Published online September 10, 2007





# Soil Management Zone Determination by Yield Stability Analysis and Classification

M. S. Cox* and P. D. Gerard


## ABSTRACT

**Multiyear yield data may lead to more accurate determination of yield–soil relationships. This study was conducted to determine if stable yield classification zones could be found, if soil and/or topographical properties differed among yield classifications, and if soil and/or topographical properties could be used to classify field locations into yield classes. Soybean (*Glycine max* L.) yields over 4 yr in three fields were classified into four zones: consistent-high, consistent-average, consistent-low, and inconsistent. Soil samples from all zones except the inconsistent zone were analyzed for pH, extractable nutrients, total C and N, texture, and elevation. Slope, plan curvature, and profile curvature at each sampling point were determined from elevation. Although differences existed, there were no consistently different soil or topographical properties among yield classes in each of the three fields. Linear discriminant analysis found unique yield-affecting factors in each field. In the North field, sand, K, and pH influenced yield classification. In the South field, clay, sand, slope, Mg, and plan curvature predicted yield classification. In the East field, pH and clay significantly influenced yield classification. For individual yield classes, the derived functions classified sampling locations into appropriate yield classes 60 to 100% of the time. The most accurate prediction rate came when classifying the soil sampling points into the high yield zone in the East field. The highest error rate occurred in this field when attempting to predict which points fell into the average classification. The combination of yield classification and linear discriminant analysis seems to be promising for determining soil-topography-yield relationships and hence soil management zones.**


IDENTIFYING SOIL MANAGEMENT ZONES within a field has traditionally been a hurdle when applying precision agriculture practices to a crop production system. Crop yields typically vary over space and time; therefore, determining consistent yield patterns that may reflect soil influences can be difficult (Huggins and Alderfer, 1995; Schepers et al., 2004). Lamb et al. (1997) conducted a 5-yr study to determine whether corn (*Zea mays* L.) yield patterns were similar over a number of years and if yields from one or more years could be used to predict future yields. They concluded that the yields in their study were not spatially consistent from year to year, and only 4 to 42% of the yield variability could be accounted for by the yields from a previous year. In a similar study, corn and soybean yields in a variety of rotations were monitored over a 10-yr period (Porter et al., 1998). Yield variability among years was approximately three times greater for soybean and four times greater for corn than variability among plots (Porter et al., 1998). Eghball and Varvel (1997) concluded that, when temporal variability was great, yield patterns may not be useful in making future management decisions.

Temporal instability can also be problematic when attempting to determine yield–soil relationships (Yang et al., 1998). Many studies have shown that relationships between yield and soil and/or topographical features vary from year to year (Cox et al., 2005; Jaynes et al., 1995; Halvorson and Doll, 1991). Cox et al. (2006) attempted to determine soil and topographical properties that influenced yields in three fields over 2 yr. They found that the number and magnitude of yield influencing properties varied yearly. Kaspar et al. (2003) were able to develop soil–yield relationships that explained 78% of yield variability only when restricting the analysis to years with below-normal precipitation.

Jaynes et al. (2003) put forth the idea that identification of within-field areas that behave similarly may be more successful rather than trying to predict specific yield within a field. One approach is to use long-term yield data to attempt to identify patterns of yield within a field (Lark and Stafford, 1997). Boydell and McBratney (2002) used 11 yr of remotely sensed imagery to develop stable yield zones in cotton (*Gossypium hirsutum*) and concluded there was a strong degree of temporal stability in the fields used. Blackmore (2000) proposed a simple, empirical classification method for determining temporally stable areas of a field by using the CV across years to separate yield into classes of temporally stable or temporally unstable. The method then further classifies the temporally stable areas into zones of high yield and low yield (Blackmore, 2000).

Once the multiple-year yield data have been classified, discriminant analysis can relate yield classes to soil or topographical factors. Discriminant analysis is appropriate when the dependent variable is categorical and the categories are known a priori and the independent variables are quantitative (Hair et al., 1987). The assumptions for discriminant analysis are multivariate normality and equal covariance structures. However, there is evidence that discriminant analysis is not sensitive to violations of these assumptions (Hair et al., 1987). The resulting discriminating function determines what variables may be used to classify a location and then predict yield behavior where yield data may be limited (Jaynes et al., 2003). The combination of spatiotemporally stable yield classes and discriminant analysis to determine which soil-topographical properties separate those yield classes can give producers and agronomists insight into developing efficient and effective soil management zones. Jaynes

M.S. Cox, Department of Plant and Soil Sciences, Mississippi State University, Box 9555 Mississippi State, MS 39762. P.D. Gerard, Experimental Statistics Unit, Mississippi State University, Mississippi State, MS 39762. Approved for publication as Journal Article No. J-11071 of the Mississippi Agricultural and Forestry Experiment Station, Mississippi State University. *Corresponding author (mcox@pss.msstate.edu).

Published in Agron. J. 99:1357–1365 (2007).
Site-Specific Analysis & Management
doi:10.2134/agronj2007.0041


**Abbreviations:** DGPS, differentially corrected Geographical Positioning System; GIS, Geographical Information System.

et al. (2003) used cluster analysis to find temporal and spatial patterns in 6 yr of corn yield data. They then applied multiple discriminant analysis to predict the spatial occurrence of the clusters from a variety of field topographical attributes. Based on soil electrical conductivity, plan curvature, slope, elevation, and profile curvature, Jaynes et al. (2003) were 76 and 80% (using a holdout sample approach) successful in classifying yield plots into the correct yield cluster and concluded that, if response curves for inputs were unique for each yield cluster, then the method could be beneficial in determining management zones within fields. Ping et al. (2005) attempted to delineate management zones in cotton using discriminant analysis. They found that soil pH, extractable Ca and Mg, K saturation, clay content, and soil N/P ratio were related to cotton classification and resulted in two potential management zones. Based on these soil parameters, the analysis procedure misclassified points 27% of the time, but the misclassifications were mostly located near transitional areas (Ping et al., 2005). Their overall conclusion was that the yield classes, when combined with other information, could serve as potential management zones in irrigated cotton (Ping et al., 2005).

Our objectives for this study were to determine (i) if classification zones of consistently low, average, and high yield could be found based on yield history; (ii) if soil and/or topographical properties differed among yield classification zones; and (iii) if soil and/or topographical properties could be used to classify field locations into yield classes.

## MATERIALS AND METHODS

The study was conducted on an 8.4-ha field (North), a 15-ha field (South), and a 16-ha field (East) on the Mississippi Research and Extension Black Belt Branch Experiment Station near Brooksville, Mississippi. The major soil series in all three fields is a Brooksville silty clay loam (fine, smectitic, thermic Aquic Chromudert). Each field contains small amounts of Okolona silty clay (fine, smectitic, thermic, Oxyaquic Hapludert) and Demopolis silty clay loam (loamy, carbonatic, thermic, shallow Typic Udorthent) soils. These three soil series range from deep and somewhat poorly drained with very slow permeability to shallow and well drained. They are nearly level to gently sloping with slopes ranging from 0 to 5% and are formed in acid silty clay or clay underlain by Selma Chalk (Brent, 1986). The climatic conditions during this study were similar to those presented for the first 2 yr (1998 and 1999) in Cox et al. (2003), which were generally wet in the spring with dry to drought-like conditions common during the summer. Detailed field histories have been described in Cox et al. (2003). These three fields had been in continuous soybean production since or before 1997. Fertilizer management consisted of 34 kg ha$^{-1}$ P and 68 kg ha$^{-1}$ K applied in the spring of each year.

We measured soybean yields on each field for 4 yr (1998, 1999, 2000, and 2002) using a properly calibrated commercial yield monitor and differentially corrected Geographical Positioning System (DGPS) receiver mounted on a field combine. The yield monitor was configured to record yield data at 1-s intervals. This resulted in each yield location consisting of a cell approximately 1.5 by 6 m with the center point of the cell recorded as the yield location. Further description of the yield data and analysis can be found in Cox et al. (2003). The historical yield data from the fields were then subjected to spatial and temporal trend analysis as described by Blackmore (2000). To compare yields over the 4-yr period of this study, yield data in each field were standardized based on the mean yield for that field using the equation:

$$SY_i = 100\ (y_i/\bar{y}) \qquad [1]$$

Where $SY_i$ is the standardized yield at location $i$ in the field, $y_i$ is the original yield at that point, and $\bar{y}$ is the field mean (Blackmore, 2000), thus resulting in the field mean equaling 100 and the individual standardized yield values at location $i$ in the field representing the proportion of that mean realized (Ping et al., 2005). The standardized yield data for each year were then spatially joined using ArcView Geographical Information System (GIS) (ESRI, Redlands, CA) using the 1998 yield data as the base layer. Because yield locations varied slightly from year to year, yield values located closest to the center point of the 1998 yield cell were used to represent the subsequent 3 yr of yield data. The maximum distance between the 1999 base yield data and the other yearly yield data was never greater than 3 m. These four standardized yield values were averaged to create one mean standardized yield for each yield location in the field. Coefficients of variation (CV) for each yield location in the field were determined using the equation

$$CV_{SY_i} = \frac{\left(\dfrac{n\sum\limits_{t=1}^{t=n} SY_{i_t}^2 - \left(\sum\limits_{n=1}^{t=n} SY_{i_t}\right)^2}{n(n-1)}\right)^{0.5}}{\overline{SY}_i} \qquad [2]$$

described by Blackmore (2000) to determine the amount of temporal variability in the data. In this equation, $CV_{SY_i}$ represents the CV of the standardized data at location $i$ over t = 1 to $n$ years. These $CV_{SY_i}$ were used to filter the mean standardized yield. Based on the literature review of Wollenhaupt et al. (1997), yield locations in the field with $CV_{SY_i} \geq 30\%$ were considered to be highly variable and classified as inconsistent. Because these locations were closely related and interspersed with low-yielding areas of the fields and because our goal was to determine spatiotemporally stable soil–topography–yield relationships, no soil samples were collected from these areas. Standardized mean yield data with CV <30% were arbitrarily divided into three yield classes. The class divisions were determined based on the lowest SD in $\overline{SY}_i$ among the three fields, which was approximately 20% for the South field, resulting in conservative classification criteria. Thus, mean standardized yield values >120% were considered high, values >80% and <120% were considered average, and values <80% were considered low. This analysis resulted in temporally stable yield class maps for each field (Fig. 1). All like-classed yield cells (contiguous or not) were considered to be in the same zone.

Soil sampling locations were randomly generated within each yield class using HGIS Data Acquisition Software (Starpal, Fort Collins, CO). Soil samples were collected in the fall of 2002 to relate chemical and topographical properties to the yield classes using a DGPS. The number of sample locations within each yield class varied based on the size of the class, with a minimum of three sample points within each class. This resulted in the South field having a total of 31 soil samples (consistent-high: 11; consistent-average: 17; consistent-low: 3), the North field having 24 soil samples (consistent-high: 8; consistent-average: 10; consistent-low: 6), and the East field having 31 soils samples (consistent-high: 9; consistent-average: 10; consistent-low: 12). Each soil sample (0–15 cm) consisted of eight subsamples collected from a 10-m radius around the sample point. After

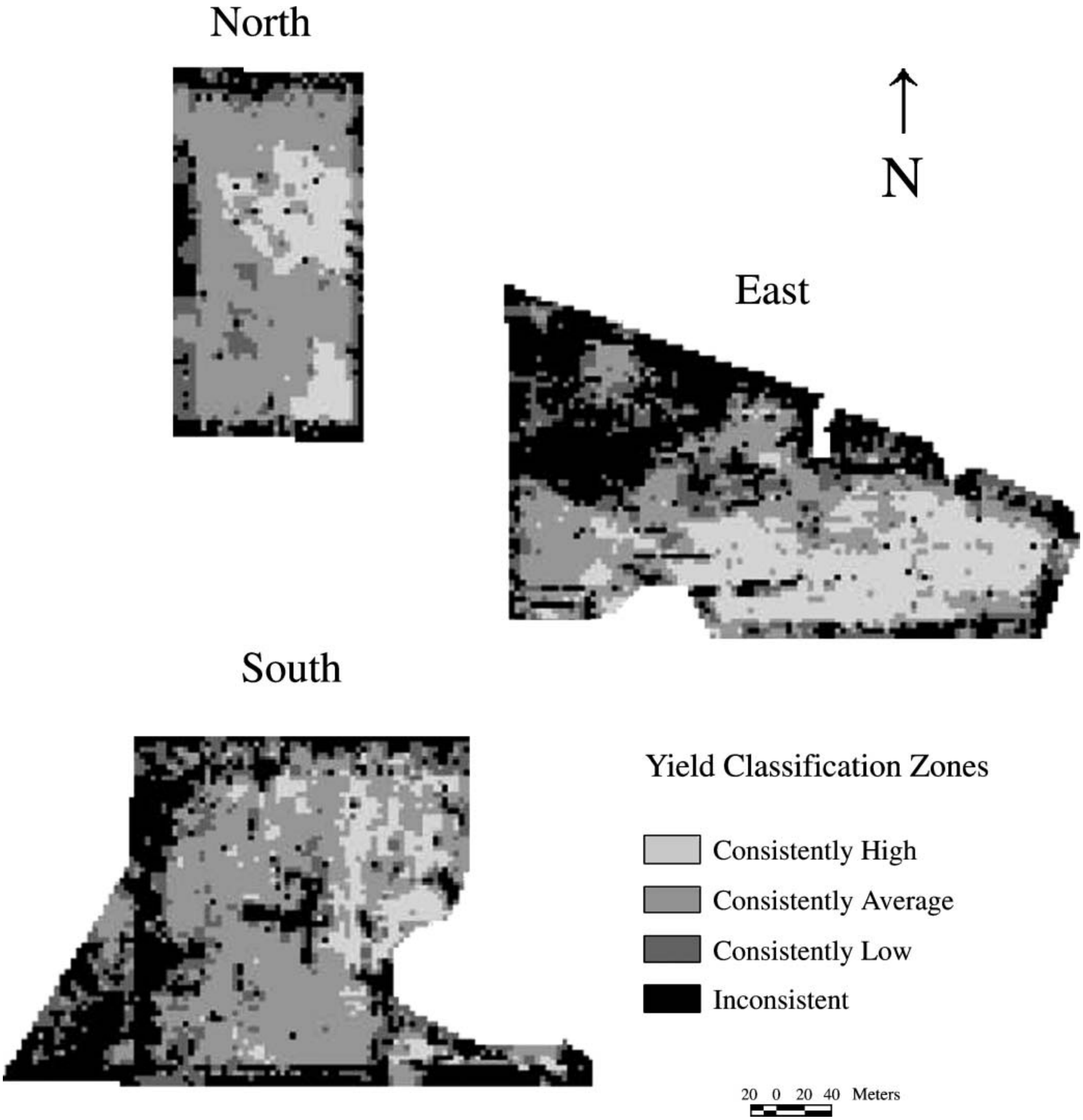


**Fig. 1. Yield classification zones and relative locations of the North, South, and East Fields. Scale bar applies to within, and not between, fields.**

collection, soil samples were allowed to air dry and ground to pass a 2-mm sieve. Soil samples were analyzed for pH in water (1:1) and extractable Ca, K, Mg, and P by the Lancaster method (Cox, 2001). Total C and N were determined by dry combustion using a Vario EL *III* elemental analyzer (Elementar Inc, Mt. Laurel, NJ). Texture was determined by the hydrometer method (Gee and Bauder, 1986). Elevation relative to a local benchmark was collected at each sample point using DGPS-equipped land surveying equipment with subcentimeter accuracy (Cox et al., 2003). ArcView GIS (ESRI, Redlands, CA) was used to develop digital elevation models for each field. From these digital elevation models, slope, plan curvature (curvature of the surface perpendicular to the direction of slope), and profile curvature (curvature of the surface in the direction of slope) were determined at each soil sampling point. The $SY_i$ data were spatially joined to the soil sampling data using ArcView GIS (ESRI) for statistical analysis similar to the method outlined previously for joining the yearly yield data. The yield locations with the centerpoint located closest to the soil sampling point were used to represent $SY_i$ at that sampling point.

Descriptive statistics for the soil, topographical, and yield data were computed using PROC UNIVARIATE of SAS Ver. 9 (SAS Inst., Cary, NC). Correlations among variables were calculated using PROC CORR of SAS using the Spearman option for nonparametric correlation (SAS Inst.) within each field. An ANOVA with Duncan's mean separation test was conducted to relate each soil-topographical property to yield classification using PROC GLM of SAS and $\alpha = 0.05$ to determine if significant differences in explanatory variables among yield classes existed. PROC STEPDISC (SAS Inst.) with a stepwise selection procedure was used to determine which soil and/or topographical properties best distinguished or revealed the differences among the yield classes. Soil and topographical factors had to meet a 0.15 level of significance to remain in the model. Once the contributing soil and/or topographical properties were determined, PROC DISCRIM with the pool and crossvalidate options (SAS Inst.) was used to develop a discriminant function that could be used to categorize locations in each field into the proper yield class based on the contributing soil and/or topographical properties. Based on the results of the pool option used to test for distribution normality, a pooled covariance matrix was used to develop the linear discriminant functions. The crossvalidate option was used to reduce bias in assessing performance of the classification rule by using a discriminant function computed using all other observations but the one in question when attempting to classify a given observation.

## RESULTS AND DISCUSSION

### Classification of the Standardized Mean Yield

The yield classification method produced the spatial trend maps shown in Fig. 1. Spatial and temporal trends can be identified visually in each of the three fields. The consistent-high–yielding areas of the South field were located in the northeast corner, whereas the southwest section of the field seemed to fall into the consistent-low–yielding or inconsistent yield classes along the field boundaries (Fig. 1). The southwest corner of this field tended to have large weed infestations through the course of this study, which could help explain these results due to nutrient and/or water competition or shading. In addition, a small area in the center of this field had consistent-low or inconsistent yields. This area contains a drainage way that may have affected yield. Of 6959 total yield cells, 14% were classified as consistent-high, 45% were classified as consistent-average, 3% were classified as consistent-low, and 38% were classified as inconsistent.

The majority of the mean standardized yield values fell into the consistent-average yield class in the North field (Fig. 1). Consistent-high yield classes were apparent in the east-central and southeast areas of this field, whereas consistent-low yield class occupied two small areas in the center and the borders. Inconsistently yielding areas of this field were also located around the field borders. Of a total of 3339 yield cells, 19% were classified as consistent-high, 57% were classified as consistent-average, 8% were classified as consistent-low, and 16% were classified as inconsistent.

The consistent-high yielding areas of the East field were located in the south-central and southeast portions of the field (Fig. 1). The consistent-low yielding and inconsistent yield classes were located in the northwest corner and along the field boundaries. This northwest area of the field is extremely eroded and has exposed areas of the calcareous subsoil. Previous research noted high pH values (7.3) and visual stunting and chlorosis of soybean plants (Cox et al., 2003). Of 8544 total yield cells, 26% were classified as consistent-high, 30% were classified as consistent-average, 5% were classified as consistent-low, and 39% were classified as inconsistent.

The spatiotemporally stable high and average yield classed cells tended to be arranged in distinct groups in all three fields; however, those areas classified as consistent-low yielding were, in general, associated with areas classified as inconsistent (Fig. 1). These areas of the fields accounted for 24% of the North field, 41% of the South field, and 44% of the East field. The North field had these areas primarily located in the field borders. The southwest corner and west edge of the South field had steadily decreasing yield through the first 3 yr of the study. Mean standardized yields in this area of the field decreased from 81% in 1998 to 74% in 1999 to 59% in 2000 and increased to 65% in 2002, leading to a CV of 48%. Thus, mean standardized yields in this area of the field would have been classified as low in all but the first year of the study had the data not been so variable. The northeast corner of the East field exhibited the opposite trend. Mean standardized yields in this area of the field increased from 18% in 1998 to 34% in 1999 to 47% in 2000 before decreasing to 36% in 2002. The variability in this portion of the field led to a CV of 74%.

### Yield Analysis at Soil Sampling Points

Spearman rank correlation coefficients for yields at the soil sampling points indicated that correlations between years were strong in each field with only one exception. The 1998 yield in the South field was not significantly correlated with the other 3 yr of yield data (Table 1). Similar to the findings of Jaynes et al. (2003), these results suggest that predictions of yield from one year to another would not necessarily prove to be accurate and that multiple years of data are needed to increase the accuracy of these predictions. In each of the fields used in this study, all four years of yield data were highly correlated with the mean standardized yield data used for the classification procedure. Correlation coefficients ranged from 0.57 to 0.67 in the South field (Table 1), 0.81 to 0.90 in the North field (Table 2), and 0.74 to 0.93 in the East field (Table 3), suggesting that the mean standardized yield value was a better predictor of potential yield than individual yearly data.

### Soil and Topographical Differences among Yield Class

Duncan's mean separation tests were conducted to determine if differences existed in soil and topographical properties between the yield classes in each field. The results in the South field indicated no significant differences between the consistently high and average yield classes in the soil or topographical properties (Table 4). The consistent-low yielding areas of this field were significantly lower in Mg and clay and higher in pH, sand, and elevation than the other two areas of the field (Table 4). Soil or topographical properties that were sig-

Table 1. Spearman rank correlation coefficients for the measured soil and topographical properties, the 4 yr of yield data, the standardized average, SD of the normalized yield data, and the CV of the standardized yield data in the South field ($n = 31$).

| | Ca | K | Mg | P | pH | N | C | Sand | Clay | Elev. | Slope | Plan | Profile | 1998 yield | 1999 yield | 2000 yield | 2002 yield | $\overline{SY_i}$ | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0.39* | | | | | | | | | | | | | | | | | | |
| Mg | 0.41* | 0.91* | | | | | | | | | | | | | | | | | |
| P | 0.17 | 0.74* | 0.61* | | | | | | | | | | | | | | | | |
| pH | 0.27 | −0.49* | −0.53* | −0.35* | | | | | | | | | | | | | | | |
| N | 0.23 | 0.45* | 0.44* | 0.37* | 0.02 | | | | | | | | | | | | | | |
| C | 0.23 | 0.18 | 0.22 | 0.13 | 0.26 | 0.93* | | | | | | | | | | | | | |
| Sand | −0.33 | −0.40* | −0.45* | −0.15 | 0.26 | −0.2 | −0.18 | | | | | | | | | | | | |
| Clay | 0.23 | 0.46* | 0.54* | 0.05 | −0.59* | −0.12 | −0.24 | −0.52* | | | | | | | | | | | |
| Elev. | −0.29 | −0.38* | −0.43* | −0.12 | 0.15 | −0.42* | −0.39* | 0.71* | −0.49* | | | | | | | | | | |
| Slope | 0.21 | 0.36* | 0.31 | 0.33 | −0.13 | −0.02 | −0.17 | 0.01 | 0.23 | 0.02 | | | | | | | | | |
| Plan | −0.2 | −0.15 | −0.16 | 0.15 | −0.1 | −0.18 | −0.25 | −0.03 | 0.01 | −0.07 | 0.14 | | | | | | | | |
| Profile | 0.25 | −0.29 | −0.15 | −0.36* | 0.24 | −0.41* | −0.29 | 0.23 | 0.05 | 0.21 | −0.07 | −0.12 | | | | | | | |
| 1998 yield | −0.13 | −0.32 | −0.37* | −0.37* | 0.24 | 0.08 | 0.22 | −0.02 | −0.25 | 0.12 | −0.24 | −0.14 | 0.01 | | | | | | |
| 1999 yield | 0.33 | 0.55* | 0.50* | 0.22 | −0.07 | 0.60* | 0.59* | −0.59* | 0.32 | −0.79* | −0.21 | −0.19 | −0.33 | 0.01 | | | | | |
| 2000 yield | 0.05 | 0.59* | 0.57* | 0.3 | −0.53* | 0.41* | 0.23 | −0.58* | 0.52* | −0.65* | 0.07 | −0.07 | −0.24 | −0.07 | 0.59* | | | | |
| 2002 yield | 0.36* | 0.64* | 0.55* | 0.37* | −0.24 | 0.18 | 0.08 | −0.67* | 0.36* | −0.38* | 0.05 | −0.15 | −0.11 | 0.04 | 0.52* | 0.51* | | | |
| $\overline{SY_i}$ | 0.11 | 0.38* | 0.26 | 0.12 | −0.13 | 0.43* | 0.44* | −0.49* | 0.17 | −0.45* | −0.18 | −0.29 | −0.2 | 0.58* | 0.67* | 0.57* | 0.58* | | |
| SD | −0.06 | 0.1 | 0.14 | 0.06 | 0.04 | 0.11 | 0.05 | 0 | −0.21 | 0.17 | −0.18 | −0.26 | 0.13 | −0.23 | −0.03 | 0.06 | 0.15 | −0.15 | |
| CV | −0.09 | −0.08 | −0.01 | −0.03 | 0.11 | −0.05 | −0.1 | 0.16 | −0.28 | 0.31 | −0.14 | −0.11 | 0.19 | −0.33 | −0.27 | −0.18 | −0.13 | −0.45* | 0.93* |

* Significant at the 0.05 probability level.

nificantly different between classes were not always related to the mean standardize yield; only sand (negatively) and elevation (negatively) were related to the mean standardized yield value (Table 1).

The results of the mean separation tests revealed that the consistent-high yield class in the North field had significantly greater K, Mg, sand, and clay and significantly lower pH and elevation than the other consistent yield classes in the field at the time of soil sampling (Table 5). These soil and topographical factors were also correlated with the mean standardized yield. There were no significant differences in any of the soil or topographical properties between the consistent-average yielding and the consistent-low yielding areas of the field.

The East field mean separation tests indicated a much more complex situation. Calcium was significantly higher in the consistent-low yield class, and Mg was significantly higher in the consistent-high yield class with no differences between the other classes (Table 6). The pH was significantly different between the three classes in the order consistent-high < consistent-average < consistent-low (Table 6). Total C was significantly higher in the consistent-low yield class when compared with the consistent-average yield class (Table 6). Sand was significantly lower and clay significantly higher in the consistent-high yield class (Table 6). The slope in this yield class was less than that in the consistent-low yield class (Table 6). Of these soil and topographical proper-

Table 2. Spearman rank correlation coefficients for the measured soil and topographical properties, the 4 yr of yield data, the standardized average, SD of the normalized yield data, and the CV of the standardized yield data in the North field ($n = 24$).

| | Ca | K | Mg | P | pH | N | C | Sand | Clay | Elev. | Slope | Plan | Profile | 1998 yield | 1999 yield | 2000 yield | 2002 yield | $\overline{SY_i}$ | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0.05 | | | | | | | | | | | | | | | | | | |
| Mg | −0.31 | 0.78* | | | | | | | | | | | | | | | | | |
| P | −0.11 | 0.57* | 0.51* | | | | | | | | | | | | | | | | |
| pH | 0.79* | −0.33 | −0.67* | −0.26 | | | | | | | | | | | | | | | |
| N | −0.06 | −0.14 | −0.15 | −0.24 | 0.15 | | | | | | | | | | | | | | |
| C | 0.11 | −0.09 | −0.12 | −0.31 | 0.15 | 0.91* | | | | | | | | | | | | | |
| Sand | −0.43* | 0.53* | 0.66* | 0.35 | −0.76* | −0.4 | −0.4 | | | | | | | | | | | | |
| Clay | −0.43* | 0.53* | 0.66* | 0.35 | −0.76* | −0.4 | −0.4 | 1.00 | | | | | | | | | | | |
| Elev. | −0.01 | −0.66* | −0.66* | −0.47* | 0.43* | 0.64* | 0.54* | −0.63* | −0.63* | | | | | | | | | | |
| Slope | −0.43* | 0.1 | 0.40* | −0.24 | −0.41* | 0.23 | 0.18 | 0.26 | 0.26 | 0.03 | | | | | | | | | |
| Plan | −0.15 | 0.19 | 0.21 | 0.13 | −0.18 | 0.17 | 0.17 | 0.23 | 0.23 | 0.02 | 0.07 | | | | | | | | |
| Profile | 0.22 | −0.06 | −0.14 | −0.1 | 0.21 | 0 | −0.1 | −0.15 | −0.15 | 0.06 | 0.19 | −0.4 | | | | | | | |
| 1998 yield | −0.32 | 0.69* | 0.83* | 0.42* | −0.55* | −0.2 | −0.2 | 0.54* | 0.54* | −0.63* | 0.26 | 0 | −0.15 | | | | | | |
| 1999 yield | −0.37 | 0.69* | 0.75* | 0.36 | −0.69* | −0.3 | −0.2 | 0.76* | 0.76* | −0.62* | 0.2 | 0.27 | −0.08 | 0.71* | | | | | |
| 2000 yield | −0.18 | 0.65* | 0.68* | 0.27 | −0.53* | 0.11 | 0.14 | 0.59* | 0.59* | −0.47* | 0.21 | 0.25 | −0.11 | 0.65* | 0.72* | | | | |
| 2002 yield | −0.36 | 0.62* | 0.70* | 0.23 | −0.61* | 0.06 | 0.15 | 0.52* | 0.52* | −0.45* | 0.31 | 0.36 | −0.04 | 0.69* | 0.79* | 0.74* | | | |
| $\overline{SY_i}$ | −0.38 | 0.72* | 0.77* | 0.33 | −0.67* | −0.1 | 0 | 0.70* | 0.70* | −0.59* | 0.3 | 0.29 | −0.13 | 0.81* | 0.90* | 0.88* | 0.89* | | |
| SD | −0.1 | 0.68* | 0.55* | 0.58* | −0.25 | −0.1 | −0.2 | 0.42* | 0.42* | −0.42* | 0.15 | 0.15 | 0.15 | 0.54* | 0.52* | 0.39 | 0.31 | 0.51* | |
| CV | 0.01 | 0.46* | 0.28 | 0.51* | −0.01 | −0.2 | −0.2 | 0.2 | 0.2 | −0.26 | 0.07 | 0.05 | 0.25 | 0.24 | 0.25 | 0.03 | −0.03 | 0.15 | 0.91* |

* Significant at the 0.05 probability level.

Table 3. Spearman rank correlation coefficients for the measured soil and topographical properties, the 4 yr of yield data, the standardized average, SD of the normalized yield data, and the CV of the standardized yield data in the East field ($n = 31$).

| | Ca | K | Mg | P | pH | N | C | Sand | Clay | Elev. | Slope | Plan | Profile | 1998 yield | 1999 yield | 2000 yield | 2002 yield | $\overline{SY_i}$ | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | −0.05 | | | | | | | | | | | | | | | | | | |
| Mg | −0.25 | 0.35* | | | | | | | | | | | | | | | | | |
| P | −0.41* | 0.32 | −0.18 | | | | | | | | | | | | | | | | |
| pH | 0.92* | −0.15 | −0.46* | −0.41* | | | | | | | | | | | | | | | |
| N | −0.32 | 0.57* | 0.14 | 0.65* | −0.39* | | | | | | | | | | | | | | |
| C | 0.53* | 0.41* | 0.18 | −0.17 | 0.44* | 0.3 | | | | | | | | | | | | | |
| Sand | 0.31 | −0.3 | −0.46* | −0.16 | 0.52* | −0.32 | 0.04 | | | | | | | | | | | | |
| Clay | −0.45* | 0.01 | 0.62* | −0.14 | −0.63* | −0.1 | −0.2 | −0.60* | | | | | | | | | | | |
| Elev. | −0.2 | −0.42* | −0.31 | −0.07 | −0.04 | −0.45* | −0.40* | 0.63* | −0.06 | | | | | | | | | | |
| Slope | 0.15 | −0.19 | −0.40* | −0.21 | 0.23 | 0.01 | 0.09 | 0.37* | −0.41* | 0.25 | | | | | | | | | |
| Plan | −0.21 | 0.21 | −0.12 | 0.31 | −0.25 | 0.21 | −0.16 | −0.21 | −0.1 | 0.01 | 0.08 | | | | | | | | |
| Profile | 0.3 | −0.25 | −0.07 | 0.07 | 0.25 | −0.24 | 0.1 | 0.16 | −0.05 | 0.07 | −0.19 | −0.2 | | | | | | | |
| 1998 yield | −0.55* | 0.18 | 0.33 | 0.41* | −0.69* | 0.50* | −0.23 | −0.48* | 0.31 | −0.17 | −0.18 | 0.36* | −0.18 | | | | | | |
| 1999 yield | −0.77* | 0.11 | 0.51* | 0.40* | −0.87* | 0.31 | −0.47* | −0.49* | 0.55* | 0.08 | −0.33 | 0.24 | −0.11 | 0.72* | | | | | |
| 2000 yield | −0.40* | 0.32 | 0.57* | 0.25 | −0.52* | 0.21 | −0.09 | −0.47* | 0.45* | −0.28 | −0.58* | 0.11 | −0.02 | 0.48* | 0.62* | | | | |
| 2002 yield | −0.61* | 0.33 | 0.70* | 0.18 | −0.73* | 0.32 | −0.22 | −0.60* | 0.51* | −0.21 | −0.38* | 0.3 | −0.19 | 0.66* | 0.82* | 0.64* | | | |
| $\overline{SY_i}$ | −0.71* | 0.15 | 0.53* | 0.37* | −0.84* | 0.33 | −0.38* | −0.53* | 0.51* | −0.04 | −0.39* | 0.29 | −0.16 | 0.84* | 0.93* | 0.74* | 0.84* | | |
| SD | 0.34 | 0.28 | −0.05 | −0.2 | 0.33 | −0.04 | 0.51* | 0.00 | −0.09 | −0.15 | −0.14 | 0.05 | −0.03 | −0.2 | −0.41* | 0.02 | −0.23 | −0.21 | |
| CV | 0.60* | 0.05 | −0.3 | −0.33 | 0.64* | −0.22 | 0.58* | 0.3 | −0.27 | −0.01 | 0.12 | −0.14 | 0.21 | −0.56* | −0.73* | −0.32 | −0.61* | −0.62* | 0.85* |

* Significant at the 0.05 probability level.

ties, Ca, total C, pH, sand, and slope were negatively correlated with the mean standardized yield value, whereas the clay content and Mg were positively correlated (Table 3).

Based on these results, there were no soil or topographical factors that were consistently different between each yield class in the three fields. This method did seem to delineate some soil or topographical differences between the consistent-low yield and consistent-high yield classes in each field. Properties found to be different between classes were not always related to the mean standardized yield. Hence, using soil or topographical differences between yield zones is efficient for determining management zones.

## Linear Discriminant Analysis

The results from the stepwise discriminant analysis indicated that different soil and/or topographical properties were contributing to the classification of the consistent yield classes in each field. Clay, sand, slope, Mg, and plan curvature (in order of appearance in the final model) were the significant ($P \leq 0.07$) contributing factors in the South field. In the North field, again in order of appearance in the model, sand, K, and pH contributed significantly to the classification. The stepwise discriminant analysis in the East field found pH and clay to be the most significant factors. In general, these results agreed with those of Ping et al. (2005), who identified

Table 4. Descriptive statistics for the soil, topographical, and standardized average yield parameters for the whole field and consistently high-, average-, and low-yield zones in the South field.

| | Soil factors | | | | | | | | | Topographical factors | | | | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Statistic | Ca | K | Mg | P | pH | N | C | Sand | Clay | Elevation† | Slope | Plan | Profile | $\overline{SY_i}$ |
| | mg kg$^{-1}$ | | | | | % | | | | m | % | % m$^{-1}$ | | % |
| | | | | | | Total field ($n = 31$) | | | | | | | | |
| Mean | 4600 | 116 | 100 | 44 | 6.0 | 0.1 | 1.5 | 15 | 31 | 3.6 | 2.4 | 0.1 | −0.1 | 109 |
| SD | 941 | 40 | 46 | 15 | 0.5 | 0.0 | 0.2 | 3.4 | 4.8 | 0.7 | 1.0 | 0.4 | 0.4 | 19 |
| Skew | 0.7 | 0.7 | 0.8 | 0.7 | 1.3 | 0.3 | 0.3 | −0.2 | −1.0 | −0.1 | 0.3 | −0.8 | −1.7 | −0.4 |
| | | | | | | High ($n = 11$) | | | | | | | | |
| Mean | 4820a‡ | 134a | 125a | 45a | 5.9a | 0.1a | 1.6a | 13a | 32a | 3.1a | 2.0a | −0.1a | −0.2a | 125 |
| SD | 1010 | 31 | 34 | 15 | 0.4 | 0.0 | 0.1 | 2.2 | 3.8 | 0.4 | 0.5 | 0.4 | 0.4 | 15 |
| Skew | 1.2 | 1.6 | 1.8 | 0.3 | 0.5 | 0.3 | 0.4 | −1.2 | 0.1 | −0.1 | −0.2 | −1.9 | 0.4 | −0.7 |
| | | | | | | Average ($n = 17$) | | | | | | | | |
| Mean | 4471a | 109a | 90a | 43a | 5.9a | 0.1a | 1.4a | 16a | 32a | 3.7a | 2.8a | 0.2a | 0.0a | 104 |
| SD | 914 | 44 | 49 | 17 | 0.4 | 0.0 | 0.1 | 3.3 | 3.2 | 0.7 | 1.1 | 0.3 | 0.4 | 10 |
| Skew | 0.45 | 0.9 | 1.1 | 0.9 | 0.3 | 0.3 | 1.3 | −0.6 | 0.1 | −0.6 | 1.4 | 1.9 | −2.1 | 0.6 |
| | | | | | | Low ($n = 3$) | | | | | | | | |
| Mean | 4533a | 91a | 62b | 41a | 6.8b | 0.1a | 1.5a | 20b | 21b | 4.4b | 2.8a | 0.2a | −0.2a | 76 |
| SD | 1034 | 9.8 | 10 | 5.0 | 0.8 | 0.1 | 0.7 | 1.3 | 4.8 | 0.0 | 1.1 | 0.4 | 0.6 | 20 |
| Skew | −0.5 | −1.2 | 1.7 | 1.3 | −1.4 | 0.0 | −0.2 | −0.9 | 0.0 | −1.7 | 1.4 | 1.7 | 0.8 | −1.7 |

† Relative to a local benchmark.
‡ Within columns, zone means followed by the same letter are not significantly different according to Duncan's mean separation test (0.05).

**Table 5. Descriptive statistics for the soil, topographical, and standardized average yield parameters for the whole field and consistently-high-, average-, and low-yield zones in the North field.**

| Statistic | Soil factors: Ca | K | Mg | P | pH | N | C | Sand | Clay | Topographical factors: Elevation† | Slope | Plan | Profile | Yield: $\overline{SY_i}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg kg$^{-1}$ | | | | | % | | | | m | % | % m$^{-1}$ | | % |
| **Total field ($n$ = 24)** | | | | | | | | | | | | | | |
| Mean | 3983 | 74 | 47 | 9.5 | 6.4 | 0.2 | 2.6 | 11 | 27 | 0.7 | 4.2 | −0.1 | 0.0 | 104 |
| SD | 731 | 13 | 30 | 11 | 0.7 | 0.0 | 0.2 | 3.4 | 8.5 | 0.6 | 1.6 | 0.8 | 0.6 | 26 |
| Skew | −0.16 | 0.8 | 0.9 | 0.6 | 0.0 | 0.9 | 0.6 | −0.1 | −0.1 | 0.3 | 0.3 | 0.2 | −1.4 | 0.1 |
| **High ($n$ = 8)** | | | | | | | | | | | | | | |
| Mean | 3765a‡ | 89a | 79a | 14a | 5.8a | 0.2a | 2.5a | 14a | 36a | 0.3a | 5.0a | 0.1a | 0.0a | 133 |
| SD | 482 | 11 | 23 | 9.0 | 0.3 | 0.0 | 0.2 | 0.9 | 2.3 | 0.4 | 1.4 | 0.6 | 0.4 | 12 |
| Skew | 0.2 | 0.2 | −0.2 | 2.2 | 0.8 | 1.0 | 1.7 | 1.8 | 1.8 | −0.4 | 0.4 | −0.7 | −1.8 | 0.2 |
| **Average ($n$ = 10)** | | | | | | | | | | | | | | |
| Mean | 3919a | 69b | 38b | 8.4a | 6.4b | 0.2a | 2.7a | 9.0b | 22b | 0.9b | 3.8a | −0.1a | 0.0a | 100 |
| SD | 896 | 4.2 | 19 | 11 | 0.7 | 0.0 | 0.2 | 2.8 | 7.1 | 0.6 | 1.8 | 0.3 | 0.5 | 5.6 |
| Skew | −0.6 | −0.1 | 2.1 | 0.2 | −0.6 | 0.8 | −0.5 | −0.1 | −0.1 | 0.9 | 0.5 | 1.0 | 2.7 | 0.1 |
| **Low ($n$ = 6)** | | | | | | | | | | | | | | |
| Mean | 4380a | 64b | 20b | 5.9a | 7.0b | 0.2a | 2.5a | 8.7b | 22b | 1.1b | 3.8a | −0.2a | 0.0a | 70 |
| SD | 708 | 8.4 | 4.7 | 15 | 0.4 | 0.0 | 0.1 | 1.6 | 4.1 | 0.3 | 1.1 | 1.5 | 1.0 | 3.0 |
| Skew | 0.3 | 0.3 | 1.3 | 1.3 | 0.3 | 0.3 | 0.6 | 0.2 | 0.24 | 0.2 | 0.1 | 0.6 | −2.1 | −1.4 |

† Relative to a local benchmark.
‡ Within columns, zone means followed by the same letter are not significantly different according to Duncan's mean separation test (0.05).

pH, Ca, Mg, K saturation, texture, and soil N/soil P ratio as variables related to two cotton yield classes.

These results differ appreciably from those of Cox et al. (2003), who collected soil, topographical, and yield data from a 0.5-ha grid to investigate the amount of variability in these properties and relate the soil and topographical factors to yield in these three fields. Using a separate dataset and a principle component analysis approach, the 2003 study found Ca, K, Mg, P, pH, elevation, and clay content related to yield in the South field; Mg and topography related to yield in the North field; and K, Mg, P, and clay content related to yield in the East field. However, the purpose of the current study was to identify areas of the three fields where yield behaved similarly among years and then determine which soil properties might contribute to the yield response as suggested by Jaynes et al. (2003), rather than trying to define specific yield within a field, as in Cox et al. (2003). In addition, yield estimates for the 2003 study were based on an average yield value calculated from a 10-m radius around each soil sampling point (Cox et al., 2003). Also, the 2003 study results were based on a yearly analysis of the soil-topography-yield data, and the inconsistent yielding areas of the field were not apparent and were therefore included in the analysis. These different approaches, different methods of estimating yield, and possible inclusion of inconsistently yielding areas could explain the different results of the two studies.

Linear discriminant analysis functions were calculated for each field based on the soil and topographical parameters determined to be significant from the stepwise discriminant procedure. For individual yield classes, the

**Table 6. Descriptive statistics for the soil, topographical, and standardized average yield parameters for the whole field and consistently high, average, and low yield zones in the East field.**

| Statistic | Soil factors: Ca | K | Mg | P | pH | N | C | Sand | Clay | Topography: Elevation† | Slope | Plan | Profile | Yield: $\overline{SY_i}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg kg$^{-1}$ | | | | | % | | | | m | % | % m$^{-1}$ | | % |
| **Total field ($n$ = 31)** | | | | | | | | | | | | | | |
| Mean | 13,341 | 108 | 25 | 19 | 7.3 | 0.2 | 2.8 | 13 | 9 | 2.2 | 6.8 | −0.2 | −0.04 | 90 |
| SD | 11,529 | 15 | 26 | 17 | 0.8 | 0.0 | 0.7 | 4.0 | 3.0 | 2.0 | 3.7 | 0.9 | 0.9 | 34 |
| Skew | 1.7 | −0.6 | 0.5 | 0.8 | −0.6 | −0.2 | 1.7 | 0.2 | 0.3 | 0.9 | 1.1 | 2.0 | −1.3 | −0.5 |
| **High ($n$ = 9)** | | | | | | | | | | | | | | |
| Mean | 5960a‡ | 109a | 52a | 18a | 6.5a | 0.2a | 3.0ab | 10a | 13a | 2.4a | 4.5a | −0.3a | −0.1a | 126 |
| SD | 1063 | 9.0 | 18 | 8.0 | 0.5 | 0.0 | 0.2 | 3.0 | 1.3 | 2.0 | 2.3 | 0.7 | 0.6 | 8.0 |
| Skew | −0.9 | −1.7 | 0.2 | −0.8 | −0.7 | 0.6 | 0.0 | 1.4 | −0.1 | 0.8 | 0.2 | −0.89 | −1.6 | 1.3 |
| **Average ($n$ = 10)** | | | | | | | | | | | | | | |
| Mean | 9583a | 108a | 16b | 27a | 7.3b | 0.2a | 2.7a | 13b | 7.0b | 2.2a | 7.1ab | 0.1a | −0.1a | 98 |
| SD | 6079 | 19 | 21 | 15 | 0.6 | 0.0 | 0.4 | 2.8 | 2.2 | 2.0 | 3.1 | 0.7 | 0.6 | 15 |
| Skew | 1.7 | −0.5 | 2.1 | 1.2 | −0.1 | 0.4 | −0.3 | 0.7 | 0.5 | 1.4 | 1.4 | −0.82 | −0.3 | 0.4 |
| **Low ($n$ = 12)** | | | | | | | | | | | | | | |
| Mean | 22,007b | 108a | 11b | 13a | 8.0c | 0.2a | 3.2b | 14b | 8.0b | 2.1a | 8.3b | −0.3a | 0.1a | 57 |
| SD | 13,961 | 15 | 19 | 21 | 0.2 | 0.0 | 0.9 | 3.9 | 1.8 | 1.0 | 4.3 | 1.2 | 1.3 | 23 |
| Skew | 0.5 | −0.4 | −0.1 | 1.3 | −1.3 | −0.2 | 1.0 | −0.4 | 0.0 | 0.2 | 0.9 | 2.6 | −1.4 | 0.0 |

† Relative to a local benchmark.
‡ Within columns, zone means followed by the same letter are not significantly different according to Duncan's mean separation test (0.05).

**Table 7. Cross-validation classification accuracies of the linear discriminant functions developed for soil sampling positions in the South, North, and East fields. These functions were developed to determine potential soybean yield classes from soil-topographical properties.**

| Actual yield class | Predicted yield class: Consistent-high | Consistent-average | Consistent-low |
|---|---|---|---|
| | % Classification | | |
| | | South | |
| Consistent-high | 81.9 | 18.2 | 0.0 |
| Consistent-average | 23.5 | 70.6 | 5.9 |
| Consistent-low | 0.0 | 33.3 | 66.7 |
| | | North | |
| Consistent-high | 87.5 | 10.0 | 12.5 |
| Consistent-average | 10.0 | 70.0 | 20.0 |
| Consistent-low | 0.0 | 16.7 | 83.3 |
| | | East | |
| Consistent-high | 100.0 | 0.0 | 0.0 |
| Consistent-average | 10.0 | 60.0 | 30.0 |
| Consistent-low | 0.0 | 16.7 | 83.3 |

resulting functions classified the soil sampling points into the correct yield class from 60 to 100% of the time (Table 7). The highest error rate occurred when trying to predict which points in the East field would fall into the average yield class. The function misclassified these points into the low-yield class 30% of the time and into the high-yield class 10% of the time (Table 7). However, it was in this field that the functions correctly classified the samples into the high yield class 100% of the time (Table 7). The functions tended to have the most difficulty classifying points located in the average yield class in all three of the fields. Correct classification of these points ranged from 60% (East field) to 71% (South field) (Table 7). Ping et al. (2005) had similar results, where misclassifications occurred near boundaries or yield–class transitional areas.

For the discriminant analysis functions to be useful in making management decisions, they must accurately identify the consistently high- and low-yield classes in each field. Consistently high-yielding areas in the South field were accurately identified 82% of the time (i.e., 9 of 11 points) (Table 7). However, the consistently low-yielding areas of the South field were accurately predicted only 67% of the time (2 of 3) (Table 7). This particular function predicted that 33% of the points (1 of 3) in the low-yield class would have been classified as average (Table 7). Although the percentage for inaccurate prediction is somewhat high, there were only three sampling sites located in the consistently low-yield classes due to the large amount of association between this class and the inconsistent-yield class. This close association made sampling from the consistent-low yield class in this field difficult and limited the number of soil samples collected.

The prediction accuracy of the discriminant functions for the consistently high-yielding points in the North field were accurately identified 88% of the time (7 of 8), which is similar to that of the South field, whereas the consistently low-yielding points were identified 83% of the time (5 of 6) (Table 7). These percentages would indicate that the functions would accurately predict consistent yield areas of this field based on the soil properties sand, K, and pH.

The prediction accuracies of the functions in consistently high- and low-yielding areas of the East field were similar to those of the North field at 100% (consistent-high) (9 of 9) and 83% (consistent-low) (10 of 12) (Table 7). This accuracy indicates the functions could predict the consistently high- and low-yield sample points based on the soil properties K, Mg, P, and clay content.

The correct prediction accuracies for the three fields used in this study were comparable to those found by Jaynes et al. (2003). They were able to classify yield plots into the correct yield class 76 and 80% of the time when using multiple discriminant analysis and splitting their data into calibration and validation subsets. These results also agreed with those of Ping et al. (2005), who found that classification of cotton yield based on six soil properties (pH, extractable Ca and Mg, K saturation, clay content, and soil N/P ration) was correct 73% of the time.

In this study, consistently low-, average-, and high-yield classifications, based on yield history, could be found for the three fields used. Some soil and/or topographical properties differed among yield classes in each field; however, these differences were not consistent among fields, emphasizing the field specificity of these results. Differences in soil-topographical properties among yield zones determined in one field could not be extrapolated to the other fields despite their close proximity. In addition, the properties found to be significantly different among zones within a field did not always appear in the linear discriminant analysis when relating soil and topographical properties to yield, nor were all of the soil or topographical properties related to yield significantly different among zones. This research did find that yield classes within individual fields could be separated by soil and/or topographical properties with varying levels of accuracy. In addition, when inaccuracies in classification did occur, the linear discriminant analysis tended to err within the adjacent classification (e.g., a misclassification between consistent-high and consistent-average rather than a misclassification between consistent-high and consistent-low). Hence, the combination of multiyear yield classification as an indicator of yield behavior and discriminant analysis with soil-topographical measurements seems to be beneficial in the formation of soil-topography management zones. Further research is needed to determine if management of those soil-topographical factors found by the discriminant analysis would affect yield in subsequent years and, possibly, result in changes in the yield classification zones. It is also probable that, if management of the yield-topographical factors are successful, then the yield classification zones and the results of the discriminant analysis would evolve with time because the yield-related factors would most likely change.

## REFERENCES

Blackmore, S. 2000. The interpretation of trends from multiple yield maps. Comput. Electron. Agric. 26:37–51.

Boydell, B., and A.B. McBratney. 2002. Indentifying potential within-field management zones from cotton-yield estimates. Precis. Agric. 3:9–23.

Brent. Floyd. 1986. Soil survey of Noxubee County, Mississippi. United States Department of Agriculture. Washington, DC.

Cox, M.S. 2001. The Lancaster soil test method as an alternative to the Mehlich 3 soil test method. Soil Sci. 166:484–489.

Cox, M.S., P.D. Gerard, and D.B. Reynolds. 2005. Selected soil property variability and their relationships with cotton yield. Soil Sci. 170:928–937.

Cox, M.S., P.D. Gerard, M.C. Wardlaw, and M.J. Abshire. 2003. Variability of selected soil properties and their relationships with soybean yield. Soil Sci. Soc. Am. J. 67:1296–1302.

Cox, M.S., P.D. Gerard, and M.J. Abshire. 2006. Selected soil property variability and their relationships with yield in three Mississippi fields. Soil Sci. 171:541–551.

Eghball, B., and G.E. Varvel. 1997. Fractal analysis of temporal yield variability of crop sequences: Implications for site-specific management. Agron. J. 89:851–855.

Gee, G.W., and J.W. Bauder. 1986. Particle size analysis. p. 383–411. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA. Madison, WI.

Hair, J.F., R.E. Anderson, and R.L. Tatum. 1987. Multivariate data analysis with readings. 2nd ed. Macmillan, New York.

Halvorson, G.A., and E.C. Doll. 1991. Topographic effects on spring wheat yields and water use. Soil Sci. Soc. Am. J. 55:1680–1685.

Huggins, D.R., and R.D. Alderfer. 1995. Yield variability within a long-term study: Implications for precision farming. p. 417–426. *In* P.C. Robert et al (ed.) Site-specific management for agricultural systems. Proc. Int. Conf., 2nd. Minneapolis, MN. 27–30 Mar. 1994. ASA, CSSA, and SSSA, Madison, WI.

Jaynes, D.B., J.M. Novak, T.B. Moorman, and C.A. Cambardella. 1995. Estimating herbicide partition coefficients from electromagnetic induction measurements. J. Environ. Qual. 24:36–41.

Jaynes, D.B., T.C. Kaspar, T.S. Colvin, and D.E. James. 2003. Cluster analysis of spatiotemporal corn yield patterns in an Iowa field. Agron. J. 95:574–586.

Kaspar, T.C., T.S. Colvin, D.B. Jaynes, D.L. Karlen, D.E. James, D.W. Meed, D. Pulido, and H. Butler. 2003. Relationship between six years of corn yields and terrain attributes. Precis. Agric. 4:87–101.

Lamb, J.A., R.H. Dowdy, J.L. Anderson, and G.W. Rehm. 1997. Spatial and temporal stability of corn grain yields. J. Prod. Agric. 10:410–414.

Lark, R.M., and J.V. Stafford. 1997. Classification as a first step in the interpretation of temporal and spatial variability of crop yield. Ann. Appl. Biol. 130:111–121.

Ping, J.L., C.J. Green, K.F. Bronson, R.E. Zartman, and A. Doberman. 2005. Delineating potential management zones for cotton based on yields and soil properties. Soil Sci. 170:371–385.

Porter, P.M., J.G. Lauer, D.R. Huggins, E.S. Opligner, and R.K. Crookston. 1998. Assessing spatial and temporal variability of corn and soybean yields. J. Prod. Agric. 11:359–363.

Schepers, A.R., J.F. Shanahan, M.A. Liebig, J.S. Schepers, S.H. Johnson, and A. Luchiari, Jr. 2004. Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Agron. J. 96:195–203.

Wollenhaupt, N.C., D.J. Mulla, and C.A. Gotway Crawford. 1997. Soil sampling and interpolation techniques for mapping spatial variability of soil properties. p. 19–53. *In* F.J. Pierce and E.J. Sadler (ed.) The state of site specific management for agriculture. ASA, CSSA, and SSSAJ, Madison, WI.

Yang, C., C.L. Peterson, G.J. Shropshire, and T. Otawa. 1998. Spatial variability of field topography and wheat yield in the Palouse region of the Pacific Northwest. Trans. ASAE 41:17–27.