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Comparison of Site-Specific Management Zones: Soil-Color-Based and Yield-Based

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ABSTRACT

Numerous techniques of management zone delineation have been studied; however, few comparisons between techniques exist in the literature. The objectives of this study were: (i) to determine how consistently two management zone delineation techniques (a soil-color-based management zone [SCMZ] technique and a yield-based management zone [YBMZ] technique) characterize regions of high, medium, and low grain yield; and (ii) to compare the relative accuracies with which the two management zone delineation techniques characterize the grain yield within low, medium, and high productivity potential management zones. This study was conducted for three site years in northeastern Colorado. Management zones were delineated before planting. The SCMZ technique used: (i) bare-soil imagery, (ii) topography, and (iii) farmer's experience. The YBMZ relied on: (i) bare-soil imagery, (ii) soil organic matter, (iii) cation exchange capacity, (iv) soil texture, and (v) the previous season's yield map. Grain yields ranged from 6.9 to 15.5 Mg ha^{-1} across all site years. Grain yields were significantly different between SCMZ zones for all site years. Grain yield in the SCMZ high zones were up to 1.88 Mg ha^{-1} higher than YBMZ high zones. Areal agreements for the SCMZ technique were 37, 41, and 45% for Site Years I, II, and III. Based on the approaches used in this study to classify grain yield patterns, the SCMZ technique was found to be relatively better than the YBMZ technique.

DEVELOPMENT of the variable-rate application (VRA) map is an important step in conducting variable-rate fertilizer application (Sawyer, 1994; Ferguson et al., 1996). Intensive grid soil sampling was among the first methods used to map soil fertility levels and remains a commonly practiced means of generating VRA maps. Grid soil sampling has been widely reported as a method that is both expensive and time consuming. Several studies have been aimed at lowering the cost of grid soil sampling by reducing the total number of soil samples taken without sacrificing the accuracy of the VRA map (Hammond, 1992; Franzen and Peck, 1995; Anderson-Cook et al., 1999); however, even at a large sampling scale, grid soil sampling is arguably too expensive to be considered cost effective (Gotway et al., 1996; Khosla and Alley, 1999), and the degree to which it characterizes the spatial variability of crop-limiting soil factors is questionable.

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Management Zones

Management zones have been studied as an alternative method of developing VRA maps. Doerge (1999) defined management zones as subregions of a field with homogeneous yield-limiting factors. Using a management zone approach, a field can be separated into areas of similar productivity potential, and fertilizer can be applied variably in accordance with the nutrient needs of each zone. There have been several different techniques of management zone delineation proposed in the literature; however, one commonality in all the techniques described is that they are minimally intrusive (i.e., do not rely strictly on soil sampling) and therefore have the potential to be more economically feasible than the grid soil-sample-based VRA.

Soil survey maps have been investigated as a means of generating site-specific management zones. Franzen et al. (2002) found Order 2 soil survey maps (i.e., 1:15 840–1:30 000) to be inadequate but found Order 1 (i.e., 1:500–1:10 000) to be useful in developing N management zones. It is important to note that, although many older NRCS soil surveys are at a scale of 1:15 840, the newer soil surveys are being developed at a scale of 1:24 000 to correspond with USGS 7.5-min topographic quadrangle maps. Order 1 soil surveys are generally not available free of charge to the public, as their Order 2 counterparts are (NRCS 1:15 840 and 1:24 000 county soil surveys) and, as such, the acquisition of soil surveys at this scale would require hiring a soil consultant to generate a custom map of the area. Depending on the size of the area, this could be very expensive.

Variation in field topography has also been used to generate variable-rate nutrient application maps. Studies have described the association of field topography and soil N content (Bruulsema et al., 1996; Cassel et al., 1996) as well as topography and yield variability (Ciha, 1984; Verity and Anderson, 1990; Kravenchenko and Bullock, 2000). Topography with ancillary data (i.e., organic matter, cation exchange capacity, P, and K) was found to account for 40% of the variability in grain yield (Kravenchenko and Bullock, 2000). Topography has been used as a basis for conducting directed sampling or "zone sampling" for assessment of soil N and P levels (Franzen et al., 2000). Nolan et al. (2000) found that zones based on elevation, curvature, and slope could account for as much as 51% of the variability in crop yield.

Apparent soil electrical conductivity (EC_a) has been shown to be an indicator of multiple soil properties (Sudduth et al., 1995; Doolittle et al., 1994; Jaynes et al., 1995). Ammons et al. (1989) used soil EC_a to differentiate between Natraqualf and Ochraqualf map units. Inman et al. (2002) found soil EC_a to be strongly related

Abbreviations: EC_a, apparent soil electrical; SCMZ, soil color-based management zone; YBMZ, yield-based management zone.

to sand content in a loess-derived soil in southwest Tennessee. Johnson et al. (2001) found clay content and $CaCO_3$ to be the dominant factors controlling soil EC_a in semiarid soils. Although soil EC_a is effective at characterizing the spatial variability of some soil properties, Johnson et al. (2003) acknowledged that the soil properties that control soil EC_a do not necessarily correspond to yield-limiting factors. In their study, Johnson et al. (2003) found that patterns on soil EC_a maps were poorly correlated with yield variability in corn (*Zea mays* L.). Not surprisingly, they also found no consistent relationship between EC_a-based management zones and corn grain yield (Johnson et al., 2003).

Aerial or satellite-based remote sensing is a promising alternative to intensive grid soil sampling and analysis for characterizing the spatial variability of soil properties for the purpose of variable-rate nutrient application. Spectral reflectance of soil has been shown to be significantly correlated with soil organic matter (Page, 1974; Coleman and Montgomery, 1987; Bhatti et al., 1991; Coleman and Tadesse, 1995) as well as soil moisture content (Bowers and Hanks, 1965; Skidmore et al., 1975; Lobell and Asner, 2002). Soil reflectance, as measured by satellite imagery, has also been correlated to soil texture (Ray et al., 2004). In addition to characterizing soil properties, remote sensing has been studied as a means of generating management zones. Grain yield between management zones, based on unsupervised classification of aerial imagery, was found to be statistically different; however, plant nutrient content was not found to be statistically different between zones (Yang et al., 1998).

Yield monitoring equipment has become commonplace on many grain combines sold in the USA (Griffin et al., 2004). Data from yield monitors can easily be coupled with global positioning system (GPS) data to produce a map of the yield for a given field. These maps can be used to classify the field into areas of differential yield. Using data from yield monitoring equipment to identify management zones, however, has been met with marginal success. One reason for this is that yield patterns are inconsistent between growing seasons (Kitchen et al., 1995; Lamb et al., 1996; Colvin et al., 1997; Stafford et al., 1998). Although yield maps alone are not appropriate for delineating management zones, they do provide valuable ancillary data (Stafford et al., 1998). For example, coupling grain yield data with other soil variables could potentially explain variability associated with both crop and soil parameters.

Several "hybrid" methods of management zone delineation have been proposed in which a combination of techniques were used. Fridgen et al. (2000) used elevation, soil EC_a, and slope to create management zones and Fraisse et al. (1999) found that these were the most important variables to consider when delineating management zones on a claypan soil. Luchiari et al. (2000) found the zones delineated using topography, soil color, and soil EC_a accounted for 65% of the spatial variation in corn grain yield. A more subjective approach by Fleming et al. (1999) used bare-soil color, farmer's perception of yield, and field topography to classify fields into three productivity zones (high, medium, and low). Results from Fleming et al. (2000) and Khosla et al. (2002) indicate that the zone delineation technique proposed by Fleming et al. (1999) is effective in identifying areas of differential productivity. In addition to being easy to implement, this technique has also been shown to be more profitable than uniform nutrient application (Koch et al., 2004).

Management zone delineation techniques proposed in the literature are numerous; however, to date there are few studies that compare these techniques on the basis of their relative performance to characterize areas of differential productivity. Before informed decisions can be made, there needs to be a quantitative assessment of management zone delineation techniques. The objectives of this study were: (i) to determine how consistently two management zone delineation techniques (SCMZ and YBMZ) characterize regions of high, medium, and low grain yield; and (ii) to compare the relative accuracies with which the two techniques characterize the grain yield within low, medium, and high productivity potential management zones.

MATERIALS AND METHODS

Study Sites

This study was conducted for three site years. Sites were located in northeastern Colorado and were under a continuous corn cropping system. Fields were irrigated using center-pivot sprinkler systems. Site Years I and III were located on a 57-ha field that was mapped as having Albinas loam (fine-loamy, mixed, superactive, mesic Pachic Argiustoll), Ascalon fine sandy loam (fine-loamy, mixed, superactive, mesic Aridic Argiustoll), and Haxton sandy loam (fine-loamy, mixed, superactive, mesic Pachic Argiustoll) soils (Soil Survey Staff, 1981). These soils are very deep and well drained. The Ascalon series occurs on upland positions and is formed from calcareous parent material. Haxtun soils consist of eolian deposits that overlie buried soil and occur in drainages and depressions. The Albinas soil is alluvial and occurs on fans and terraces. These soils are all characterized by having accumulated carbonates in the solum.

Site Year II was located on a 69-ha field that has Bijou loamy sand (coarse-loamy, mixed, superactive, mesic Ustic Haplargid), Truckton coarse sandy loam (coarse-loamy, mixed, superactive, mesic Aridic Argiustoll), and Valentine fine sand (mixed, mesic Typic Ustipsamment) soils (Soil Survey Staff, 1968). These soils are characterized as very deep; the Truckton is well drained, Bijou is somewhat excessively drained, and the Valentine is excessively drained. Both Truckton and Bijou soils are derived from arkose parent material and occur on terraces, fans, and uplands. Valentine soils are eolian derived and occur on uplands.

Experimental Procedure

Before planting each season, grid soil sampling was performed to measure soil properties used during the YBMZ delineation technique. Sample locations were determined using a systematic unaligned grid; cell size was 63.7 by 63.7 m. Soil samples were collected using a truck-mounted Giddings hydraulic soil sampling probe. Each soil sample core was separated into the following depth increments: 0 to 20, 20 to 60, 60 to 90, and 90 to 120 cm for analysis. Soil samples were air dried and ground to pass a 2-mm sieve (Soil Survey Staff, 1996). Soil pH was analyzed using a 1:1 soil/water mixture (McLean, 1982). Particle size analysis was conducted using the hydrometer method (Gee and Bauder, 1986). Total NO_3–N was determined using the method of Keeney and Nelson (1982). Soil test P levels were determined using the Olsen test, $NaHCO_3$ procedure (Olsen and Sommers, 1982). Available K was determined using NH_4OAc extraction procedure (Knudesen et al., 1982). Cation exchange capacity (pH 7) was determined using the NH_4OAc rapid distillation procedure (Chapman, 1965).

Management Zone Delineation

Two management zone delineation techniques were evaluated in this study: SCMZ and YBMZ. Both techniques were used to classify the fields into areas of high, medium, and low productivity potential (Fig. 1). Details of the two techniques are presented below.

Soil Color-Based Management Zones

The SCMZ technique used the commercially available AgriTrak Professional software for zone delineation (Fleming et al., 1999). This program relies on three data layers: (i) bare-soil aerial imagery of a conventionally tilled field; (ii) the farmer's perception of field topography; and (iii) the farmer's past crop and soil management experience. After the aerial imagery was acquired, we sat down with the cooperating farmers to incorporate their experiences from their field(s). Using the AgriTrak Professional software, the cooperating farmers created polygons that reflected their knowledge and past management experiences with the fields. In other words, using a stylus, the farmers delineated areas of the fields that were consistently low yielding, consistently high yielding, that were upland positions, and that were low lying or drainages. These data layers were then incorporated into a geographic information system (GIS) database to generate mathematical interpolation surfaces to develop three management zones (Khosla et al., 2002). Traits such as regions of dark color, areas of low-lying topography, and areas of historic high yields as reported by the farmer were designated as zones of potentially high productivity or high zones. Details of this technique are provided in Fleming et al. (1999), Khosla et al. (2002), Koch et al. (2004), and Inman et al. (2005).

Yield-Based Management Zones

The YBMZ technique used in this study is a new technique and was developed with the intent to further improve the accuracy of the SCMZ technique in classifying high-, medium-, and low-productivity areas of the field. This technique relies on five GIS data layers for zone delineation: (i) multispectral bare-soil aerial imagery (red, green, and near-infrared bands), (ii) soil organic matter, (iii) soil cation exchange capacity, (iv) soil texture (sand, silt, and clay content); and (v) the yield map from the previous growing season.

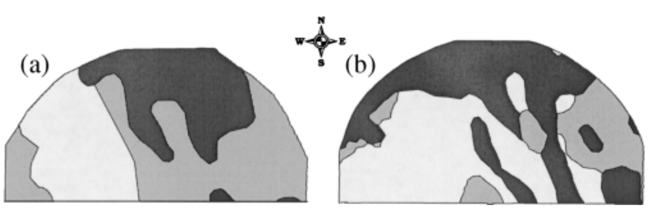

Fig. 1. (a) Soil-color-based management zone technique and (b) yield-based management zone technique for Site Year I. Low productivity = dark gray, medium productivity = light gray, high productivity = white.

Bare-soil imagery was acquired for each location by aircraft after field preparation (i.e., conventional tillage) and before planting, using a DuncanTech MS 3100 three-band digital camera (Redlake MASD, San Diego, CA). Imagery recorded radiance in three spectral bands (green, red, and near infrared). Geometric correction was performed in ERDAS Imagine 8.6 (Leica Geosystems GIS & Mapping LLC, Atlanta, GA) using image-to-image registration; the root mean square error was <1 pixel for all images. Radiance was converted to apparent reflectance by using the histogram minimization method of Chavez (1975) in ERDAS Imagine software.

Surfaces for selected soil properties (soil organic matter, cation exchange capacity, sand, silt, and clay content determined from grid-based [2.5 sample ha^{-1}] soil sampling) were created using median-polish kriging. Yield monitor data were interpolated using ordinary kriging. Cressie (1993) introduced the median polish kriging method, which is based on the median polish approach for two-way tables to extract a mean surface from spatial data and then use ordinary kriging for spatially predicting the residual process.

The yield maps, aerial imagery, and the interpolated soil surfaces (soil organic matter, cation exchange capacity, sand, silt, and clay) were brought to the same spatial resolution (10 m) by resampling using cubic convolution. These data layers were used with K-means clustering to produce three clusters (Splus 6.2, Insightful Corp., Seattle, WA). The resulting clusters were "smoothed" using a 7 by 7 m focal majority moving window. The size of the window was chosen to correspond with the size of the fertilizer applicator used in this study. Finally, the smoothed data were imported into MapInfo 6.0 (MapInfo Corp., Troy, NY) to develop the management zones.

Experimental Design and Analysis

Experimental strips were randomly allocated and consisted of 24 rows that spanned the length of the entire field (>700 m). Treatments were replicated once and were nested within management zones (Inman et al., 2005). Nitrogen treatments were made at the six-leaf crop growth stage (V6) using undiluted urea–NH_4NO_3 32% (UAN 32) applied with an eight-row cultivator. Nitrogen treatments were based on the N-rate algorithm of Mortvedt et al. (1996):

$$\text{N rate} = 35 + 1.2\text{EY} - 8(\text{soil NO}_3 - \text{N}) - 0.14\,(\text{EY})(\text{OM}) - (\text{other N credits}) \quad [1]$$

where EY = expected yield and OM = organic matter. It should also be noted that Eq. [1] takes into account other N credits such as residual soil N, N in irrigation water, and past manure applications.

The three N treatments were (i) the recommended N rate from Eq. [1], (ii) half the recommended N rate, and (iii) a control of 0 kg N ha^{-1}. Recommended N rates were: 102, 192, and 202 kg N ha^{-1} for Site Years I, II, and III, respectively. To avoid any N-rate-induced variability, only uniform N treatments were used. The N rates (recommended and one-half) were applied uniformly across the management zones for each experimental strip.

At physiological maturity, the crop was harvested using a combine equipped with a yield monitor and a differentially corrected GPS. Yield monitor data were cleaned to remove erroneous pixels and, to minimize errors associated with "lag," a five-pixel sliding average was used (Pierce and Novak, 1999). Yield data were subsampled using a sample size of n = 40 within each management zone (Hornung et al., 2003). Bootstrapping was then used to obtain grain yield variance estimates for each management zone (Efron and Tibshirani, 1993). A two-tailed *t*-test was used to test significant differences in grain yield between management zones within each delineation technique and across both techniques.

The management zone delineation techniques were evaluated using three approaches: (i) the farmer's approach, (ii) a quantitative approach, and (iii) a subjective approach. The farmer's approach was the simplest. This approach was suggested by the cooperating farmers, and was based on grain yield production between the two techniques. In other words, the cooperating farmers were interested in finding the best technique that would result in the greatest yield from high management zones and the lowest grain yield in the low management zones. Hence, using the farmer's approach, comparisons were made for grain yields produced in each zone for the two techniques. For example, the grain yield from the high zone delineated using the SCMZ technique was compared with the grain yield from the high zone delineated using the YBMZ technique.

The quantitative approach used a K-means clustering algorithm to group the grain yield into three clusters of high, medium, and low grain yield. Grain yield clusters were then compared with the management zones using areal agreement and kappa statistics (Campbell, 2002). Areal agreement and kappa statistics are determined in an error matrix (Campbell, 2002). Using an error matrix, two areal classifications can be quantitatively compared with each other by superimposing the maps (the management zone maps, grain yield clusters, and subjective yield classes) and conducting a point-by-point comparison. The areal agreement is the percentage of points compared that share a common classification; however, areal agreement does not provide a rigorous assessment of how well two classifications agree. According to Campbell (2002), "a chance assignment of pixels to classes can result in surprisingly good results as measured by percent correct." The kappa statistic provides a more robust measure of how two classifications agree compared with a "chance" agreement and is, therefore, a more rigorous statistic with which to compare two classifications.

The subjective approach involved grouping the grain yield data into three subjectively determined yield classes. Yield classes were determined after consultation with area producers and were as follows: low yield class <9 Mg ha^{-1}, medium yield class 9 to 12 Mg ha^{-1}, and high yield class >12 Mg ha^{-1}. The yield classes reflect the region's below-average, average, and above-average irrigated corn grain yields, respectively. Yield classes were compared with the management zones using areal agreement and kappa statistics (Campbell, 2002).

RESULTS AND DISCUSSION

Grain yields ranged from 6.9 to 15.5 Mg ha^{-1} across all site years (Fig. 2 and 3) and were responsive to N treatments.

Soil-Color-Based Management Zones

Grain yield for each treatment within each management zone for the SCMZ technique is presented for all site years in Fig. 2. For Site Year I, overall grain yield was impacted across the field by hail damage incurred during the late vegetative growth. From field observations, the hail damage was most severe in the area of the field corresponding to the high management zone. This observation is reflected in the grain yield measured for the high management zone, which was 0.4 to 1.1 Mg ha^{-1} lower than that of the medium management zone across all N treatments. Despite the hail damage, the SCMZ technique was able to differentiate grain yield between low and medium management zones for all treatments in Site Year I.

Grain yield was found to be significantly different between management zones for Site Year II. Across management zones, grain yield ranged from 6.9 to 12.8 Mg ha^{-1}. The high zone had a significantly higher grain yield than that of the medium zone across all N treatments. Likewise, the medium zone had higher grain yields than the low zone across all N treatments.

Grain yield trends observed for Site Year III were similar to grain yield trends observed for Site Year II. Mean grain yield increased with the productivity potential of the management zones in two out of three treatments. The low zone had the lowest grain yields within treatments (9.3–14.7 Mg ha^{-1}), the medium zone had slightly higher yields (11.1–14.7 Mg ha^{-1}), while the high zone had the highest yields (10.0–15.3 Mg ha^{-1}). In two out of three treatments, however, statistically significant differences in grain yield were found only for the low and high management zones. These results are similar to those of Inman et al. (2005), who found that the soil-color-based management zone technique consistently differentiated N uptake levels between low and high productivity zones. In their study, they attributed the lack of consistent differentiation of the medium zone from either the low or high zones to isolated and small inclusions of both high and low management zones within the medium management zones. These inclusions are relicts of the intentional "smoothing" that is performed on the management zone maps. The smoothing makes it practical for fertilizer application equipment to use the management zone maps for variable-rate application.

Yield-Based Management Zones

For Site Year I, the YBMZ technique differentiated grain yield between low and medium and medium and high management zones. Observed mean grain yield in the medium zone was significantly higher than that of the low zone for the recommended N rate and the control (Fig. 3). Grain yield in the high management zone was negatively impacted by hail damage during late vegetative growth, and therefore did not reflect the designated productivity potential.

For Site Year II, grain yield differences between zones did not follow the expected pattern. Within treatments, our results indicate that the grain yield does differ among zones delineated using the YBMZ technique; however, the grain yield did not follow a logical trend as designated by the productivity potential of the zones. Across treatments, the medium zone was significantly different from the high zone. Average grain yield in the low zone was higher than grain yield observed in the medium zones for the recommended and half recommended N rate treatments (Fig. 3).

Grain yields for Site Year III increased with the productivity potential of the management zones for the

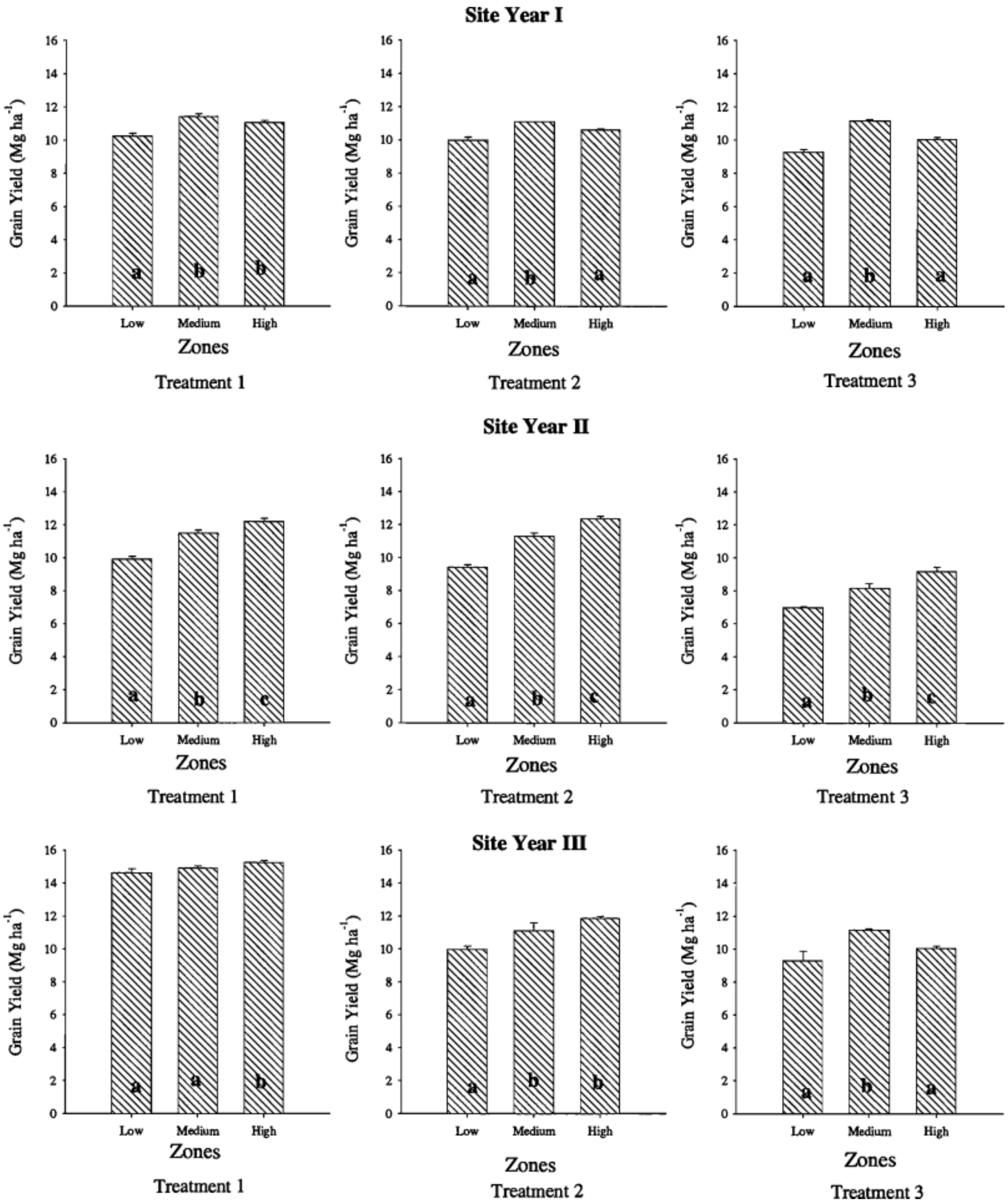

Fig. 2. Mean grain yield for the soil-color-based management zone technique for each treatment and site year. Treatment 1 = recommended N rate as determined by Mortvedt et al. (1996), Treatment 2 = half the recommended N rate, and Treatment 3 = control treatment. The standard deviation of the mean is represented by error bars. Within each treatment, bars with different letters are statistically different at $P \leq 0.05$.

recommended N treatment only (Fig. 3). Results of the *t*-test indicate that the low and high zones had significantly different grain yield ($P \leq 0.05$) for the recommended N treatment only. In contrast, the low and high zones were statistically equivalent for the half recommended and control treatments.

Based on these results, the YBMZ technique did not consistently differentiate productivity potential of the management zones. This finding could be because (i) the YBMZ technique is not characterizing all of the spatial variability in the yield-limiting factors that affect overall productivity, (ii) some of the spatial variability is lost in the smoothing step during the management zone delineation process, or (iii) a combination of the two.

Comparing the Two Management Zone Techniques

Farmer's Approach

This approach was the simplest and evaluated the accuracy of the management zone techniques based on grain yield production between the two techniques. Grain yield differences for the high, medium, and low management zones and delineation techniques are presented in Table 1. Overall, the high and medium zones delineated using the SCMZ exhibited higher grain yields than the corresponding management zones delineated with the YBMZ technique, indicating that the SCMZ technique is accurately characterizing the high

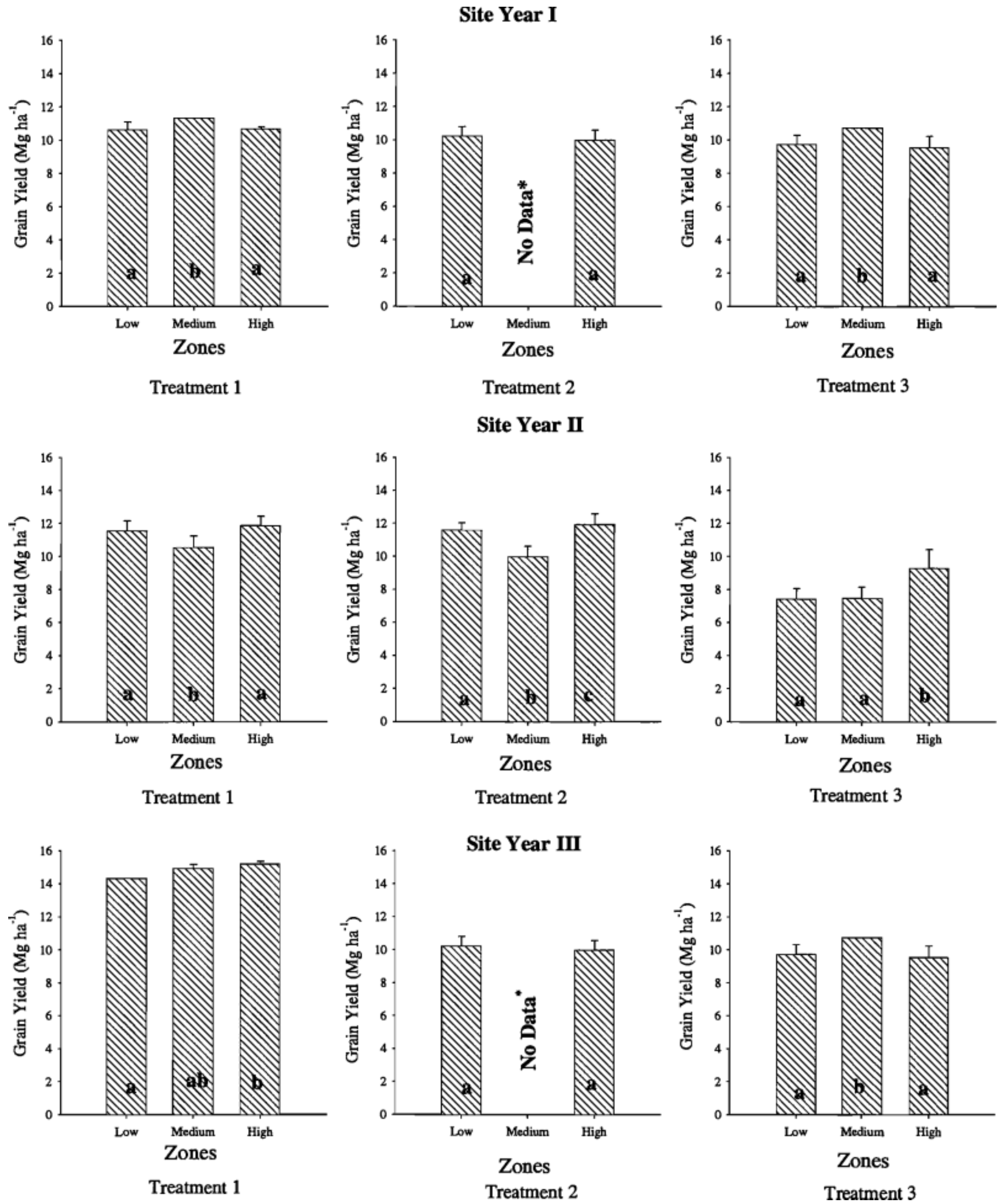

Fig. 3. Mean grain yield for the yield-based management zone technique for each treatment and site year. Treatment 1 = recommended N rate as determined by Mortvedt et al. (1996), Treatment 2 = half the recommended N rate, and Treatment 3 = control treatment. The standard deviation of the mean is represented by error bars. Within each treatment, bars with different letters are statistically different at $P \leq 0.05$. *For Site Years I and III, the Treatment 2 experimental strip did not cross the medium zone.

and medium yielding areas of the field. Grain yield differences were significant in 12 out of 25 yield comparisons across the three site years between the SCMZ and the YBMZ techniques ($P \leq 0.05$). Management zones delineated using the SCMZ technique were up to 1.88 Mg ha^{-1} higher than the corresponding YBMZs (Table 1). Zones that were designated as "low" using the YBMZ technique were as much as 1.63 Mg ha^{-1} higher than the zones delineated as "low" using the SCMZ technique, indicating that the YBMZ technique is not accurately characterizing the low-yielding areas of the field. Based on the results of the farmer's approach, the SCMZ technique performed relatively better than the YBMZ technique in terms of correctly classifying grain yield potential for each zone. The SCMZ technique was more accurate at distinguishing high, medium, and low productivity potential areas than the YBMZ technique.

Quantitative Approach

The quantitative approach relied on a K-means clustering algorithm to group data into yield classes. Yield clusters were quantitatively compared using areal agreement and kappa statistics. General interpretation guidelines of the kappa statistic are provided in Table 2

Table 1. Grain yield differences between soil-color-based management zones (SCMZ) and yield-based management zones (YBMZ) for Site Years I, II, and III.

Site year	N treatment	Management zone High	Medium	Low
		Mg ha^{-1}†		
I	rec.‡	0.38*	0.13	−0.38
	½ rec.	0.63*	–	−0.38
	control	0.50	0.44*	−0.44
II	rec.	0.13	1.0*	−1.63*
	½ rec.	0.38	1.25*	0.63
	control	−1.63	−2.19*	−0.50**
III	rec.	0.01	0.06	0.31
	½ rec.	1.88*	–	−0.25*
	control	0.50*	0.44	−0.44*

* Indicates statistically significant at $P \leq 0.05$.
** Indicates statistically significant at $P \leq 0.01$.
† Grain yield differences were calculated by subtracting the grain yield of the YBMZ zones from the grain yield of the SCMZ zones.
‡ rec. = recommended N rate as determined by Mortvedt et al. (1996).

(Landis and Koch, 1977). Results of the quantitative approach are presented in Table 3. Across site years, the SCMZ technique had higher areal agreement percentages in two out of the three site years when compared with the YBMZ technique. Areal agreement was 37, 41, and 45% for the SCMZ technique and 24, 38, and 48% for the YBMZ. The kappa statistic is a measure of how well a classification is compared with a completely random classification. As stated above, the kappa statistic is a more robust statistic for assessing agreement between two classifications. According to Table 2 (Landis and Koch, 1977), both SCMZ and YBMZ have "slight agreement" with yield clusters, indicating that both techniques are deficient at completely characterizing the inherent spatial variability in productivity potential across the fields used in this study. The guidelines of Landis and Koch (1977; Table 2) indicate that the kappa statistics were higher for the SCMZ technique across all site years, suggesting that the SCMZ technique is relatively better than the YBMZ technique.

Subjective Approach

The subjective approach compared subjectively determined yield classes to management zones using areal agreement and kappa statistics. Comparisons of management zones from the SCMZ and YBMZ to subjective yield classes are presented in Table 4. Across site years, the YBMZ technique had the highest areal agreement in two out of three site years. Areal agreement ranged from 24 to 40% for the SCMZ technique and 32 to 59% for the YBMZ. Across site years, the SCMZ technique had higher kappa statistics than the YBMZ technique. Based on the guidelines provided in Table 2

Table 2. Guidelines for interpreting kappa statistics (from Landis and Koch, 1977).

Kappa statistic	Strength of agreement
<0	poor
0–0.20	slight
0.21–0.40	fair
0.41–0.60	moderate
0.61–0.80	substantial
0.81–1.0	almost perfect

Table 3. Areal agreement and kappa statistics for comparisons made between (i) soil-color-based management zones (SCMZ) and grain yield clusters† and (ii) yield-based management zones (YBMZ) and grain yield clusters for Site Years I, II, and III.

Comparison	Areal agreement I	II	III	Kappa statistic I	II	III
	%					
SCMZ and yield	45	41	37	0.17	0.12	0.08
YBMZ and yield	38	24	48	0.02	0.09	0.02

† Yield clusters were determined using K-means clustering algorithm (K = 3 clusters).

(Landis and Koch, 1977), the SCMZ technique had a "slight" agreement with subjective yield classes for all site years, whereas the YBMZ technique had "poor" agreement in two out of three site years. Again, based on these results, the SCMZ technique is relatively more accurate than the YBMZ technique in differentiating areas of low, medium, and high yields.

Overall, based on the three approaches used in this study, it appears that the SCMZ technique more accurately characterizes low, medium, and high productivity areas of the field; however, areal agreement and kappa statistics both indicate that there is significant room for improving the delineation process of the management zone techniques. Currently, the spatial resolution with which we delineate management zones is limited by the fertilizer applicator's spray boom width, which is commonly 18 to 27 m wide. Consequently, the delineation process involves intentional smoothing to accommodate equipment of this size. Any management zone unit that is smaller than the width of the application boom is assimilated into the surrounding (larger) management zone unit during the smoothing process. Although the smoothing step is also used during the YBMZ technique, the YBMZ technique is dynamic in nature. The shape and size of the management zones delineated using the YBMZ technique are apt to change because of the inclusion of the previous year's yield map. In contrast, the SCMZ technique is based on stable soil properties and, in turn, results in a stable shape and size of management zones.

The overall relatively poor performance of the YBMZ technique compared with the SCMZ technique could be attributed to lack of weights assigned to the various data layers (i.e., bare-soil imagery, soil organic matter, cation exchange capacity, soil texture, and the previous season's yield map). We hypothesize that

Table 4. Areal agreement and kappa statistics for comparisons made between (i) soil-color-based management zones (SCMZ) and subjective grain yield classes† and (ii) yield-based management zones (YBMZ) and subjective grain yield classes for all site years.

Comparison	Areal agreement I	II	III	Kappa statistic I	II	III
	%					
SCMZ and yield	24	40	29	0.03	0.01	0.0
YBMZ and yield	32	34	59	0.02	−0.004	−0.01

† Grain yield classes were subjectively determined and were as follows: high >12 Mg ha^{-1}, medium 9 to 12 Mg ha^{-1}, and low <9 Mg ha^{-1}.

assigning appropriate weights to the data layers during the management zone delineation process could increase the accuracy with which the YBMZ technique characterizes spatially variable productivity potential. More research is needed to develop appropriate weights for the data layers.

CONCLUSIONS

In this study, SCMZ and YBMZ techniques were evaluated for grain yield production and the accuracy with which they characterize grain yield within low, medium, and high productivity potential management zones. Results from this study indicate that the SCMZ technique is relatively more accurate than the YBMZ technique for characterizing in-field areas of different productivity potential. Both techniques have deficiencies and could be improved. This study does, however, indicate that the inclusion of more data layers to a management zone delineation technique does not necessarily improve the overall accuracy of the technique, as evidenced by the data-intensive YBMZ technique being less accurate than the SCMZ technique.

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