DEVELOPING, DELINEATING, AND MANAGING PRODUCTION LEVEL NUTRIENT MANAGEMENT ZONES

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ABSTRACT

Grid soil sampling has been used to develop nutrient maps to guide precision fertilizer applications since the inception of precision agriculture. However, the cost and labor associated with collection and analysis of soil samples to accurately describe spatial properties of fields can be prohibitive for most agronomic crops. As a result of these limitations, much interest is now being directed to the use of production level "management zones" (MZ) to allow implementation of precision agriculture. The objective of our research was to evaluate four methods that develop production level MZ for precision N fertilizer management. The four methods evaluated were: 1) Bare-soil panchromatic aerial photography and the producer's past production experience and knowledge of the topography of the field (SCMZ); 2) Apparent soil electrical conductivity (ECaMZ) as measured by the Veris® E.C. cart; 3) Bare-soil panchromatic aerial photography, topography, soil OM content, CEC, texture and the previous year's yield map (YBMZ); 4) Bare soil image (Red, Green, and Blue wavelengths) to guide cluster based soil sampling, followed by multi-variate spatial statistical analysis to generate a MZ surface map (RCMZ). Production level MZ were classified as high, medium or low production potential. Grain yields were also classified as high, medium and low using non-parametric analysis. Two-way analysis was used to compare the accuracy of MZ delineation techniques compared to actual crop yield. The average accuracy ranged from 18 to 52%, depending on the MZ delineation technique. Ninety two percent of the areal associations of the delineation techniques with yield classes were statistically significant, based upon the Chi-square goodness of fit, indicating these techniques are identifying yield patterns in the fields.

INTRODUCTION

Grid soil sampling is typically used to develop variable rate fertilizer maps. However, costs associated with the collection and analysis of soil samples at a density that accurately defines soil spatial dependency is generally prohibitive for agronomic crops. If data are not spatially dependent it is not statistically correct to spatially analyze the data and it is not possible to develop reliable fertilizer application maps. As a result of these limitations, the use of production level "management zones" (MZ) is being investigated to allow implementation of precision agriculture. Several studies have indicated that production level MZ could be used as an alternative to grid soil sampling to develop nutrient maps for variable rate fertilizer applications (Khosla and Alley, 1999; Khosla et al., 2002). Management zones are defined as a sub-region of a field that expresses a homogenous combination of yield limiting factors for which a single crop input is appropriate to attain maximum efficiency of farm inputs (Doerge, 1999). The determination of sub-regions in a field is difficult due to the complex combination of factors that may affect crop yield.

Different MZ delineation techniques have been proposed to develop prescription soil maps for managing variability. One technique utilizes soil survey maps to define N management zones (Franzen et al., 2000). Another utilizes distinctions in topography or landscape positions (Kravenko and Bullock, 2000). Also, an *in-situ* method utilizing the application of electromagnetic induction to measure apparent soil electrical conductivity (ECa) is being used to delineate MZ (Sudduth et al., 1998). Fleming et al., 1999, evaluated a MZ approach based on soil color reflectance, topography and farmers past production experience.

The objective of this study was to compare four techniques for delineating MZ. Each method uses a unique set of soil, yield, and/or remotely sensed data. The level of technological expertise required to develop the MZ ranges from very simple (i.e. most producers with limited computer skills could implement) to more complex techniques requiring computer and data management skills.

MATERIALS AND METHODS

This study was conducted on three center-pivot irrigated fields in northeastern Colorado. All fields had been managed under continuous corn (*Zea mays* L.) for several years by individual farmers. Management zones were delineated to identify areas of high, medium, and low-yield potential using four techniques. Each method uses a unique set of soil, yield, and/or remotely sensed data. The level of technological expertise required to develop these MZ range from very simple to relatively complex. The techniques being evaluated, from the least to most technical, are: Technique 1; a commercially available technique that utilizes panchromatic bare-soil imagery, as well as the farmers past management experiences and knowledge of the field topography (Fleming et al., 1999; Khosla et al., 2002) (SCMZ, soil color). Technique 2; a technique that utilizes a Veris®E.C. cart to measure apparent soil electrical conductivity (ECa), employing only one GIS layer (ECaMZ). Technique 3; a technique that uses multi-spectral bare-soil imagery, soil OM, CEC, texture (% sand, silt and clay), and the previous year's yield monitor map as the data layers (YBMZ). Technique 4; a technique that utilizes bare-soil imagery to develop a stratified cluster soil-sampling design for each field (RCMZ). Soil samples collected from these points are analyzed for EC, OM, NH_4-N, NO_3-N, and Zn. The bare-soil imagery (red, green, and blue) and soil sample GIS data layers are used to delineate MZs.

The zero N-rate was used to evaluate the four management zone delineation techniques. Corn grain yields were determined using a commercial combine equipped with a GPS receiver and a yield monitoring system. The grain yield data were cleaned for errors and then averaged using a 5 pixel sliding average to minimize the variability in grain yield data due to lag errors (Pierce, et al., 1997). The grain yields were classified as high, medium, or low, as they fell in the different quartiles of the yield population ($<1^{st}$ quartile=low yield; .1^{st} and ,3^{rd} quartile=medium yield, $>3^{rd}$ quartile=high yield) using a non-parametric procedure.

Yield classification at each harvest location was compared to the associated management zone classification for each delineation technique. Two-way tables were then constructed to compare the accuracy of the yield and management zone classifications. A Chi-square goodness of fit test was used to compare observed vs expected values for management zones vs yield zone classes.

RESULTS AND DISCUSSION

Visual inspection of production level management zones indicates the four delineation techniques resulted in some similarities in classifications (Figure 1). General areas of the fields that fell within a particular MZ displayed some commonalities using the four techniques. However, there were differences when the delineated zones were compared in detail. The comparisons of grain yield classes (low, medium, and high) vs MZ delineation was evaluated using the two-way comparison described above. Ninety one percent (11 of 12) of the areal associations were significant. The Chi-square overall goodness-of-fit tests were all significant with the exception of with the SCMZ in field 1. These results show that the MZ delineation techniques are identifying different areas of production potential within each field.

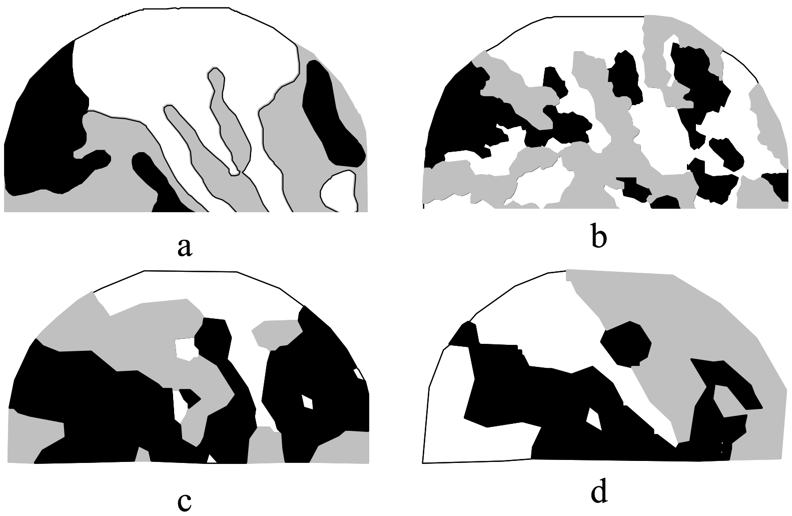

Figure 1. Productivity level management zones produced from four different delineation techniques for field 3. (Black = high productivity zone, gray = medium productivity zone, and white = low productivity zone. (a) SCMZ technique, (b) ECaMZ technique, (c) YBMZ technique, and (d) RCMZ technique.)

A more meaningful comparison is the relationship between the identification of a production level MZ (low, medium or high), as delineated by the four techniques, with the observed yield classifications (low, medium or high) (i.e., association of a high yield class vs high production level MZ, medium yield class vs medium production level MZ and a low yield class with a low production level MZ). The overall accuracy of the areal association ranged from 18 to 52% (Table 1). The average agreement between the observed yield classification and the MZ delineation at the three sites averaged 41, 46, 31 and 45% for the SCMZ, ECaMZ, YBMZ, and RCMZ techniques, respectively (Table 2). The RCMZ and the ECaMZ techniques had the most overall accuracy.

Table 1. The agreement between yield classification (high, medium, or low) using the non-parametric approach for 3 fields and 4 production management zone delineation techniques for The 0% Nitrogen treatment as evaluated with the Chi-square goodness-of-fit-test. Values are percent.

		Technique											
		SCMZ			EGMZ			YBMZ			RCMZ		
		Management Zone											
Field	Yield	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Field 1	Low	33	20	50	33	50	23	41	15	na	40	28	na
	Medium	32	80	25	37	28	15	24	51	na	47	20	na
	High	35	0	25	30	22	62	35	34	na	13	51	na
	Overall#	**34^{ns}**			**37****			**44****			**29****		
Field 2	Low	56	36	4	32	31	8	22	3	48	45	38	3
	Medium	39	36	21	31	63	31	39	20	37	27	44	20
	High	4	27	75	37	6	62	39	77	15	28	18	77
	Overall	**50****			**37****			**18****			**52****		
Field 3	Low	20	37	67	56	28	34	31	57	26	49	26	23
	Medium	29	37	26	25	34	26	36	27	33	35	30	35
	High	51	26	7	20	37	40	34	16	41	16	44	42
	Overall	**27****			**38****			**36****			**39****		

Overall accuracy values with ** indicate *p* – value <0.05; ns=not significant. Treatments without observed samples are denoted not available (na).

This accuracy of agreement is not unexpected when all the factors that go into identification of production level MZ are considered. During the MZ delineation procedure a considerable amount of data "smoothing" occurs. This is necessary to facilitate field operations. For example, the fertilizer applicator boom width ranges from 18 to 27m. Small inclusions of a low productivity MZ may be "smoothed" into a high MZ because of this application constraint. On the other hand, the grain combine usually harvests a swath 6m wide while taking a yield measurement about every 5 m.

During our yield data cleaning step, what appeared to be anomalous yield measurements are removed, when in fact they may reflect actual small scale field variability. This may add to the problem of site-specific association. Even considering this step, using our 5 pixel sliding average, the yield measurement is at a much finer scale than the fertilizer applicator is able to manage. Knowingly, we have smoothed data and may have included a low production potential area of the field with a high MZ, or all combinations of this. The result is that we smooth data until it becomes practically manageable, thus loosing precision and spatial delineation. However, this is undoubtedly not the only reason for a lack of a high agreement. Many other factors, in addition to soil characteristics, affect crop production. We are only able to evaluate the soil factors in our studies.

We have found an economical advantage to the use of variable rate N fertilizer management using the level of accuracy in MZ delineation reported here. Compared to uniform N application over the field, MZ based N management (using the SCMZ technique) resulted in a $9.27 increase in net return to N management (Koch, 2003). Compared to grid sampling, there was a $26.05/A increase in net return. If the accuracy of MZ delineation could be increased, the net return to variable rate N management using the MZ approach could be increased substantially. Developing a more accurate method of MZ delineation is a major goal of our precision agriculture program.

Table 2. Areal Association using the non-parametric approach for the 0 Nitrogen

Management Zone (MZ) Technique	Low Yield w/ Low MZ (%)	Med. Yield w/ Med. MZ (%)	High Yield w/ High MZ (%)	MZ Technique Average (%)
SCMZ	36	51	36	41
ECaMZ	40	42	55	46
YBMZ	31	33	28	31
RCMZ	45	31	60	45

CONCLUSIONS

Precision agriculture technology is in its infancy and will continue to evolve as we learn more about its advantages and limitations. We have found that the delineation of production level MZ holds promise as a method of economic implementation of MZ for N fertilizer management. Fertilizer management using the MZ concept resulted in a greater net return and is less labor intensive than grid sampling based management. Our research evaluated four methods of MZ delineation. The overall accuracy of agreement between MZ and yield classifications for the four MZ delineation techniques ranged from 31 to 45% when averaged over sites. When the same MZ was compared to the same yield zone (i.e., high MZ vs high yield zone, medium MZ vs medium yield zone, etc.) the agreement ranged from 15 to 80%. The low end of this range does not appear to have a high level of agreement, however, when one considers the data "smoothing" that occurs in MZ delineation and yield values that make it possible to use commercial application equipment for fertilizer additions, this level is not unexpected. If the accuracy of MZ delineation can be improved, the economic returns would be even greater. We conclude that the MZ concept is a viable method of implementation for precision fertilizer management technology in agriculture. Our research is investigating this concept further.

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