Terrain Modeling to Improve Soil Survey in North Dakota

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ABSTRACT

Users of site-specific technologies would prefer to use digitized soil survey boundaries to help in delineating management zones for nutrient application. However, the present scale of soil type does not allow meaningful zone delineation. A project was conducted to use terrain modeling and other site-specific tools to delineate smaller-scale soil type boundaries that would be more useful for directing within-field nutrient management. Topography, soil EC, yield mapping and satellite imagery were useful in delineating possible soil type map units; however, present terrain modeling software does not allow the concept to be applied to its full potential.

Keywords: terrain modeling, soil survey

INTRODUCTION

North Dakota has completed its first generation of soil surveys at an Order 2 scale (1:20,000 to 1:25,000), and is now in the process of updating soil surveys. With the adoption of site-specific farming techniques and site-specific environmental and conservation practices, a finer spatial resolution of soil survey information, such as an Order 1 scale (approximately 1:10,000), would be more useful (Franzen et al., 2002). In addition, has been suggested that the future of soil conservation move in a more site-specific manner (Berry et al., 2003).

Traditional methods of maintaining and updating soil surveys are expensive and very time-consuming. At current staffing levels in North Dakota, updates of all soil surveys would take decades to complete (P. Benedict, NRCS North Dakota State Soil Scientist, personal communication, April 7, 2004). Traditional soil survey data are often not spatially explicit and accuracy of data is sometimes questionable, thereby limiting potential usefulness. Often, the conceptual models of soil formation used to predict soil distribution on the landscape are not transparent, making soil survey updates difficult.

Although National Cooperative Soil Survey (NCSS) Standards outline the process of quality assurance, there is no process for archiving the model that predicted soil distribution and there is no efficient method for assessing accuracy or data richness of the soil maps (Soil Survey Staff, 2007). Upon completion of a first generation soil survey project, soil scientists normally moved on to a new area and a new soil survey project. All conceptual models used in developing the soil map units and making the soil map moved with the soil scientists. Often, supporting data (soil and site descriptions and locations) were not maintained and eventually lost. Lastly, the traditional hard copy soil survey document is inflexible. Although some soil surveys are now available in digital format for use in a geographic information system (GIS), problems with flexibility and accuracy still exist.

Some studies have focused on gathering soil physical and chemical properties from transects and developing soil maps using computer models (Odeh et al., 1992). However, these transect procedures save little in field-time than would be necessary without the computer models.

A number of studies have used terrain-modeling to predict soil attributes. Terrain modeling uses relatively densely obtained elevations from areas of interest, and then using knowledge of the position of soils within the landscape to delineate maps and classify appropriate soils within the delineations. These terrain-modeling procedures are especially useful in placing appropriate soils in a landscape of known shape (Bell et al., 1992: Hudson, 1992; Gessler et al., 2000).

Because water movement through the soil and not just over the surface may often result in development of soils with different chemical properties, such as accumulation of carbonates for example, measures of relative crop growth may help differentiate soils within a landscape class. Multi-spectral, remotely sensed data, such as satellite-derived Landsat 7 Thematic Mapper data scenes may be additionally useful.

The Pedogenic Understanding Raster Classification (PURC) methodology (Cole and Boettinger, 2003; Cole and Boettinger, 2007; Saunders and Boettinger, 2007) uses GIS, remote sensing, and terrain analysis for mapping soils. The PURC methodology consists of a three-stage process to develop, refine, and test a digital model that predicts soil distribution on the landscape. The process involves acquiring elevation and remote sensing and classifying the data layers. The process then uses expert knowledge (from scientist familiar with the soils that might be present in such a landscape) and finally the set of maps is verified in the field.

The objective of this study was to use a combination of terrain analysis and other layers of data, especially remote satellite imagery or aerial photography, to delineate areas within fields that may represent soil map units at a scale much smaller than currently mapped.

MATERIALS AND METHODS

Thirteen sites were included in this study. The attributes available for use in terrain analysis within the PURC model are displayed in Table 1. Elevation, satellite image and aerial photograph were most commonly used. Results of only seven sites are included in this report.

Table 1. Sites with relevant data, the number of data-years and the types of data available for use in developing and testing Order 1 soil survey models.

Site	Years of data	Satellite NDVI	Aerial Photo	Soil EC Sensors	Topo 33-m. grid	Residual soil nitrate, 33-m grid
Beach	1	X		X	X	X
Gardner	3	X		X	X	X
Arthur	2	X	X	X	X	X
Valley City	10	X	X	X	X	X
Mandan	9	X	X	X	X	X
Minot	3	X	X	X	X	X
Williston	3	X	X	X	X	X
St. Thomas*	4	X	X	X	RTK GPS	X
Galchutt	4	X			X	X
Oakes	4	X	X	X	X	X

*St. Thomas site consists of four different fields studied through four years.

The elevation data was the most difficult data file to construct. The data acquisition was rather elementary; however, the manipulation of the data into landscape forms is currently difficult using ArcGIS, IDRISI© or Erdas Imagine. The two landscape surrogates used were the watershed and slope gradient toolboxes within ArcGIS. Neither of these two toolboxes configures the fields as our eye sees the landscape, but depending on the landscape, it comes closer than most other options. Although IDRISI provides landscape structure of points of data within the file, it fails to construct a 3-D zone of landscape structure as a soil surveyor would see the surface.

Each data set was partitioned into five classes (zones) based on quintals of the range of values. Images were based on the 0-256 range of color or darkness. The partitioning was conducted by input of the data into ArcGIS, then running the kriging operation with variogram parameters obtained through investigation of the dataset using GS+ for Windows 7.0 (Gamma Design Software, Plainwell, MI). The resulting five kriged zones were established with values of all grid points within a particular zone given the number (1-5) of the zone category. To layer data, the kriged map with five zones was imported into Erdas Imagine© as an .img file, and the one or more additional layers of data imported the same way. After the layering image file was created, the layered file was imported into the isodata clustering merge procedure in Imagine and the merged file img was created.

RESULTS AND DISCUSSION

Beach

The Beach site is a far-western North Dakota site located about 10 miles SE of Beach. The site is no-till and has been for many years in a diversified dryland grain rotation. The elevation range in the 14-ha field is over 7 meters. Figure 1 provides perspective of the general surface of the soil with landscape features of a higher plateau in the west and a plain that drains to the southeast in the center and east. A road borders the south edge of the field.

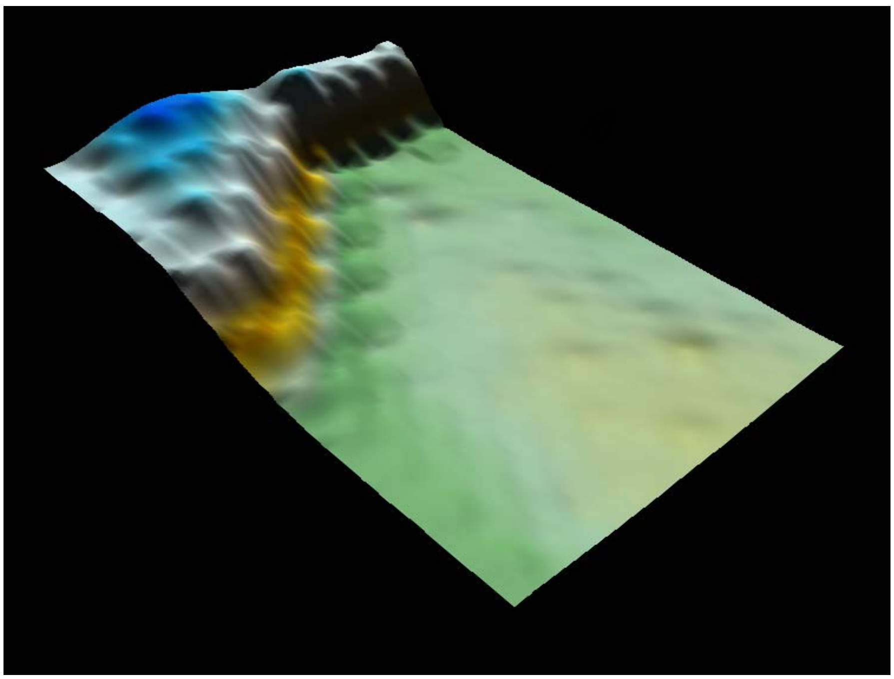
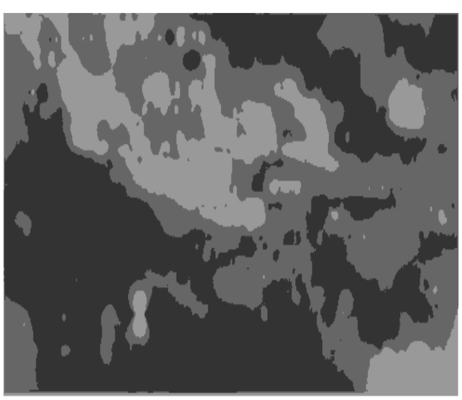


Figure 1. Beach, elevation displayed in a Surfer© (Golden Software Co., Golden, CO) surface map.



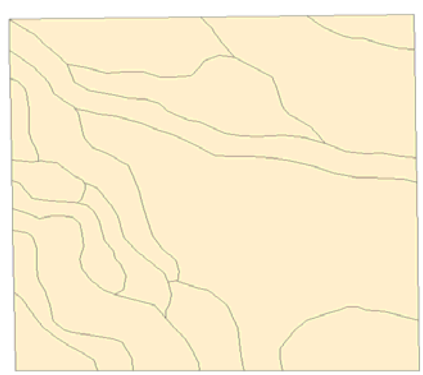


Figure 2. Beach, EC, elevation as watershed modeling and satellite imagery, clustered into zones using unsupervised classification in Imagine (left). NRCS

Order 1 soil map unit and phase boundaries independently surveyed in same area (right).

The classification in Figure 2 best described the locations of possible soil mapping units at an Order 1 scale. The plateau and slope are described in the SW, and the lowland in the center/NE is also differentiated. The slope gradient layered maps did not provide the detailing of this delineation.

Arthur

The Arthur site has only 3.5-m elevation differences from west (high) to east (low), and is located about 40-km NW of Fargo in the Red River Valley. The 12.5-ha field has been in a small grains and sugarbeet rotation for many years. The watershed model did not express the fine detail of soil differences (Figure 3). The slope gradient model generally better represented these fine soil differences in most Red River Valley sites (Arthur, St. Thomas, Galchutt).

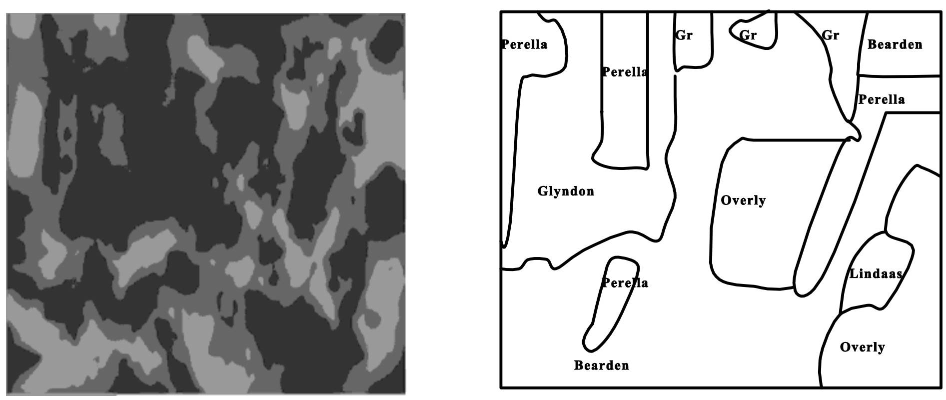


Figure 3. Arthur, slope gradient elevation model (left) with aerial photograph best described the soil map unit boundaries (right).

Galchutt

The Galchutt site has only 0.7-m elevation difference within the 12.5-ha field. The site is located in a coarser textured region of the Red River Valley about 50-km south of Fargo. The field has been in a corn-soybean-sugarbeet rotation for many years. The slope gradient elevation model with satellite imagery (Landsat 7) provided the best description of soil delineation of all the options constructed.

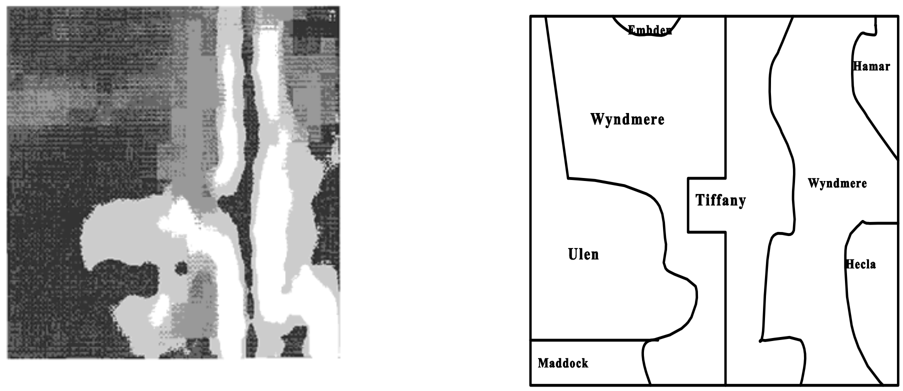


Figure 4. Galchutt, slope gradient elevation model with satellite imagery (left) compared with Order 1 soil survey of the field (right).

Gardner

The Gardner site has about 0.8-m elevation difference within the field, including the shallow drains that divide the 12.5-ha field into roughly thirds. The field has a history of alfalfa in the north third, with small grains in the south two-thirds. Within the last several years the smaller fields have been consolidated into one field with one crop covering the entire area each season. None of the delineation tools identified all of the soil map units found in the soil survey (Figure 5); however, the watershed elevation model and satellite image, and the soil EC mapping each showed major zones depicted in the survey (Figure 6).

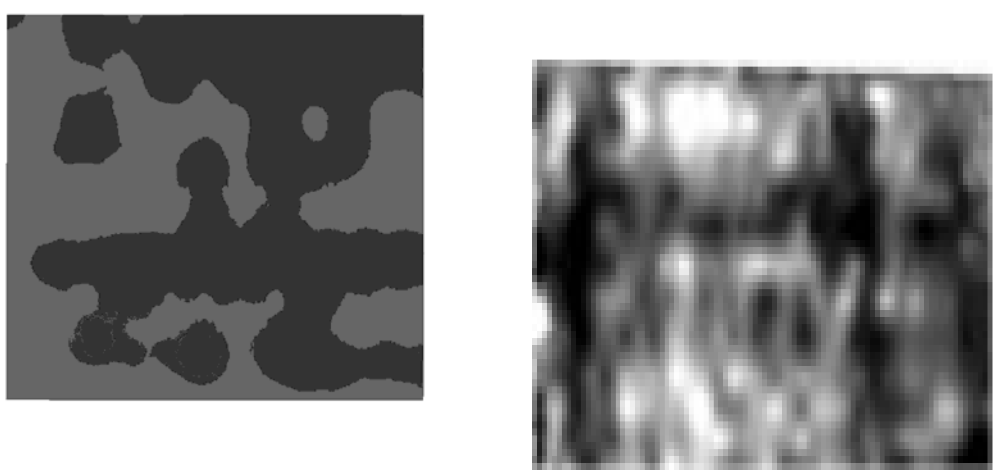


Figure 5. Gardner, watershed elevation model and satellite image (left), soil EC only (right).

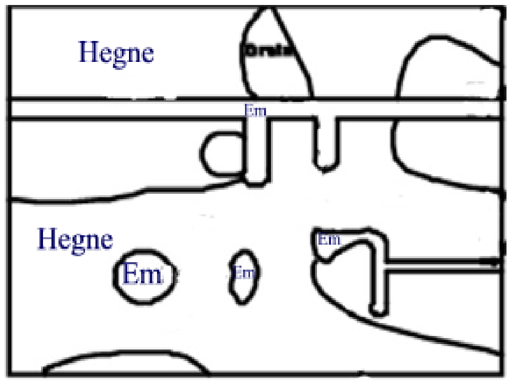


Figure 6. Gardner Order 1 soil survey.

Mandan

The Mandan site consisted of three fields within a larger 25-ha area. The fields were in a winter wheat, spring wheat, sunflower rotation for many years. The slope gradient and satellite image modeling best represented the Order 1 soils mapped by NRCS on the field (Figure 7).

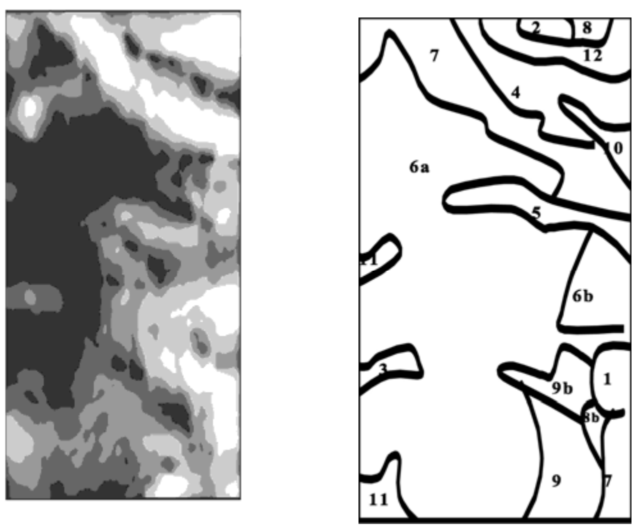
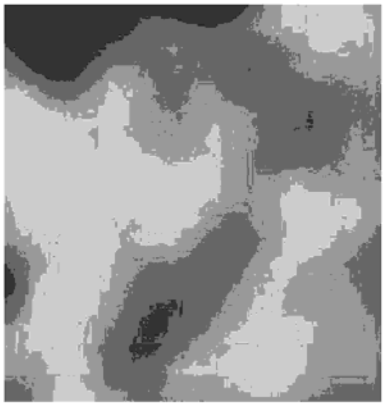


Figure 7. Slope gradient elevation modeling and satellite image (left) compared with Order 1 soil survey map unit delineation (right).

Valley City

The Valley City site has about 12-m elevation drop from the east side of the 12.5-ha field to the west side. The field has been in a no-till rotation of spring wheat, barley, and sunflower for many years. The slope gradient elevation model with satellite image provided the best representation of soil map unit delineations (Figure 8).



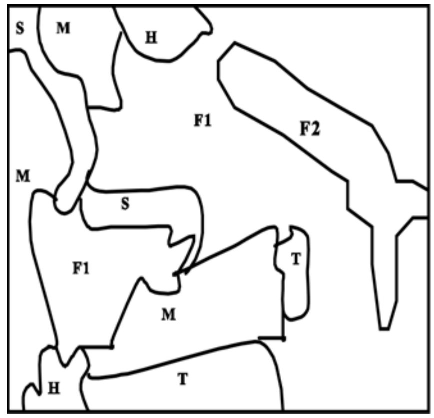


Figure 8. Valley City slope gradient model with satellite image compared with soil survey.

At both the Valley City site, watershed modeling of elevation did not perform adequately, since the general flow of water in the landscape was from west to east at Mandan, and east to west at Valley City. In long slopes, and in the Red River Valley fields, slope gradient tended to pick up subtle differences in slope that were important to pedogenesis, while watershed modeling did not.

Williston

The Williston field is a 12.5-ha area that has been in no-till continuous spring wheat for a number of years. The field is very similar in general topography to Beach, although the difference in elevation is about 10-m at Williston. The slope gradient elevation model with satellite image was the best depiction of soil survey delineations; however, the watershed model was very similar. Both are shown in Figure 9. The soil survey boundaries include phase delineations. It is probable that combining phases, as would be typical in Order 1 mapping, would increase the similarity of the soil survey with either of these delineation models.

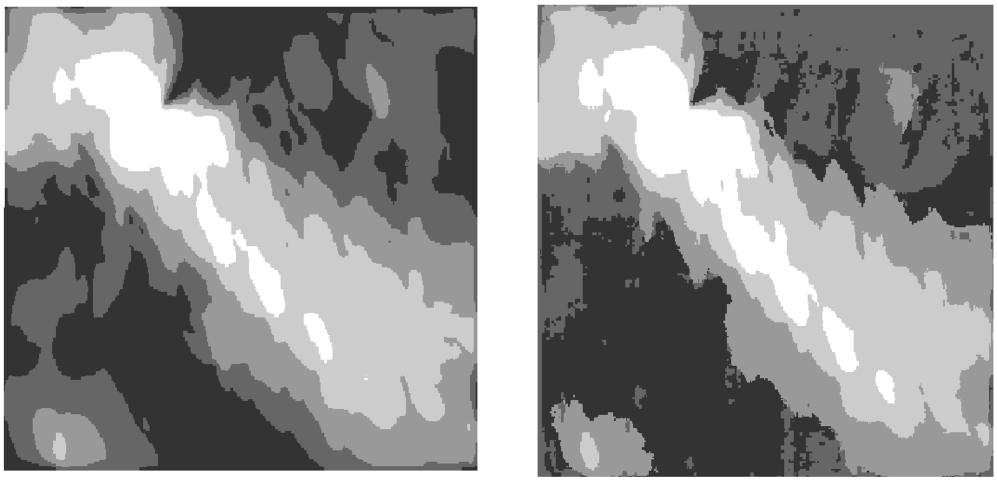


Figure 9. Williston with slope gradient elevation model and satellite image (left) and watershed elevation model and satellite image (right). Lower left of each model is a high plateau. The directional feature that is shown from upper left corner to lower left corner is a steep slope. The upper right is a lower plain.

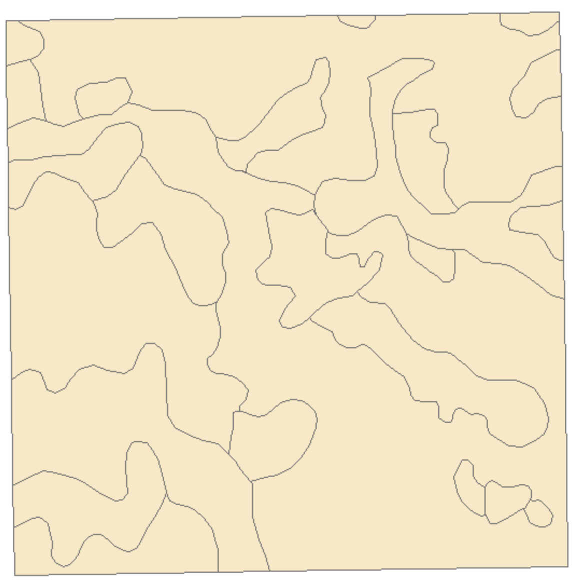


Figure 10. Williston Order 1 soil survey conducted by NRCS.

The slope gradient model was useful for fields that were characterized by nearly level landscapes and landscapes that tended to slope in one direction. The watershed model helped create better delineations of soil map unit boundaries in fields with multiple high and low areas. Satellite imagery was generally superior to the more densely detailed aerial photography except at Arthur, where smaller scale delineation was not provided by the slope gradient tool. Soil EC helped to explain soil map unit placement more than elevation modeling and aerial photography alone at Gardner. An aerial photograph was not available at comparison at this location.

SUMMARY

This study showed that elevation modeling and remote imagery could be helpful in delineating soil map unit boundaries for use by soil survey mapping. The next step in this process would be to provide soil surveyors with the model generated delineations, and then match soil map units into the zones. A better tool for defining landscape structure over what is available today in GIS software would help to better define these models.

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