An Evaluation of Methods for Determining Site-Specific Management Zones

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INTRODUCTION

Numerous procedures have been examined for identifying management areas within fields. Traditional soil surveys give a general understanding of the effects soil mapping units have on crop productivity. In the USA, county soil surveys report the average grain yield of major crops by soil series. Slope position and landform are topographic features that also have been used to explain water and crop productivity relationships (Mulla et al., 1992; Sudduth et al., 1997). Generally, footslope positions out-yield upslope positions unless poor drainage causes ponding. More detailed soil productivity indices have also been developed using various soil properties to characterize variability between soil types at a field level (Scrivner et al., 1985). However, few farmers have adopted productivity indices since measurements are expensive and time consuming.

Direct measurement of spatial crop productivity by yield monitoring and mapping is another way to determine soil variability. However, the yield map is confounded by many potential causes of yield variability (Pierce et al., 1997). Using yield maps alone to identify the influence of soil and landscape properties on soil water and crop production without also using spatial measurement of the numerous other potential and often transient yield-limiting factors (e.g., pest incidence, nutrients, and management variation) may be futile. Averaging multiple years of yield maps has been suggested as one way of establishing stable yield productivity patterns related to soil water (Stafford et al., 1996; Kitchen et al., 1995; Colvin et al., 1997). In some cases however, high producing areas of a field during "dry" years can be low producing areas of the same field in "wet" years (Colvin et al., 1997; Sudduth et al., 1997).

Spatial measurement of soil electrical conductivity (EC) has also been reported as a potential measurement for predicting crop production variation caused by soil water differences (Jaynes et al., 1995; Sudduth et al., 1995). After dividing claypan fields into sub-fields using soil EC and relative elevation, correlation coefficients between yield and soil-test data (e.g., soil-test pH, P, K, Mg, and Ca) were improved over correlations performed on a whole-field basis (Sudduth et al., 1996).

For site-specific management, careful consideration of the likely management operation or agrichemical input(s) to be employed is needed in order to determine the procedure of how to divide a field into different management zones. With some management operations, grid-soil sampling and mapping of nutrients may be the most appropriate option (e.g., variable-rate application of immobile nutrients on fields with a history of manuring). Other management considerations warrant sampling by differences in soil type or elevation (e.g., determination of soil nitrates). When a field has little history of fertilization and manuring, availability of immobile nutrients may be related to soil mapping unit. Misidentifying the appropriate management zones for a given operation or input may be no better than managing the field uniformly.

However management zones are determined, each zone should represent a unique combination of potential yield-limiting factors for which we can improve the site-specific management prescription. Unfortunately the evaluation of management zones is seldom done because most fields, once landscape and soil properties are measured and mapped, also receive some type of site-specific management (e.g., variable-rate applications). This variable management may make it difficult to determine whether or not the correct or appropriate management zones have been identified. Relative to management dependent on soil/landscape variation, the question considered here is "how should different management zones be determined?"

OBJECTIVE

The objective of this research was to evaluate various soil surveys (order 1 and order 2 surveys) and a quantitative method (soils classed by topsoil depth and elevation) for determining which method best identified sub-field areas that behaved similarly from year to year.

MATERIALS AND METHODS

Research Field Description

Yield and soil data were collected on a 88-acre claypan soil field located near Centralia, in central Missouri. The research field is characterized primarily by the Mexico-Putnam association (fine, montmorillonitic, mesic Udollic Ochraqualfs). Because of extensive weathering, the claypan soil is usually low in natural fertility and pH. Plant-available water from the claypan is low because a large portion of the stored water is retained with the clay at the wilting point. With these characteristics, variations in the depth of topsoil above the claypan can lead to significant variations in crop productivity. Topsoil depth on this field ranged from less than 10 cm to greater than 110 cm.

Soil and Yield Measurements

Data obtained on the study field included grain yield, elevation, and a number of soil properties. Grain yield measurements were obtained using a full-size combine equipped with a commercial yield-sensing system and standard processing techniques. Detailed topographic data were obtained using a total station surveying instrument and standard mapping procedures.

Based on our previous work (Sudduth et al., 1995), topsoil depth above the claypan was estimated from soil conductivity. A mobile measurement system described by Kitchen et al. (1996) was used to obtain root-zone soil electrical conductivity (EC) data with a commercial electromagnetic induction EC sensor. Our regression from soil conductivity to topsoil depth, based upon a calibration set taken within the study field, provided good results ($r^2 = 0.90$, std. err. = 2.6 in).

The field was soil sampled on a 100-ft (nominal) grid in the spring of 1997. A hand soil probe was used to collect soil cores to a 8-in depth. Eight soil cores obtained within a 3-ft radius of each sample position were combined, oven dried and analyzed by the University of Missouri Soil and Plant Testing Services Laboratory. Soil properties measured were phosphorus and potassium, pH, and organic matter.

Yield and topsoil depth data were analyzed using geostatistics, and appropriate semivariogram models and parameters were used to krige the data to a grid with a 33-ft cell size. Data from the grid cell centered closest to each soil sampling point was extracted and combined with the soil sample data for analysis. If any data was missing for a grid cell, that cell was eliminated from the analysis. A more thorough description of the data collection and analysis procedures used in compiling this dataset is contained in Sudduth et al. (1996).

Soil Surveys and a Quantitative Measure for Management Zones

Soil surveys were conducted on the study field on four different occasions by the USDA Natural Resource Conservation Service (NRCS). An order 2 soil survey (IISS) at a 1:25,000 scale was done in 1989-1991 to update the county soil survey. In 1991, the Missouri state office of the USDA-NRCS conducted an order 1 soil survey (ISS91) at a 1:5,000 scale. Two years later in 1993, a revised order 1 soil survey (ISS93) with more detailed laboratory analysis was done. Then in 1997, a team of soil scientists from the Missouri State NRCS office and from the National Soil Survey Center in Lincoln, Nebraska conducted a third order 1 soil survey (ISS97). In addition to the routine tools and techniques used for an order 1 soil survey, mapped data from our research work on this field (i.e., yield, elevation, and topsoil depth) were provided for the ISS97 survey. In this way it was an "enhanced" order 1 soil survey.

A method relying on quantitative measures for delineating management zones was developed by dividing the field into 5 sub-field areas on the basis of elevation and topsoil depth, as described by Sudduth et al. (1996). It was thought that the relationship of yield to soil and site parameters might be more predictable within these areas than across the entire field. The two relatively static parameters of elevation and topsoil depth were chosen because previous analysis indicated that these had the most consistent impact on yields of all the measured parameters in the dataset. To create the sub-field areas, each field was first divided into areas of low (<25 cm), medium, and high (>50 cm) topsoil depth. The medium and high topsoil depth areas were then subdivided into the lower 1/3 of the landscape and the higher 2/3 of the landscape.

Uniqueness of the Research Field

The field used for this evaluation is unique in that it has been the focus of extensive soil, landscape, and crop yield evaluation since 1992, but has not received any site-specific management. Kriged maps of plant-available potassium, phosphorus, and pH follow historical management patterns generally running in an east-west direction and range from low to high soil-test levels. Elevation decreases from the east and west sides to about the middle of the field and then decreases to the north end of the field. Most all surface runoff leaves the field at one point on the north end. Visually, soil fertility maps bear no resemblance to soils, elevation, or topsoil depth maps. This field provides a situation where potential water-related management zones determined by soil/landscape factors may contain both low and high soil-test levels.

Data Analysis

Analysis of variance was performed to determine how much yield variation was explained by the individual management zone methods. Linear correlation coefficients between yield and soil-test potassium, phosphorous, pH, and organic matter were determined by each zone for each method. In order to compare the management zone methods, a rating based upon significant (Ho: $R=0$ at $Pr=0.05$) area-weighted correlation coefficient was calculated. For example, if within a specific sub-field area defined by a management zone method the correlation between yield and a soil-test measurement was found to be significant ($R \neq 0$), then that R value was multiplied by the fraction of the field represented by that sub-field area. These area-weighted R values were then summed together for a management zone method. Significant negative correlations were included because we were interested in soil parameters that were potentially yield limiting as well as soil parameters colinear to other yield-limiting factors. Rating values were averaged across the 5 year period from 1993 to 1997.

RESULTS AND DISCUSSION

Soil survey procedures produced four unique soil maps (Figure 1). From the order 2 soil survey (IISS) to the most recent order 1 survey (ISS97), the amount of information gathered during surveys increased. This resulted in more soil mapping units with each survey. The soils used for each survey were similar, but again with each survey new soils were included to give a more detailed description of the field. Comparing the three order 1 soil surveys illustrates how difficult it is to obtain repeatable results using traditional soil survey methods.

The field was also classified into five potential management areas using the georeferenced and

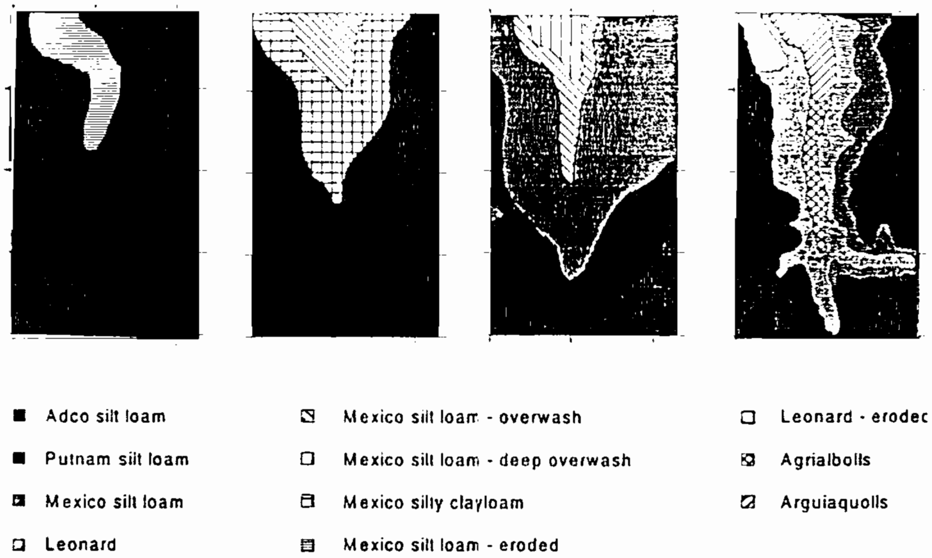

Figure 1. Soil surveys conducted on the research field. From left to right: order 2 soil survey done in 1989-91 (IISS); order 1 soil survey done in 1991(ISS91); order 1 soil survey done in 1993 (ISS93); "enhanced" order 1 soil survey done in 1997 (ISS97).

quantitative measures of topsoil depth and relative elevation (TD/ELE) (Figure 2). The five divisions using the TD/ELE classification method tend to be less continuous and have smaller areas (including some isolated 10 m cells) than the soil surveys. This can be attributed to the greater density of data collected for the TD/ELE method and the objective decision rules used to place each small area within a sub-field. An advantage to developing management zones using a procedure like TD/ELE is that you could expect a very similar map if measurements were repeated.

The four soil surveys (Figure 1) and the quantitative method (Figure 2) were each evaluated for determining management zones. Variation in grain yield was poorly explained ($R^2 \leq 0.11$) by all management zone methods for 1993, 1995, and 1996, years of adequate or excessive within-season rainfall (Table 1; Table 2). In years when precipitation was low and crop water stress occurred (1994 and 1997), more variation in yield was attributable to management zones (R^2 values no greater than 0.30). Management zone methods ISS93 and TD/ELE were the most consistent in accounting for yield variation.

Averaged area-weighted correlations were used to rate of how well each management zone method captured unique response areas (Table 3). The highest rating for any given soil-test parameter came from the order one soil surveys. Averaged over all four soil-test parameters the 1993 order one soil survey gave the greatest rating (ISS93) . This implies that the soil mapping units identified with this survey were the best at distinguishing potential management zones exhibiting relatively homogenous yield response to the measured soil parameters. The lack of variation between the ratings for the different methods and a rating done on a whole field basis for soil-test pH and organic matter suggests that either differences in these properties over the field were small, or that their influence on yield (or colinearity with other yield limiting factors) were small.

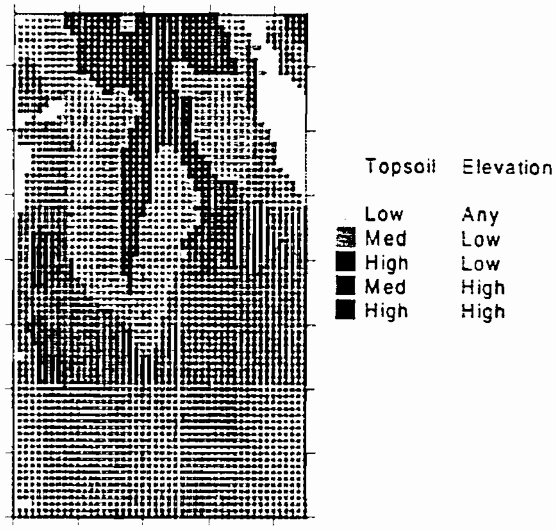

Figure 2. Management zones created by topsoil depth and elevation (TD/ELE).

The quantitative method using topsoil depth and elevation performed approximately equal to the order II soil survey. Ratings for drier years and/or years with corn or grain sorghum tended to be higher than those for wet years and/or in soybean (data not included).

Using this procedure to test these various management zone methods, no method was clearly better than the rest. Correlations were generally higher with management zone methods distinguishing small sub-field areas, but these areas also contained fewer cells usable for the correlation analysis. In calculating the ratings for Table 3, these small sub-fields gave little contribution to the area-weighted rating. Thus, a characteristic of this rating procedure is that a small area with a high R may contribute less to the overall rating than a large area with a much lower R.

CONCLUSIONS

This research field is unique because of the intensity and duration of spatially referenced yield and soil data, along with the absence of site-specific management. It is ideal for assessing yield-limiting factors. We were able to evaluate various soil surveys of the field along with a quantitative method of classifying sub-fields by inspecting correlations between yield and four soil-test parameters. Overall order I soil surveys gave the best results, but the improvements were not dramatic. On the other hand, because the TD/ELE method involves quantified and georeferenced measures in the field, it has the advantage of being repeatable, unlike traditional soil surveys. The order 2 soil survey (the level of soil survey generally available to farmers) was better than no sub-field delineation.

Table 1. Analysis of variance model R^2 values for grain yield using various management zone methods as classed variables for a Missouri claypan soil field.

Management Zone Method	1993 corn	1994 soybean	1995 sorghum	1996 soybean	1997 corn
IISS	0.01	0.06	0.05	<0.01	0.02
ISS91	<0.01	0.24	0.02	0.01	0.08
ISS93	0.05	0.30	0.11	<0.01	0.22
ISS97	0.02	0.23	0.11	0.05	0.13
TD/ELE	0.03	0.19	0.06	0.05	0.22

Table 2. Cropping season precipitation on study field.

Year	Crop	Apr	May	Jun	Jul	Aug	Sep	Total
		cm						
1993	corn	5.5	3.5	5.5	6.3	5.1	14.2	40.2
1994	soybean	10.2	1.2	3.5	0.4	1.6	2.4	19.3
1995	sorghum	5.5	10.2	6.7	2.8	6.7	2.4	34.3
1996	soybean	2.4	6.7	3.5	2.8	4.7	3.5	23.6
1997	corn	3.9	5.1	3.9	1.6	3.5	2.4	20.5

Table 3. Results of correlation analysis conducted between yield and soil-test measurements to compare four soil surveys and a quantitative method for determining stable year-to-year site-specific management zones. Table values are an area-weighted average of significant† |R| over 1993-1997.

Method	Potassium	Phosphorus	pH	organic matter	Mean Rating
whole field	0.035	0.046	0.121	0.090	0.073
IISS	0.052	0.090	0.141	0.094	0.094
ISS91	0.137	0.082	0.152	0.081	0.113
ISS93	0.117	0.153	0.126	0.093	0.122
ISS97	0.099	0.094	0.140	0.117	0.113
TD/ELE	0.078	0.095	0.106	0.083	0.091

† $R \neq 0$ at $Pr=0.05$.

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