LARGE SCALE MAPPING OF SOLONETZIC SOILS USING IMAGE ANALYSIS AND GLOBAL POSITIONING SYSTEMS (GPS)

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Abstract

Image analysis is a valuable tool that can be used to map soil properties that affect management practices in Solonetzic-Chemozemic soil landscapes. Because of the highly variable nature of these soil landscapes, only large-scale maps can provide the level of detail necessary for farm-scale planning. Image analysis of black and white aerial photographs can be used as a cost effective method to delineate soil landscape units within these soil landscapes. In this study, extensive field sampling and laboratory analysis were used to create a soil landscape model for a Brooking (Solonetzic)-Amulet (Chernozemic) soil landscape. Soil landscape units derived from this model were closely related to soil subgroups which in turn were associated with tonal variation on the scanned black and white aerial photograph. Image classification was achieved by grouping the digital values on the scanned photograph into classes based on soil landscape units. This procedure had a mapping accuracy of 7 1.4% at the specific sampling site pixel and 85.7% at a one pixel or 3 meter radius from the site. These levels of accuracy would indicate that this technique shows considerable promise for mapping soil landscape units within Solonetzic-Chemozemic map units.

Introduction

Solonetzic soils display characteristics that retard cereal production and rangeland productivity. In the Solonetzic soil order, the diagnostic feature is a dense, clay-enriched B horizon. Clay accumulation is facilitated by sodium-induced clay dispersion in the A horizon and the subsequent translocation to the B horizon. Because of the dense nature of the B horizon, root development is largely restricted to the ped exteriors. During periods of drought, the restricted rooting exacerbates plant drought stress, resulting in lower productivity.

Appropriate management practices can mitigate the degree to which root development is restricted. In order to implement appropriate management practices, farm managers must be able to identify soil landscape units where Solonetzic soils occur. Soil maps that are currently available in Saskatchewan provide valuable information for broad soil landscapes but they do not, however, contain the detail needed to delineate units within specific soil landscapes. The objective of this study is to determine if Image Analysis and Global Positioning Systems (GPS) can provide an accurate and inexpensive way to identify and delineate soil landscape units within Solonetzic-Chemozemic landscapes. If successful, this method of unit delineation can provide farm managers, environmental consultants, and government officials with the detailed information needed to manage the soil resource for the maximum benefit to society.

Methods and Materials

Studv Site Description

The study site is located 25 km north of Weybum, Saskatchewan (SW 36-10-14W2). Upper Cretaceous Shale from the Riding Mountain Formation form the bedrock surface at the site (Whitaker, 1974). Glacial processes have incorporated sodium rich shale from this formation into the parent material, creating a shale-modified glacial till. The sodium content of the parent material has been further augmented through the discharge of sodium rich groundwater from what appears to be a regional groundwater flow system. Concentration of sodium in the glacial till is reflected in the soil distribution across this landscape. Solonetzic Brooking soils dominate the lower portions of the landscape where sodium concentrations are the highest. On mid- and upper-slope positions, less sodium in the glacial till has facilitated the development of Chemozemic Amulet Soils. Soil profile distribution over this landscape appears to be largely determined by the degree of shale modification and groundwater influence.

Site Design

Extensive sampling was necessary to establish the relationship between photograph tonal patterns and soil properties. A grid sampling configuration was used as a guide during the data gathering procedure. Because of the cyclical soil distribution pattern from knoll to depression to knoll, the grids were positioned in a manner that would ensure that all the soils would be sampled in area covering one half cycle: the soil catena extending from a upper slope position down into a depression. At this site one half of the soil distribution cycle was encompassed within a 7 by 7 grid with a 25 meter sampling interval creating a 49 sample point grid.

Surveying and Sample Collection

Once the approximate grid positions were established within the landscape, the grids were then laid out, surveyed, and sampled. A theodolite and a measuring wheel were used to establish the points within the grids. A Total Station was used to gather topographic and positional information for both the sampling points and the topographic inflection points within and around the grid periphery. At each grid point, soil cores were extracted and extruded using a truck mounted coring apparatus. Once extruded, the soil cores were described using the Canadian System of Soil Classification (Agriculture Canada, 1978). Samples of the Ap and B horizons were taken for further analysis. Finally, in an effort to assess in situ soil salinity, EM 38 reading were taken at each site.

Before any of the soil data can used for image analysis, the sampling points must be georeferenced to the surrounding area with the use a coordinate system. In this study, Global Positioning System Units (GPS) were used to establish the UTM coordinates for comers of the sampling grids. In order to obtain an accuracy within 1 meter, Differential GPS measurements were taken using 2 Garmin II GPS units. One unit acted as a base station and was set up on an obstruction-free site near the comer of the section. The second instrument was used as a field unit and was deployed to gather positional information for the grid comers and road intersections in the surrounding area. The two instruments gathered positional data simultaneously and stored it within the units. The data were subsequently downloaded into a DOS-based computer where the UTM coordinates were established for each point through post processing.

Laboratorv Methods

The soil samples collected in the field were subjected to a series of analytical procedures that provided information needed to characterize the soils. A number of chemical properties were examined: inorganic carbon, organic carbon, exchangeable cations, water-soluble cations, and electrical conductivity. Physical components include particle size distribution and moisture content. Standard analytical techniques were used to gather all the information. The data generated from these procedures facilitated the classification and delineation of management units within the study areas.

Data Processing

The geographical and pedological data from the sites were processed to produce a soil landscape model representing the spatial distribution of soil properties. The first step in this process is to create a digital elevation model (DEM) using the survey data. A series of Fortram programs created by Pennock et al. 1987 were used in the formulation of the DEM and the subsequent calculation of seven landform elements that reflect the redistribution of both surface runoff and throughflow: (1) divergent shoulders, DSH; (2) convergent shoulders, CSH; (3) divergent backslopes, DBS; (4) convergent backslopes, CBS; (5) divergent footslopes, DFS; (6) convergent footslopes, CFS; and (7) level slopes, L. These landform elements were analysed in conjunction with the soil parent material and the pedological data to produce a soil landscape model for the site.

Image Analvsis

The image analysis techniques that were used in this study consists of 5 basic components: (1) image capture, (2) georeferencing, (3) enhancement, (4) analysis, and (5) classification. The first step in this process is image capture or the conversion of an aerial photograph to a digital image. The photograph for this site was obtained from Central Survey and Mapping Agency in Regina, Saskatchewan, Canada and was photographed at a scale of approximately 1:30,000. The photo was then scanned at a resolution of approximately 600 dots per inch with the use of a AGFA Arcus Scanning Device. The area of interest on each photo was delineated and saved as a digital image. Digital images are composed of a two dimensional array of pixels or grid cells. For black and white digital images, the grey tone of each pixel is expressed as a digital number ranging from 0 to 255 with 0 representing black and 255 white.

Before a digital image can be utilized in the image analysis process, the inherent distortion must be corrected through image rectification (ERDAS, 1991). This process involves the projecting of the data onto a plane, and making it conform to a map projection system. The technique utilizes ground control points that act as reference points from which the image points are corrected and assigned UTM coordinates.

Image enhancement is the process in which spatial and spectral enhancement techniques are used to make an image more interpretable for a particular application (ERDAS, 1991). In this study, three enhancement procedures were used on the image to improve its quality: (1) histogram matching, (2) low pass filtering, and (3) histogram stretching. Histogram matching was used to correct for different vegetative cover in areas outside the study site. A low pass filter was used to remove much of the random noise on the image caused by cultivation patterns and uneven straw distribution. Histogram stretching was used to increase the contrast of the image in an effort to facilitate classification.

Once the enhancement process was completed, the digital number for each sample point in the grid had to be established, analyzed, and grouped into categories. The sample grid was digitized and superimposed onto the enhanced image where the digital numbers for the sample sites were recorded. These numbers were then grouped according to the soil subgroup they represent. The soil subgroups were further categorized by using the groups from the soil landscape model as a guide. Box and whisker plots were used to identify and define the characteristic ranges of digital numbers associated with the observed landscape units. These ranges were used as training samples for the training or classification of the remaining unknown pixels in the image. Once all the pixels in the image had been reclassified, the categories were assigned colours that were used to produce a GIS map of the landscape units for the study area.

Results and Discussion

Soil Landscane Model Development

The spatial pattern of the soils at the study site appears to be controlled by three major factors: (1) surface form, (2) parent material, and (3) groundwater. In developing the soil landscape model, the relationship between these three factors was examined by grouping different combinations of them and then comparing the resulting categories to the soil subgroups. This process continued until a satisfactory separation of the soil subgroups was obtained (Table 1). The final soil landscape units were further validated by examining their association with a number of quantifiable soil properties.

Table 1. Intial Soil Landscape Units and Soil Subgroups.

	Shld	SmLevL	SmLevH	LgLevSl	LgLevM&H
Calcareous	0† (0)††	0 (0)	1 (11)	0 (0)	0 (0)
Eluviated	1 (11)	4 (40)	1 (11)	5 (83)	0 (0)
Orthic	5 (56)	1 (10)	6 (67)	0 (0)	0 (0)
Rego	1 (11)	0 (0)	0 (0)	0 (0)	0 (0)
Solod	1 (11)	3 (30)	0 (0)	0 (0)	2 (13)
Solonetz	1 (11)	1 (10)	0 (0)	1 (17)	0 (0)
Solodized Solonetz	0 (0)	1 (10)	1 (11)	0 (0)	13 (87)
Total	9 (18)	10 (20)	9 (19)	6 (12)	15 (31)

† Number of sites.
†† Percentage of site in soil landscape units.

The soil landscape units that were created for this study area are contained in Table 1. The shoulder complex (Shld) represent 18 % of the landscape with Chemozemic soils occupying 78% of the sites. This complex occupies the well drained higher positions in the landscape. The dominance of Chemozemic soils in this group reflects the relatively low exchangeable sodium levels (Figure 1) which can most likely be attributed to the slight to moderate shale modification of the parent material and the absence of any sodium enrichment from the groundwater flow system.

SmLevL and SmLevH represent level elements with small catchment areas: less than 54 m^2. The two classes are divided on the basis of elevation: SmLevL represents sites with elevations lower than 4.1 meters and SmLevH occurs on sites with elevations that are higher than 4.1 meters. SmLevL sites occupy 20% of the study area with Solods and Eluviated soils being the dominant soil subgroups (Table 1). The higher exchangeable sodium associated with this site (Figure 1) indicates that this landscape unit represents a transitional area in the landscape between slightly shale-modified parent material found in the higher positions and the moderate to highly shale-modified material in the lower landscape positions. In contrast, SmLevH sites have low exchangeable sodium levels (Figure 1) and are comprised of 89% Chemozemic soils (Table 1). The dominance of Chemozemic soils in this unit is indicative of slightly shale-modified parent material that has not been subjected to appreciable sodium enrichment. The lack of sodium enrichment combined with the low catchment area and high position in the landscape makes this unit comparable to the shoulder landscape unit.

Soil landscape units LgLevSl and LgLevM&H are level landform elements with large catchment areas: greater than 54 m^2. LgLevSl has slightly shale modified parent material whereas LgLevM&H sites contain parent material that is moderately and highly shale modified (Table 1).

The degree of shale modification is strongly reflected by the soil subgroups in each category. LgLevSl sites are dominated by Chemozemic Eluviated profiles whereas LgLevM&H sites are almost entirely comprised of Solodized Solonetz soils (Table 1). Exchangeable sodium data for these sites further supports the differentiation between these units on the basis of parent material: the LgLevSl sites have low levels of exchangeable sodium while the LgLevM&H have the highest levels of any of the landscape units (figure 1). These high exchangeable sodium levels facilitate the development of dense Bnt horizons that require special consideration from farm managers.

The soil landscape units illustrated in Table 1 formed the basis for the development of the final soil landscape units that were used to classify the digital image. The Shld and SmLevH units were combined because they are both dominated by Orthic Chemozemic soils that occur in the upper level and shoulder parts of the landscape on sites with small catchment areas (Figure 2). The Rego and Calcareous soils were separated from this group because they occupy the relatively dry, upper most portions of the landscape (Figure 2). SmLevL and LgLevSl units were amalgamated because they represent a transitional area between the Chemozemic soils on the upper landscape and the Solodized Solonetz soils of the LgLevM&H unit. Solodized Solonetz soils are the most problematic soils in this landscape and therefore, were not combined with any other landscape unit.

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Figure 1 Landscape Units & Exchangeable Sodium

Figure 2 Three Dimensional Depiction of the Soil Landscape

The soil surface organic carbon levels were examined for the final soil landscape units to determine the general trend in soil organic carbon across this landscape. In most prairie landscapes, soil organic and inorganic carbon largely dictate soil colour (Schmidt, 1993). The soil surface inorganic carbon levels at this site are very low (<0.3%) and therefore, are unlikely to have a direct influence on soil colour. In contrast, the organic carbon content within this landscape ranges from 1.0 to 2.8% (Figure 3). The lowest levels are associated with the upper parts of the landscape that are dominated by Rego, Calcareous, Orthic, and Solonetz soils. Higher levels of organic carbon are found in the lower level portions of the landscape that are dominated by Eluviated, Solodic, and Solodized Solonetz Soils.

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Figure 3 Final Soil Landscape Units & Organic Carbon

Digital Image Classification

Soil colour is reflected in the tonal pattern or digital values on grey scale digital images (Schmidt, 1993). In past studies, (Schmidt, 1993) Munsell Colour Charts have been used to measure the soil colour at different landscape positions. Munsell Colour data was gathered at this site but the colour range was too narrow (1 value unit) to differentiate between major landscape units. Munsell Colour units appear to be too coarse to detect the subtle tonal gradations across this landscape. In contrast, the enhanced digital image contains 160 gradations of grey across the study area and 255 within the entire quarter section.

The final soil landscape units correspond to distinct groups of digital numbers. Box and whisker interquartile ranges were used as guides to establish the digital number ranges associated with each soil landscape unit (Figure 4). The Calcareous-Rego unit had the highest digital numbers with a range from 182 to 223. These high numbers reflect the low organic carbon levels and slightly modified parent material that is present at these sites. The second highest digital number grouping represents the Orthic and Solonetz soils. Digital numbers associated with this groups range from 149 to 18 1. This range reflects the fact that these soil occupy relatively dry shoulder and level landscape elements with small catchment areas. Dry conditions result in relatively low organic carbon levels and high digital numbers. The range of digital numbers from 123 to 148 represent the transitional zone where Eluviated and Solodic soils are found. The higher catchment area associated with many of the soils in this group creates a relatively moist environment resulting in elevated organic carbon levels and lower digital numbers. Solodized Solonetz soils are represented by the lowest range of digital numbers at the study site: 21- 122. Despite having similar organic carbon levels as the Eluviated and Solod unit (Figure 3), the Solodized Solonetz unit's digital numbers are distinctly lower (Figure 4). Why the lower digital numbers? The highly shale modified parent material has a dark matrix that likely has reduced the digital number at these sites. Also, organic carbon from the Bnt horizon has been incorporated into the Ap horizon at a number of sites. This organic carbon may have different spectral properties than the organic carbon associated with Chernozemic soils and hence, produce lower digital numbers.

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Figure 4 Final Soil Landscape Units & Digital Numbers

The digital number groupings were utilized to classify the study area into soil landscape units. Classification accuracy was assessed by comparing site soil descriptions with the classified map. The accuracy for all the landscape units was 7 1.4% at the specific site pixel level. At a radius of 1 pixel or 3 meters from the sampling site, the accuracy improves to 85.7%. Of the individual units, the Solodized Solonetz and Orthic-Solonetz units both have accuracies of 80%. The Eluviated-Solod unit has an accuracy of 58.8% but increases to 76.5% when assessed on the basis of a one pixel radius around the sampling point. Because this unit represents a transitional zone, the boundaries between the units are quite convoluted. Therefore, the latter assessment of accuracy may be the most appropriate one for this unit. The accuracy for the Rego-Calcareous unit was only 50%. The low accuracy can be attributed to the low sample size: two.points The Calcareous site fell just below the unit's lower limit. Finally, no Gleysolic soils were included within the sampling grid so their accuracy data is not available. Training data for these soils was derived directly from the digital image. Once all the classification accuracies were established, the quarter section surrounding the study area was classified into soil landscape units (figure 5).

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Figure 5 Quarter Section Soil Landscape Map of the Weyburn Site

Conclusion

Image analysis of scanned panchromatic aerial photographs is an effective and inexpensive tool for deliniating soil landscape units within Solonetzic-Chemozemic landscapes. The level of accuracy and detail obtained with this method could otherwise be only achieved through a very detailed soil survey at considerable expense. Image analysis is not, however, a panacea. In order for the technique to be effective, the study area must be characterized with the use of existing soil survey information and ground truthing data. The 1: 100,000 scale soil survey information acts as a generally guide for the broad characterization of soil landscapes. Ground-truth data, when collected in conjunction with a GPS, provides the information needed to locate and establish the spectral properties of specific soil types within the soil landscape. Ground-truth data would not, however, need to be collected for all study sites with the same map unit. Once the spectral properties of a representative site were characterized, the information could easily be extrapolated to other sites with the same map unit. Utilizing image analyis in this manner should enable pedologists to extend the current series of 1: 100,000 soil maps to the quarter section scale.

References

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Schmidt, T. K. (1993). Mapping Soils in Saskatchewan at the Quarter-Section Level Using Image Analysis. M.Sc. Thesis. University of Saskatchewan, Saskatchewan, Canada.

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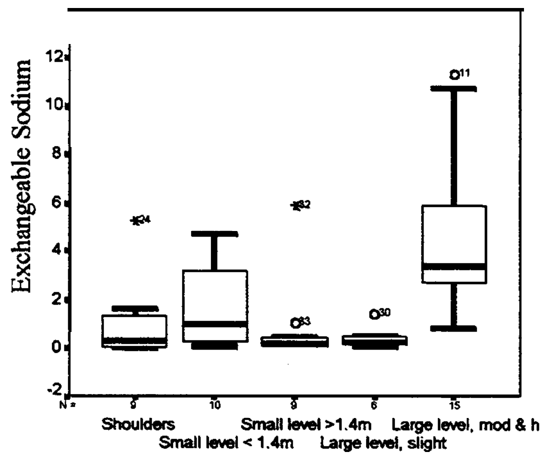
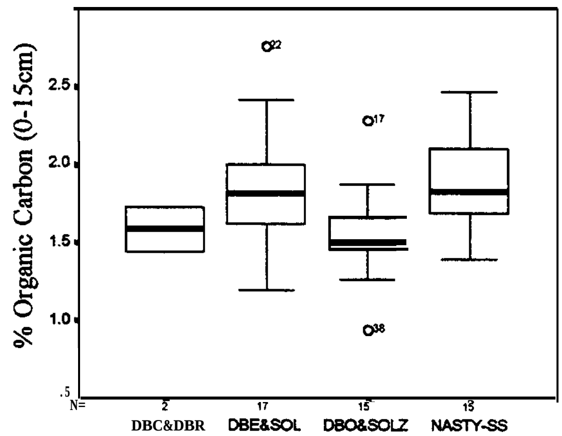
Soil Landscape Units & Exchangeable Sodium



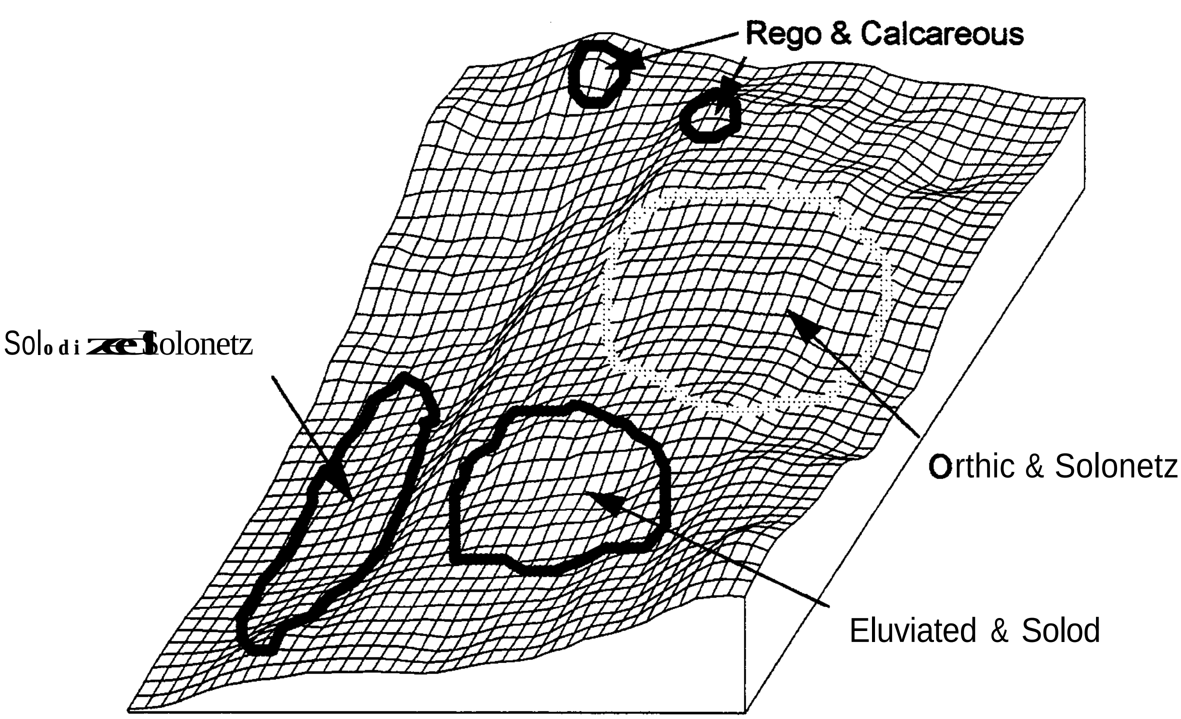
(Figure 1) Soil Landscape Units

Final Soil Landscape Units & Organic Carbon



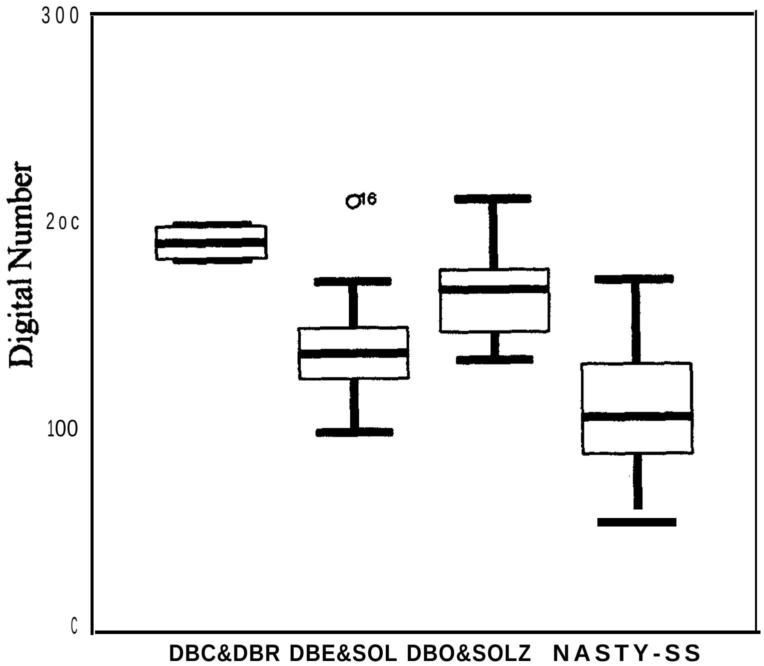
(Figure 3) Final Soil Landscape Units

Three Dimensional Depiction of the Soil Landscape



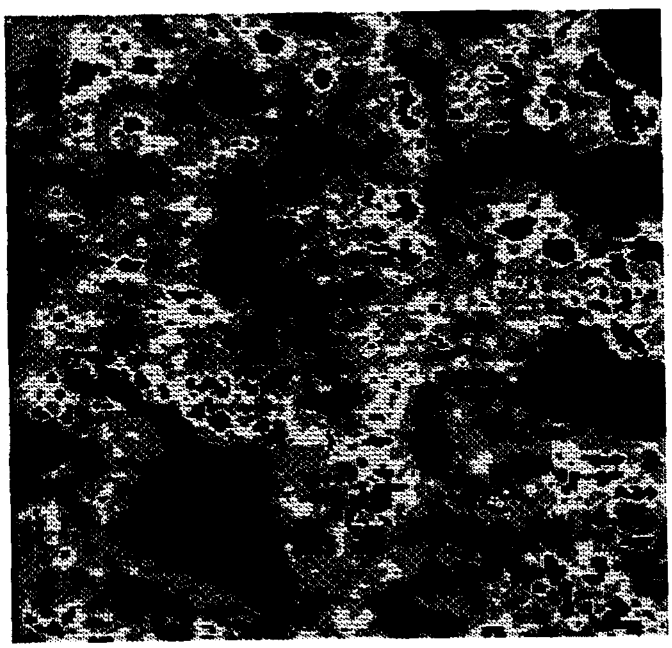
(Figure 2) 160 Meters 30 X Vertical Exaggeration

Final Soil Landscape Units & Digital Numbers



(Figure 4) Final Soil Landscape Units

Quarter Section Soil Landscape Map of the Weyburn Site



Legend

- Rego & Calcareous
- Solonetz & Orthic
- Solods & Eluviated
- Solodized Solonetz
- Gleysolic

(Figure 5)