Soil conductivity and panchromatic aerial photography as tools for the delineation of soil-water management zones

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Introduction

Precision irrigation may be defined as the placement of water in specific locations in specific amounts, as determined by the irrigator (Sadler and Camp, 1997). The use of precision irrigation allows the producer to lower input costs, thereby creating a larger profit margin. Alternatively, an inadequately managed irrigation system can become costly to operate and can damage the environment. It is impossible, however, to irrigate with precision, without knowledge of the soil-water management zones in a field.

Evans and Schneider (1996) define soil management zones as areas within a field that have been determined to be significantly different from neighboring areas. Once identified, producers can vary inputs such as seed, fertilizer or water in accordance to their yield target for each management zone. Soil-water management zones are management zones where irrigated water is the variable being adjusted.

Management zones represent the integration of detailed information regarding soil types, depth, texture, moisture, conductivity and crop type found in the field. Consequently, a database of soil characteristics becomes fundamental for the identification of the soil-water management zones.

The traditional method of developing a database of soil characteristics involves stratified (grid) soil sampling covering the entire field. Mohamed et al. (1996) suggest that the most efficient grid size is 60 square metres. This methodology has proven to be very successful, however the high laboratory costs make the procedure prohibitive for most producers (Franzen, 1998). More affordable alternatives for identifying management zones include the use of panchromatic aerial photography and soil conductivity.

Panchromatic aerial photography employs differences in tone within a photograph as indications of changes in soil moisture, organic matter content, textural variability and field topography (McCann et al., 1996). Soil-water management units are then operationally defined, based on these tonal differences.

The electrical conductivity of a substance is a measure of the difficulty or ease with which an electrical current can be made to flow through it (McNeill, 1980). Soil porosity, cation exchange capacity, moisture content, and colloid (clay) content affect soil conductivity. When soil is relatively dry, however, hygroscopic soil moisture coats colloidal surfaces and increases cation exchange capacity, thus clay content becomes the dominant factor effecting soil conductivity (McNeill, 1980).

Lund and Christy (1999) have demonstrated the benefits of using electrical conductivity as an index for soil properties. Conductivity measurements are collected and geo-referenced using the global positioning system (GPS). These data can then be displayed using a geographic information system (GIS) and included with other data such as yield maps and aerial photography to form the basis for management zone designation.

Objective

The intent of this study is to develop and evaluate two alternative methodologies for the identification of soil management zones within a field; the first based on measures of soil conductivity, and the second based on remotely sensed panchromatic aerial photography.

Study Area

The study area is located in an agricultural region of Southern Manitoba, approximately four kilometres southwest of the town of Sidney. Specifically, the southeast quarter of section thirty-one, township nine, range twelve west of the principle meridian (31-9-12W) . The field is bordered on the north and west by neighboring fields. A road runs past the south and east sides, and there are bushy areas on the northwest, southwest, and southeast corners of the study area (Figure 1). The topography is nearly level, and drainage is classified as good.

The soils are identified as Stockton Fine Sandy Loam, suitable for cultivation, but requiring careful management to prevent severe loss of soil productivity through wind erosion (Ehrlich et. al., 1957). Small grains and potatoes are commercially grown. The Stockton soils are generally low in organic matter reserve, water retention capacity and natural fertility (Ehrlich et. al., 1957).

Methodology

Soil Conductivity:

Soil conductivity data were collected in the spring of 1999 using a truck to pull a Geonics EM-31 attached to a trailer. The EM-31 had a differentially corrected GPS attached to it so that positional data could be collected at each sampling point. Conductivity data were gathered using two different measures, horizontal dipole and vertical dipole. Two thousand six hundred and fifty data points were collected on the quarter section (160 acres) study area (Figure 1). These data were stored in a text file and converted to a database file for import into ArcView 3.1 and ArcInfo 7 geographic information systems.

Yield Data:

The crop was harvested on September 24, 1999. Yield data were collected by a yield weight monitor on the potato harvester and recorded in hundredweight per acre (cwt A^{-1}). These data were stored in a text file and converted to a database file for import to ArcView and ArcInfo GIS.

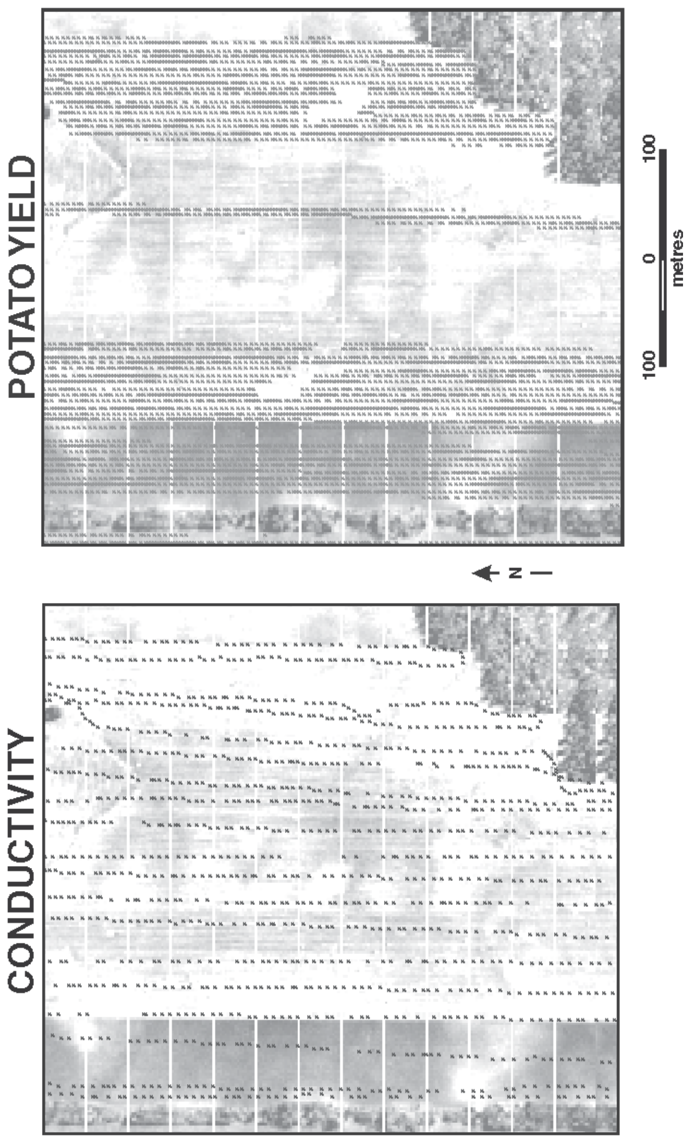

Figure 1: *Data collection points.*

Mechanical problems led to some yield data not being collected for portions of the study area (Figure 1). In addition, the yield monitor occasionally overestimated potato yield (weight) when large clumps of dirt traveled up the conveyor.

Panchromatic Aerial Photography:

The photograph, obtained from Linnet Geomatics International, was taken in October of 1997. A digital orthorectified image was produced by scanning the standard 1:60,000 contact print at 1000 dots per inch. The image was re-projected in the Universal Transverse Mercator (UTM) map projection, Zone 14, NAD83. The resulting image had a two-metre spatial resolution and eight-bit radiometric resolution. Each pixel was assigned a digital number (DN value) based on tone, ranging from zero (black) to two hundred fifty five (white).

Grid Interpolation:

Yield data and soil conductivity data were imported into ArcView 3.1 and ArcInfo 7 Geographic Information Systems. The inverse distance weighting algorithm (ArcView 3.1) was selected to interpolate grid layers for yield and conductivity since these variables are dependant upon local conditions and are more affected by local values than distant values (DeMers, 2000).

A grid cell of two-metres was selected to conform with the orthophotograph. The digital orthophotograph was converted from a tagged image file format (Tiff) to an ArcView/Info GRID file for comparison to the conductivity and yield values present in the other grids.

Cluster Analysis:

ArcInfo 7.4 and MultiSpec (Version 1.2000, Laboratory for Applied Remote Sensing, Purdue University) image analysis programs were used to create unsupervised clusters of soil conductivity values and panchromatic digital number values. An unsupervised classification was used to search for natural groupings or clusters of pixels having similar conductivity or spectral values, respectively.

The Iterative Self-Organizing Data Analysis Technique (ISODATA) was chosen as the most appropriate means of creating clusters to be evaluated as management zones in this study. The user determines the number of clusters to be created and the limiting convergence level. During the first iteration, cluster centers are arbitrarily defined and each pixel assigned to a cluster. During subsequent iterations, pixels are reassigned to the clusters with a mean DN value nearest to the respective pixel value in Euclidean space and a new mean is calculated for each cluster based on the actual location of the pixels. The algorithm continues until the designated convergence level (percent) is attained. This occurs when fewer than the specified number of pixels switch allegiance to another cluster (Jensen, 1996).

The panchromatic orthophotograph of the study area was classified three times using MultiSpec. The first unsupervised classification of DN values was directed to construct three clusters; the second classification, five clusters; and the final classification, nine clusters. The purpose of producing three different sets of clusters was to evaluate the separability between clusters. MultiSpec's transformed divergence function was used to evaluate the degree of separability of the resulting clusters. Each cluster was compared to every other cluster, generating a score between 0 and 2000. A score of 2000 represents complete separability, and a score of zero indicates no separability between clusters.

The ISODATA algorithm in ArcInfo was used to create unsupervised classifications of similar conductivity values from the conductivity grid. As with the panchromatic image, unsupervised classifications of three, five and nine clusters were constructed.

Analyses

Random File Generation:

ArcInfo was used to generate random sample files from the yield, DN, and conductivity clusters so as to conform to the assumptions of the subsequent statistical analyses.

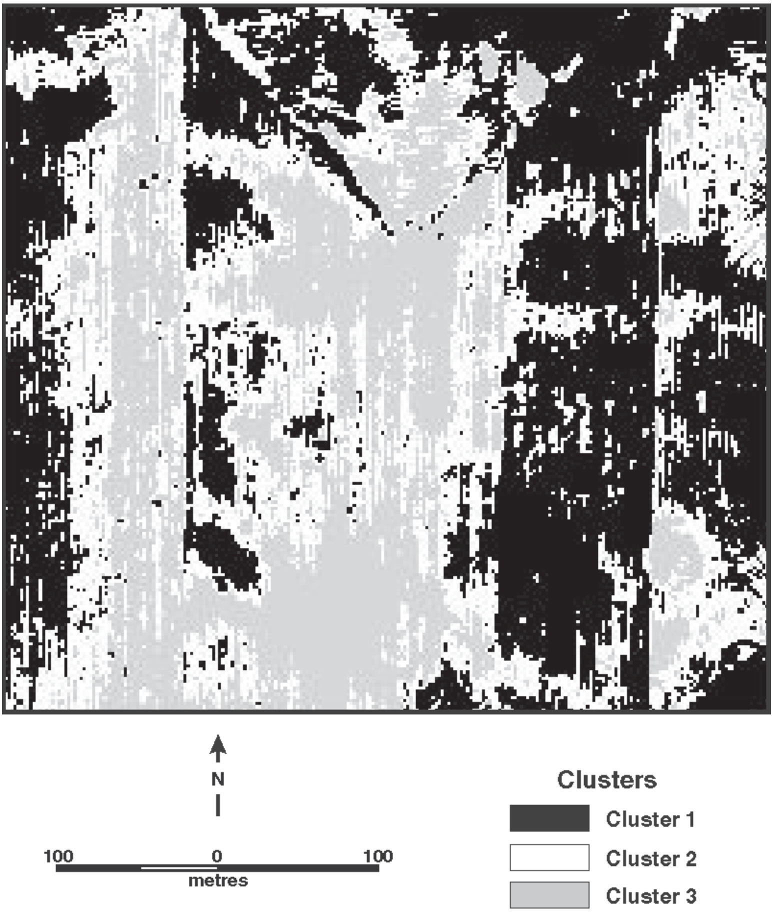

Figure 2: *An example of a digital number classification resulting in three clusters.*

Statistical Analysis:

The null hypothesis, that cluster means were derived from the same population, was statistically evaluated using the Analysis of Variance procedure (ANOVA) found in the Statistical package for the Social Sciences (SPSS). Random samples of yield and conductivity data, aggregated within the clusters derived from the panchromatic aerial photograph, were statistically evaluated to determine whether or not they came from the same population.

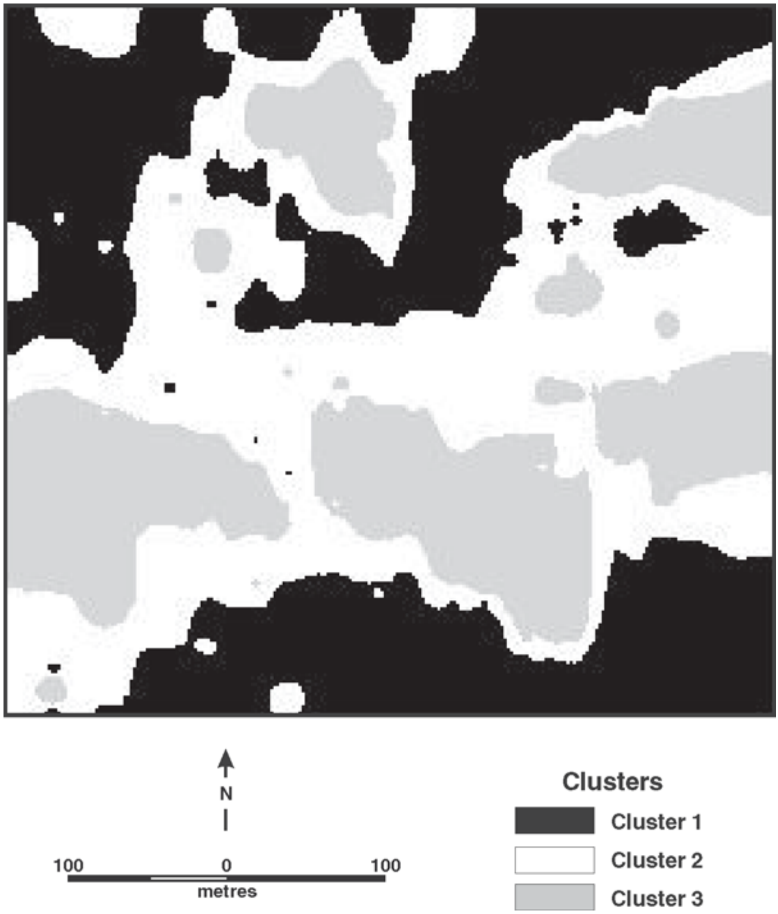

Figure 3: *An example of a soil conductivity classification resulting in three clusters.*

Next, random samples of yield and DN value, aggregated within the three different sets of conductivity clusters, were tested to determine whether or not they were derived from the same population.

ANOVA was used to test if any of the cluster means were derived from different populations. The ANOVA procedure, however, could not identify which clusters were similar. Tukey's "honestly significant difference" (HSD) post hoc test was run after the ANOVA procedure. This test identifies homogeneous subsets of clusters by organizing the cluster means into similar groups. Consequently, the Tukey's HSD test specifies the number of homogeneous subsets or groupings of clusters that are significantly different. It is hypothesized that these homogeneous subsets represent distinct soil-water management zones.

Results and Discussion

Variations in DN Value and Yield Data within Conductivity Clusters:

ANOVA indicated that the DN values aggregated within the three, five and nine conductivity clusters were significantly different. Tukey's HSD Tests suggested that no more than three homogeneous subsets were produced within any of the three, five or nine cluster classifications.

Similar results were reported when comparing yield data aggregated within the same three, five, and nine conductivity clusters. The three cluster conductivity classification produced two homogeneous yield subsets, five cluster classification gave three homogeneous subsets, and the nine cluster conductivity cluster classification resulted in four homogeneous subsets.

These results suggest that as many as four soil-water management zones can be identified based on variations in soil conductivity within the study area.

Variations in Conductivity and Yield Data within DN Value Clusters:

ANOVA indicated that the conductivity and yield values aggregated within the three, five and nine DN value clusters were significantly different. Tukey's HSD Tests indicate that digital number cluster classifications produced more homogeneous subsets than the conductivity cluster classifications. The three DN value cluster classification formed three homogeneous subsets of yield data. The five DN value cluster classification created five homogeneous yield subsets, and four homogeneous subsets were produced from nine DN cluster classification. Three homogeneous conductivity subsets were created from three DN value cluster classification, and four subsets were derived from the five DN value cluster classification. The nine DN value cluster classification produced five homogeneous conductivity subsets.

These results suggest that as many as five soil-water management zones can be identified based on variations in the spectral characteristics of the study area.

The clusters created using digital numbers produce a larger number of potential soil -water management zones than the conductivity clusters, although the results are similar between the two types of clusters. In neither case does the number of homogeneous subsets indicate that more than five soil-water management zones are present in the study area.

Conclusions

Results of this study suggest that soil conductivity data and panchromatic aerial photography can be incorporated into a GIS to delineate soil-water management zones for the precision application of irrigation water. The methodology proposed in this study represents a cost effective alternative for identifying these soil-water management zones.

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