yield data, the resulting yield residuals were used to analyze the small-scale stochastic variability using variography. The variogram analysis showed strong spatial structure for the yield residuals. The spatial correlation lengths were found to vary from about 40 m for corn to about 90 m for soybean. The range parameter of the variograms showed a significant correlation coefficient of –0.95 with the cumulative growing season rainfall. The total variance of 1995 corn yield was partitioned as 56% trend, 37% small-scale stochastic structure, and 7% as an interaction of both. Yield variance of 1996 corn was about 80% trend and 20% small-scale stochastic structure. Contrary to corn years, the total yield variance for soybean in 1997 was partitioned as about 25% trend and about 75% small-scale stochastic structure. The significant negative correlation of range with rainfall shows that small-scale variability may be controlled by factors induced directly or indirectly by rainfall. More years of data are required to substantiate these relationships. The lack of temporal stability in large-scale and small-scale variation suggest that longer duration yield data analyses are required to understand and quantify the impact of various climatic, and management factors and their interaction with soil properties on delineation of areas under consistent yield patterns before applying variable rate technology.*

***Keywords.*** *Yield variability, Median polishing, Semivariogram, Precision farming.*

Current farming practices of intensive and uniform application of chemicals across the field have resulted in soil and water contamination. The United States Environmental Protection Agency (US-EPA, 1995) identified the agricultural sector as one of the major contributors to soil and water pollution. Farmers apply fertilizers and pesticides to increase their crop yields. Regulatory agencies emphasize the need for a reduction in chemical use. Under this situation, it is necessary to develop strategies that encourage farmers to optimize chemicals while maintaining current crop yield levels.

Soil characteristics vary from point to point within a field and vary in their potentials for crop production (Jaynes et al., 1995). A study conducted by Porter et al. (1998) demonstrated a high degree of inherent spatial yield variability during their 10-year study. Farmers and researchers have long recognized variable yield potential for different soils, but prevailing technologies at those earlier times prevented implementation of varying rate applications (Goering, 1993). The present state of technology has made it possible to record yield variability across the field. On-board yield monitors can record geo-referenced yield data for a better understanding and improved assessment of the production capabilities of different field units (Ambuel et al., 1991).

The consistency of the spatial and temporal structure of crop yield across the field needs to be investigated before implementing precision farming. Several researchers have analyzed yield patterns over space and time. Lamb et al. (1997) reported lack of grain yield stability during their five-year study. They emphasized that a much longer term database may be required to develop fertilizer recommendations on site specific basis. Colvin et al. (1997) studied the yield patterns for a field located in central Iowa. They reported that only a few points exhibited yield stability during the six-year study period. Jaynes and Colvin (1997) investigating the same corn-soybean field, found that factors controlling yield are dynamic, and relate to interaction among soil hydraulic properties and climatic patterns. Stein et al. (1997) emphasized the use of spatial analysis in reducing production risks and in formulating variable resource allocation. Scharf and Alley (1993) applied nearest neighbor analysis to detect spatial yield variability from the random error term. Mulla (1991) determined that wheat

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yields were correlated to a distance of 70 m in a field located in the Palouse region of eastern Washington. Miller et al. (1988) reported a correlation distance of 80 m in a northern California wheat field. These studies concluded that a better understanding of yield variability across the field could improve management practices by including spatial information about the availability of soil water and the nutrient status of the various field units.

Yield may be thought of as a random variable that is a function of large-scale deterministic structure (or trend) and small-scale stochastic structure (Cressie, 1993). The separation of trend from small-scale stochastic structure can be accomplished using the median polishing technique proposed by Cressie (1993). Mohanty and Kanwar (1994) and Cahn et al. (1994) applied this technique to reveal trend surfaces of soil physical and chemical properties. The residuals obtained from detrending the data by the median polishing technique can be used in variography analysis to study the small-scale stochastic structure. Variography analyses have been applied to yield data to examine the spatial dependency of the random function (Jaynes and Colvin, 1997). The comparison of variograms and trend surfaces of yield data over space and time domains can help in understanding the factors controlling the yield variability. These factors can then be considered when using variable rate application technology for enhancing environmentally safe crop production (Ambuel et al., 1994).

The implementation of precision farming technologies requires delineation of the field areas with consistent yield response patterns before applying variable agricultural inputs (Bakhsh et al., 1997). Geostatistical analyses have been reported as being useful in defining these areas for site-specific agricultural inputs (Cressie, 1993; Stein and Corsten, 1991). Therefore, this study presents a spatial analysis of three-year, corn-soybean yield data collected at a field near Story City, Iowa, to:

- Compare the stability of large-scale and small-scale variations of 1995-1997 yield data.
- Investigate the extent of spatial correlation for corn and soybean yield residuals and their relationship with rainfall data.

# MATERIALS AND METHODS

## STUDY AREA AND FIELD MEASUREMENTS

The research site is a 25-ha subsurface-drained field located near Story City in Story County, Iowa, owned and managed by a farmer. Various field data from the site have been collected since 1995 to assess the feasibility of precision farming practices. The soil survey (DeWitt, 1984) of Story County indicates that soils of the study field are in the Kossuth-Ottosen-Bode Soil Association. Most of the soils within this association are poorly drained with slopes ranging from 0 to 5%. A detailed soil survey of the field, conducted on a regular grid of 50 m $\times$ 75 m, showed that the field consists of about 50% Kossuth (388), 40% Ottosen (288), 8% Harps (95), and 2% Okoboji (6) soils (fig. 1). These soils are moderately suited to corn, soybeans, and small grains if adequate drainage is provided.

The management practices of the study area included primary tillage by moldboard plow in 1995 and 1996, and chisel plow in 1997. The secondary tillage was done with disking. Corn was grown in the field in 1995-1996 and soybean in 1997. Anhydrous ammonia was injected one

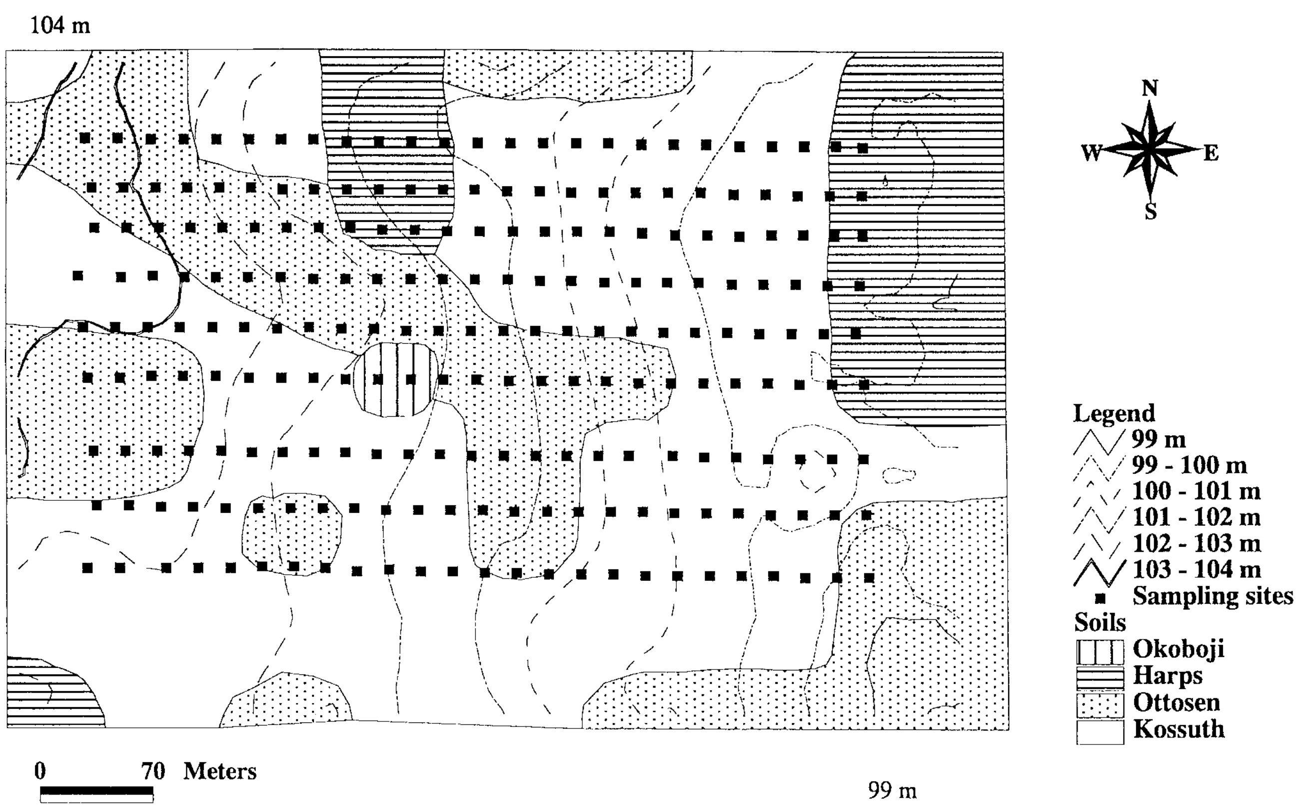


**Figure 1–Map of the study area, near Story City, Iowa, showing soil type, topography, and sampling sites of the yield data.**

week before planting in 1995 and 1996. Actual N-fertilizer treatments of 67 kg/ha categorized as low (L), 135 kg/ha categorized as medium (M), and 202 kg/ha categorized as high (H), were applied in three blocks in 1995 and 1996; no nitrogen was applied in 1997. The order of treatment application in these three blocks varied from south to north of the field as LMH, HML, and LMH for 1995, and HML, HML, and LMH for 1996. Yield measurements were made with the field-plot combine described by Colvin (1990). Corn and soybean yields were measured on nine east-west transects, with 25 yield blocks per transect. The length of each transect was 500 m. Each yield block was $20 \times 2.28$ m in size. These transects formed a grid of $9 \times 25$ yield values. The distance among transects was controlled by drain spacing and varied from 25 m in the north of the field to 37 m in the south. The weight of the grain collected over each yield block was corrected for grain moisture (155 g/kg for corn and 130 g/kg for soybean). The harvest line positions were consistent for all 225 data points for each year (1995, 1996, and 1997).

### Statistical Analysis

The descriptive statistics were computed using SAS (1985). The two main components of yield variation i.e., large-scale variation (trend) and small scale variation (stochastic variability) were studied using median polishing technique and variography, respectively (Cressie, 1993). To remove the effect of physical factors induced by crops, fertilizer treatments and years, the data were detrended by using the median polishing technique (Cressie, 1993). Jaynes and Colvin (1997) applied this technique to yield data for detrending. The technique estimates the grid yield ($Y_{ij}$) value as the sum of the overall median ($\overline{m}$), transect median ($\overline{r}$), column median ($\overline{c}$), and a residual term (R), (eq. 1):

$$Y_{ij} = \overline{m} + \overline{r}_i + \overline{c}_j + R_{ij} \qquad (1)$$

where subscripts i and j are the transect and column numbers of the grid, respectively.

The median polishing technique may not capture all of the large-scale trends, as the trend orientation is not known *a priori* (Cressie, 1993). Therefore, an additional term was included in equation 1 to detect any further trend in the polished data (eq. 2):

$$Y_{ij} = \overline{m} + \overline{r}_i + \overline{c}_j + g\left(i - \overline{i}\right)\left(j - \overline{j}\right) + R'_{ij} \qquad (2)$$

where $\overline{i}$ and $\overline{j}$ are the average transect and column number of the grid. To detect this additional trend, a regression analysis between $R_{ij}$ and $(i - \overline{i})(j - \overline{j})$ terms was done with zero intercept to check the significance level of the slope g. Only the soybean residuals (1997) showed the presence of an additional trend captured by this term. Hence, 1997 residuals were adjusted by partitioning the residuals term from equation 1 into two terms, $g(i - \overline{i})(j - \overline{j})$, and $R'_{ij}$ equation 2. The adjusted residuals were again regressed to detect the existence of any further trend, which was not found.

Variography analyses used in this study assume the data have a Gaussian distribution. Therefore, the outliers and the distribution of the residual yield data for the three years were checked by stem and leaf plots, box plots, and normal probability plots. The criterion used to identify outliers was the box plot. The box plot criteria adopted by SAS for outliers were (Ott, 1993 ):

| | |
|---|---|
| Lower and upper boundaries for mild outliers: | Q1 – 1.5 (IQR)<br>Q3 + 1.5 (IQR) |
| Lower and upper boundaries for extreme outliers: | Q1 – 3(IQR)<br>Q3 + 3(IQR) (3) |

where Q1, Q3, and IQR are the lower quartile, upper quartile, and interquartile ranges, respectively. The ordinary kriging module from GEOPACK (Yates and Yates, 1989) was used to estimate the replacement values for the extreme outliers. A preliminary variogram model fitted to the residual data including outliers was used during kriging. In order to bring the data closer to a normal distribution, only extreme outliers (two values in 1996 and one in 1997) were replaced by the kriged estimates before performing the final variography analysis (Mohanty and Kanwar, 1994).

### Stochastic Variability

Experimental variograms were calculated from the yield residuals after detecting and subtracting the large-scale deterministic variation from the yield data. All sample variogram computations and model fittings were performed using GEOPACK software, assuming isotropic conditions. The isotropic assumptions were verified by variography analysis, in north and east orientations. GEOPACK estimates the semivariance, defined as below:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2 \qquad (4)$$

where $\gamma(h)$is the semivariogram estimator for lag distance, h, $Z(x_i)$ is the yield residual value at location $x_i$ and $x_{(i+h)}$, and N(h) is the total number of sample couples.

GEOPACK uses a nonlinear least square method to fit a model to the experimental variogram. Different models were tested for fitting the data. A spherical model was found as the best fit based on correlation matrix between predicted and experimental values. The spherical model is defined as:

$$\begin{aligned} \gamma(h) &= c_o + c_s\left(\frac{3h}{2a} - \frac{h^3}{2a^3}\right) && 0 < h \le a \\ \gamma(h) &= c_o + c_s = c && h > a \end{aligned} \qquad (5)$$

where h is the lag distance (m) between pairs, $c_o$ is the nugget, $c_s$ is the spherical component, c is the sill, and *a* is the range of the semivariogram.

The appropriateness of the variogram model to the experimental variogram was checked using the cross-validation technique, proposed by Cressie (1993). This method involves estimating the value of the random function at every known sampling location while excluding the known value at that location during the estimation. The cross-validation procedure indicates an acceptable variogram model when the reduced mean and variance are approximately 0.0 and 1.0, respectively.

The range values of the variogram models were regressed to examine the correlation between this spatial parameter and the cumulative growing season rainfall (March through mid-September) as reported by Jaynes and Colvin (1997). Rainfall data for 1996 and 1997 were available from a weather station at the experimental site; whereas, rainfall data for 1995 were collected from Iowa State University's Agronomy farm about 25 km from the research site. Soil water variation occurring in the field as a result of change in season rainfall pattern and its interaction with hydraulic properties of soil and landscape may affect the spatial structure of the yield pattern (Mulla and Schepers, 1997).

The covariance matrix using SAS was calculated for each year's yield data in order to compute how the total yield variance was partitioned among the large-scale deterministic structure, the small-scale stochastic structure, and the covariance between the two.

## RESULTS AND DISCUSSION

Descriptive statistics of corn-soybean yields for 1995-97 are shown in table 1. The grain yield in 1996 was greater than in 1995, probably due to climate and nutrient carryover effect, as almost the same blocks of fertilizer treatments were retained for both years. Power et al. (1998; fig. 11) have reported greater amount of residual soil nitrates based on greater fertilizer application rates. The growing season rainfall for 1996 (738 mm) was about 16% more than that of 1995 (637 mm), and 57% more than that of 1997 (469 mm). In 1997, soybean was grown and no N-fertilizer was applied. The 1997 yield showed less variability based on its interquartile range and standard deviation among the three years of data, due to mostly no application of fertilizer treatments and probably the N-fixing ability of soybean. Almost all of the data were found to be skewed negatively. The interquartile range was found to be the greatest for 1996. Coefficient of variation (CV) was found to be the greatest for 1996, and ranged from 5 to 20% for the three years of data. The same range of CV was observed by Jaynes and Colvin (1997) and Sadler et al. (1995).

The output of the regression analysis of the additional term equation 2 is shown in table 2. The slope, g, for corn data (1995-1996) was not found significant; whereas, the slope for the soybean data was significant, and, therefore, the trend for 1997 was computed again using equation 2. Table 2 shows that the diagonal component for 1995 and 1996 may have been masked by management and N treatments for corn.

**Table 1. Descriptive statistics for corn-soybean yield (Mg/ha) data collected at 225 locations of a 25-ha field**

| | Grain Yield | | | Median Polished Yield | | | Yield Residual | | |
|---|---|---|---|---|---|---|---|---|---|
| Statistics | 1995 | 1996 | 1997 | 1995 | 1996 | 1997 | 1995 | 1996 | 1997 |
| Mean | 7.87 | 8.78 | 3.59 | 7.94 | 8.86 | 3.61 | –0.07 | –0.11 | –0.01 |
| Median | 7.93 | 9.43 | 3.60 | 7.94 | 9.57 | 3.61 | 0.00 | 0.00 | 0.00 |
| Standard deviation | 0.77 | 1.77 | 0.17 | 0.57 | 1.61 | 0.09 | 0.46 | 0.79 | 0.15 |
| Skewness | –0.54 | –0.74 | 0.09 | 0.13 | –0.73 | 0.09 | –0.48 | –1.19 | –0.03 |
| Kurtosis | 0.32 | –0.76 | 0.87 | –0.5 | –1.03 | –0.14 | 0.43 | 4.48 | 1.47 |
| Minimum | 5.49 | 3.97 | 3.06 | 6.73 | 5.62 | 3.38 | –1.61 | –4.34 | –0.47 |
| Maximum | 9.81 | 11.1 | 4.30 | 9.47 | 11.07 | 3.86 | 0.92 | 2.00 | 0.60 |
| Inter quartile range | 0.98 | 3.06 | 0.20 | 0.82 | 2.66 | 0.13 | 0.48 | 0.75 | 0.13 |
| Coefficient of variation | 9.8 | 20.1 | 4.7 | 7.2 | 18.2 | 2.49 | - | - | - |

**Table 2. Regression analysis between $R_{ij}$ and $(i - \bar{i})(j - \bar{j})$ for slope significance**

| Years | d.f. | Intercept | Regression Coefficient | P-value for Coefficient |
|---|---|---|---|---|
| 1995 | 1 | 0 | –0.006 | 0.83 |
| 1996 | 1 | 0 | 0.046 | 0.31 |
| 1997 | 1 | 0 | 0.02 | 0.01* |

* Significant at 5% level of significance; $R_{ij}$ = yield residuals for transect i and column j.

$\bar{i}, \bar{j}$ = average transect and column number

Initially, corn yield residuals failed the Kolmogorov-Simrinov test for normality (Mood et al., 1974); whereas, soybean yield residuals were found to be Gaussian in distribution at a 5% level of significance. Before performing variography analysis, different transformation techniques such as logarithmic and exponential were used to seek normal distribution of the corn yield residuals, but neither resulted in a normal distribution. The extreme outliers, indicated by the box plots (SAS Institute, 1985) were replaced by the kriged estimates for those specific locations. Only two extreme outliers from 1996 and one from 1997 were replaced; whereas, no extreme outlier was found for the 1995 data. After replacing the outliers, the histograms, and normal probability plots are shown in figures 2 and 3. Mild outliers were not replaced, as the probability plots were almost straight lines. The approximate straight lines of the normal probability plots now showed that the data did not violate the assumption of normality (Ott, 1993).

The spatiotemporal yield stability was investigated by developing a correlation matrix (unranked) between the nine transects (rows) for three years of data (table 3). Transect-wise correlation was studied to examine the stability of the field production capabilities and to see if the same sites in each transect were giving higher or lower yields for each year. The correlation matrix for raw yield data was developed to compare its stability with that of the yield residuals. Only a few transects (5, 7, 8, and 9) showed significant stable correlation for raw yield and yield residual data for a few years.

The correlation matrix for yield residuals showed that the first transect has significant positive correlation for corn years. The fifth transect showed a significant negative correlation between soybean and 1996 corn crops. The seventh transect showed positive correlation for corn years. The eighth and ninth transects also showed a positive correlation between corn and soybean crops for only 1996. About 18% of the transects showed significant correlation between yield data for any two years. No single transect showed stable yield pattern among three years of data.

The correlation coefficients for the overall trend surface for all transects for years 1995 and 1996, 1995 and 1997 were found to be about 0.44 and 0.43, respectively; whereas, for years (1996 and 1997) it was about 0.10. Better correlation between 1995 and 1996 might be explained with the same crop and almost the same N fertilizer treatments during both years. The poor relationship between 1996 and 1997 data could have resulted from the higher yield variability in 1996, no N-fertilizer application for 1997, and the different crop in

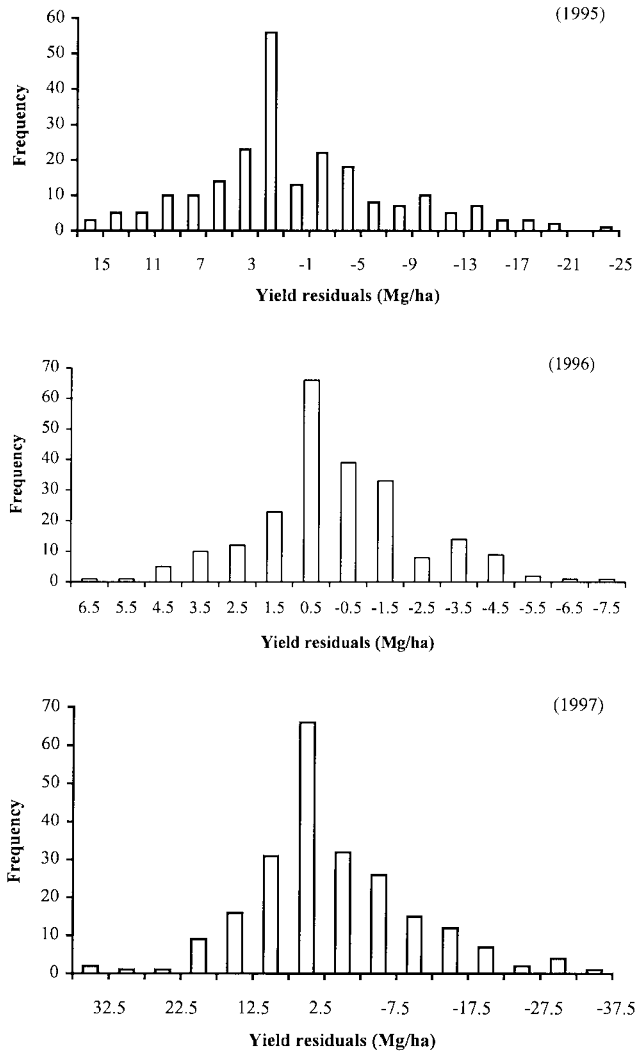


**Figure 2–Histograms of corn-soybean yield residuals.**

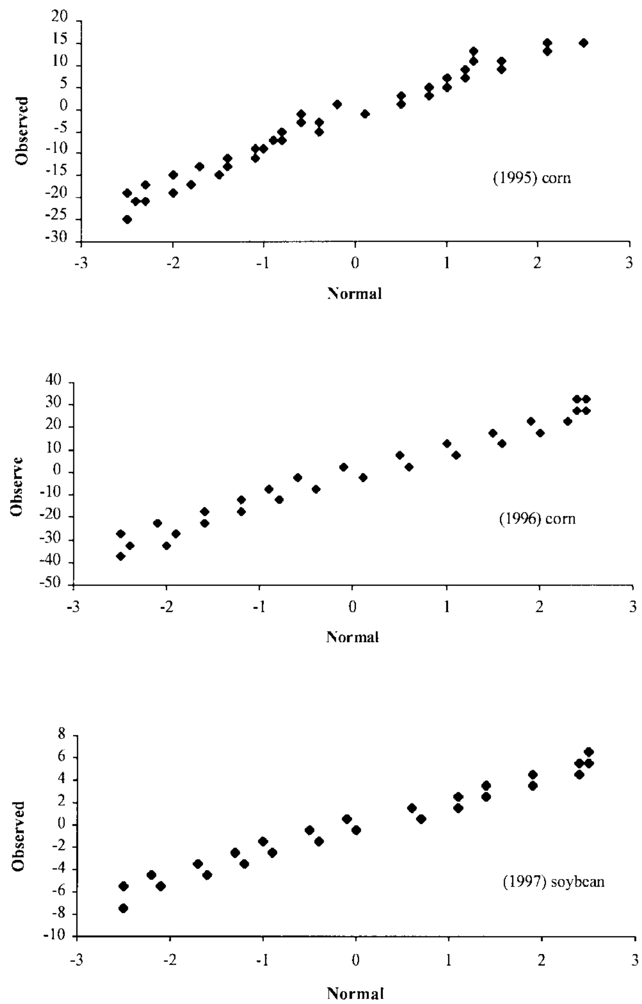


**Figure 3–Normal probability plots of corn-soybean yield residuals.**

**Table 3. Correlation matrix for 1995-1997 yield data**

| | Correlative Years | | | | | |
|---|---|---|---|---|---|---|
| | Raw Yield Data | | | Yield Residual | | |
| Transects | 95:96 | 96:97 | 95:97 | 95:96 | 96:97 | 95:97 |
| 1 | –0.09 | 0.33 | 0.01 | 0.46* | 0.31 | 0.30 |
| 2 | 0.19 | –0.03 | 0.34 | 0.20 | –0.04 | 0.22 |
| 3 | 0.39* | 0.09 | 0.15 | 0.28 | –0.15 | 0.22 |
| 4 | 0.39* | –0.02 | 0.02 | 0.02 | –0.21 | –0.07 |
| 5 | –0.17 | –0.69* | 0.33 | –0.09 | –0.67* | 0.09 |
| 6 | 0.20 | –0.01 | 0.40* | –0.26 | –0.02 | –0.02 |
| 7 | 0.43* | 0.02 | –0.07 | 0.63* | 0.15 | –0.08 |
| 8 | –0.07 | 0.56* | –0.16 | 0.01 | 0.46* | –0.01 |
| 9 | 0.33 | 0.66* | 0.07 | 0.09 | 0.41* | 0.01 |

* Significant at 5% level of significance.

1997. The amount and pattern of growing seasonal rainfall of 738 mm in 1996 was different from the rainfall of 469 mm in 1997.

### Large-scale Variability

The large-scale deterministic structure of the yield was investigated by developing the trend surface computed from median polished data (eqs. 1 and 2). To compare the trends for different crops and treatments, the trend data were normalized by division with the overall median of the respective year. The trend surfaces for the three years of data are shown in figure 4. The normalized trend surfaces show the effect of the fertilizer treatments. The trend surface for 1995 is smoother than that of 1996; whereas, the trend surface of 1996 is greatly variable. Both reflect the effects of low, medium, and high N-fertilizer treatment pattern (fig. 4). No N-fertilizer treatment was applied in 1997, therefore the trend surface for 1997 shows a relatively plane surface. The more pronounced pattern of 1996 may be due to repetition of N-fertilizer treatments and greater amount of rainfall. These trend surface plots show that the median polishing technique can be helpful in delineating areas of the field with low, medium, and high yield transects. The trend surface plots for 1995 and 1996 followed closely the low (L), medium (M), and high (H) N-fertilizer treatment effects; whereas, the 1997 trend surface plot may show the intrinsic nutrient potential of the field, as the trend surface for 1997 does not show any carryover effect of the fertilizer treatment from 1996. The variable amount of rainfall during the study period might have affected the nitrate-nitrogen leaching and in turn any carryover effect from year to year.

The trend surfaces can be explained better by combining the information from correlation matrix for the raw yield data. The transects with significant correlation coefficients

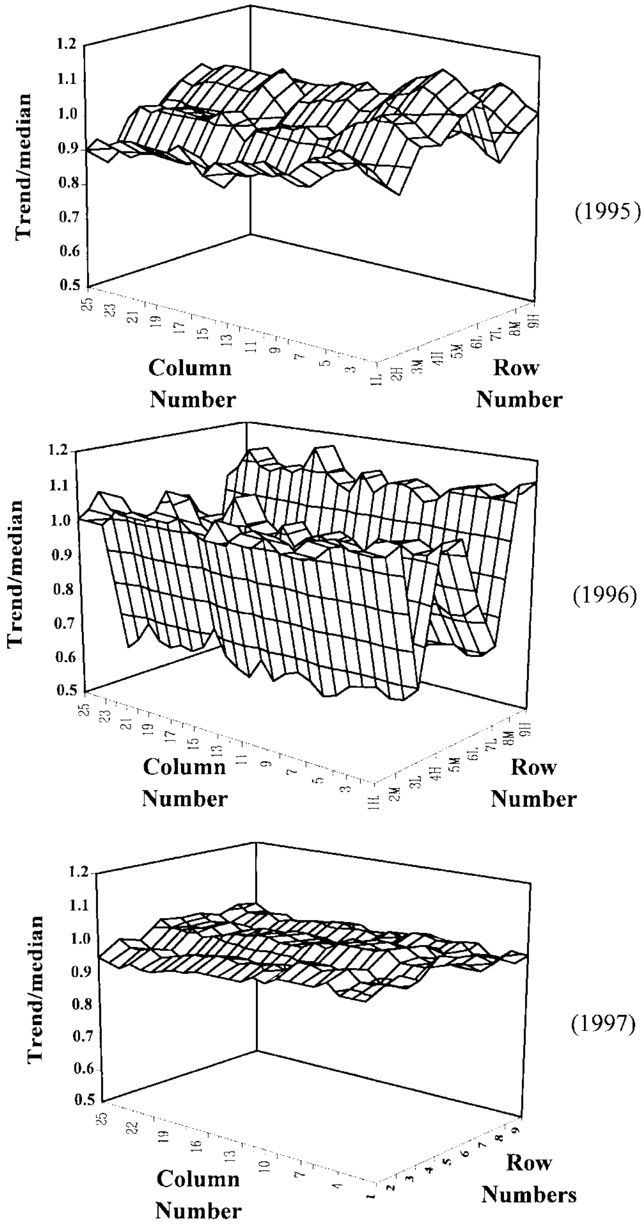


**Figure 4–Comparison of normalized trend surfaces estimated by the median polishing technique for corn-soybean crops (shown by the fertilizer treatments as L, M, H for corn; L = low; M = medium; H = high).**

(table 3) for raw yield data can be verified by viewing the trend surfaces for those transects (fig. 4). The column-wise correlation coefficients among the trends for 1995 and 1996, 1996 and 1997, and 1995 and 1997 were found to be about –0.07, 0.25, and 0.39, respectively. These poor correlations may be due to landscape effect and management practices. The trend surface analyses and correlation coefficients also show that yield patterns were more stable along transects compared with column trends. The crop management operations were also performed along the transects. This relative transect-wise stability might be attributed to the treatment effects dominating the intrinsic spatial variability.

### SMALL-SCALE VARIABILITY

Figure 5 shows the variogram analysis of the yield residuals. A spherical model was fitted to the experimental variogram. No nugget effect was found for corn for both years of 1995 and 1996. However, a nugget effect was found in the case of soybean for 1997. The nugget accounts for the microscale variability, which may have been masked in the corn data, due to higher variance for corn yield compared with that of soybean. The spherical models fitted each experimental variogram well, showing correlation coefficients of 0.99, 0.98 and 0.93 for 1995, 1996 and 1997 data. The range varied from about 40 m for corn to about 90 m for soybean. The range of spatial dependency for soybean was more than twice that of corn. The reason for increase in correlation scale for soybean is not known, but might be attributed to the effects of climate and crop rotation. Sill values of 0.22 and 0.49 $(Mg/ha)^2$ were found for 1995 and 1996 corn yield data and 0.018 $(Mg/ha)^2$ for soybean. The different sill values represent the magnitude of the small-scale stochastic variability for each year.

The cumulative growing season rainfall was used to explain the spatial variation in yield since an earlier study by Jaynes and Colvin (1997) pointed to such effect. The

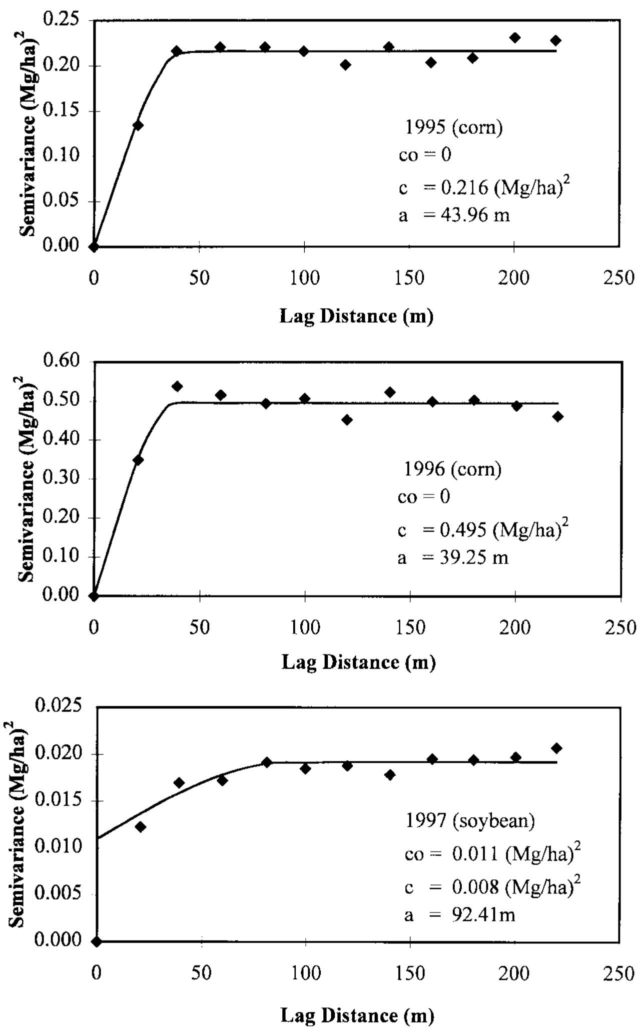


**Figure 5–Comparison of experimental and spherical model fitted semivariograms.**

presence of correlation between rainfall and range was found significant as shown in figure 6. Overall, the data points for 1995, 1996, and 1997 appear to define a negative slope, opposite of that found by Jaynes and Colvin (1997). Their results were based on six-year data and the relationship between range and rainfall was found positive. Further analysis of their data showed that years (2 out of 6) with above average rainfall had the largest value of range. Whereas our data did not show positive relationship between range and rainfall though $R^2$ was significant. In their case, rainfall increased the value of range. Therefore, rainfall might have masked the effect of water holding capacity of soils on yield variability and resulted in smoother yield patterns thus increasing the value of range. Whereas in our case, the crop rotation or interaction of crop rotation with rainfall might have masked the impact of intrinsic variability of soils and caused smoother yield patterns for soybean compared with that under corn and therefore increased the value of range. These results show that interaction of soil properties either with rainfall or crop rotation and rainfall can affect the value of range and this effect may vary from field to field. Therefore, more years of data under different rainfall and soil types are needed to substantiate these relationships.

### Components of Yield Variability

Variance distribution of yield data is shown in table 4. The statistical analysis showed that 56% of the total variance of the 1995 yield data was explained by the large-scale deterministic structure, while 37% was attributed to the small-scale stochastic structure, and about 7% was from an interaction between the two sources of variation. For the 1996 yield data, the trend represented 80% of the variability, and the remainder was covered by the yield residuals. The 1996 data showed a greater effect of fertilizer treatments, and, therefore, the trend was more dominant compared with that of 1995. This is due to the same N-fertilizer treatments being repeated on nearly the same transects. Fertilizer treatments were not applied in 1997 and, therefore, trend explained only about 25% of the yield variability. The stochastic variability was more dominant and it captured about 75% of the yield variability.

The lack of temporal stability in either the large-scale deterministic structure or small-scale stochastic structure shows that crop yield variability is not only controlled by intrinsic soil properties but also by extrinsic variables such as climate and management factors. The weed intensity and water stress may vary from year to year. The carryover effect of fertilizer application as a function of rainfall amount may also vary from year to year. In total, these factors may affect the spatial as well as temporal variability in measured crop yield. It may be necessary to include various climate and management factors, in addition to soil factors, before detailed diagnosis of the yield pattern over a longer duration can be described.

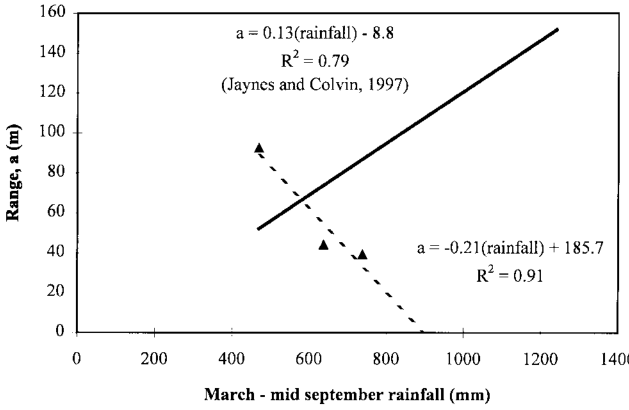


**Figure 6–Relationship of the spatial parameter ‘range’ with the cumulative growing season rainfall for three years of corn-soybean data. Solid line is a relation found by Jaynes and Colvin (1997). Dashed line is least square fit to the data.**

**Table 4. Variance $(Mg/ha)^2$ distribution of the yield data**

| Years | Total Yield Variance | Trend Variance | Residual Variance | Covariance (trend:residual) |
|---|---|---|---|---|
| 1995 | 0.59 | 0.33 (56%) | 0.22 (37%) | 0.04 (7%) |
| 1996 | 3.13 | 2.59 (83%) | 0.63 (20%) | –0.09 (–3%) |
| 1997 | 0.03 | 0.008 (29%) | 0.023 (76%) | –0.001 (–5%) |

Total yield variance = Trend variance + Residual variance + 2 × Covariance (trend:residual).

## Summary and Conclusions

Yield data from three years (1995-1997) were analyzed for improved understanding of the spatial variability and temporal pattern of yield across a 25-ha field. Corn and soybean were grown during the study period, and different fertilizer treatments were applied. In order to compare yield pattern among different crops and years, data were detrended using the median polishing technique. This technique was successful in removing the trend due to fertilizer treatments from the overall yield patterns. The trend surface plots revealed the difference in normalized yield patterns based on the different levels of N-applications.

The variogram analysis showed strong spatial correlation of the small-scale yield variability. The zero nugget effect for corn may be attributed to the higher variance in the yield data that masked the microscale variability. Due to a relatively smaller variance, soybean data showed a nugget effect, which represents the inherent unsampled microscale variability. The sill value ranged from 0.22 to 0.49 $(Mg/ha)^2$. The value of range was consistent for corn (40 m), but was significantly higher for soybean (92 m). The range showed high negative correlation coefficient of –0.95 with the rainfall. The sill values differed from year to year; whereas, range differed from crop to crop. The sill variation might have been caused by rainfall variability. The reason for range variation between crops is not known, but might have been affected by management factors such as crop rotation, fertilizer treatments, or weed intensity or their interaction with rainfall.

The total yield variance was studied by splitting it into two main components, one caused by the large-scale deterministic structure and the other contributed by the small-scale stochastic structure. This variance distribution analysis showed that the large-scale deterministic structure was dominant in corn due to fertilizer treatments that masked the stochastic variability; whereas, the small-scale stochastic structure explained about 75% of the total yield variance for soybean where no fertilizer was applied.

However, the magnitude of the variance caused by either the large-scale deterministic structure or the small-scale stochastic structure varied from year to year and from crop to crop. This lack of temporal stability in spatial yield pattern may be due to the rainfall pattern changing from season to season; which in turn causes changes in water stress and nutrient availability. The significant negative correlation of range with rainfall shows that small-scale variability is being controlled by factors induced directly or indirectly by rainfall. However, the relationship of range with rainfall showed a trend different from that found by Jaynes and Colvin, (1997). More years of data are required to substantiate these relationships. The lack of stability in large scale and small scale variation suggest that longer duration yield data analyses are required to understand and quantify the impact of various climatic, and management factors and their interaction with soil properties on variable yield patterns.

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