A DECISION SUPPORT SYSTEM FOR SOIL PRODUCTIVITY AND EROSION IN POLK COUNTY, NEBRASKA

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ABSTRACT

GIS-based decision-support systems are powerful, new tools for assessing inherent soil productivity and potential erosion. This study integrates digital soil survey (SSURGO) information, climate, LandSat TM-derived land cover, and 30m digital elevation data (NEDS) to spatially model regions of soil productivity and highly erodible lands in Polk County, Nebraska. The approach combines soil productivity indices, derived from the "Soil Ratings for Plant Growth" (SRPG), and land cover to identify poorer quality soil landscapes in corn and soybean production. Models using the Revised Universal Soil-Loss Equation test possible conservation strategies to reduce soil-loss in areas with high potential erosion rates. These decision support tools target conservation needs at both the county and farm scales and hold promise for federal and state agencies.

INTRODUCTION

Land resource evaluation is the process of assessing the suitability of land for a specified kind of land use. Physical land evaluation can provide spatial information on the potentials and constraints of land for a particular use, such as crop production, natural resource conservation (e.g., riparian zone), and urban development. Land use planning relies upon the assessments of land and its specific attributes, such as climate, topography, hydrology, and soil (Bouma., 1989; Dumanski et al., 1986). In an agricultural context, soil quality is usually defined in terms of soil productivity, and specifically in regard to soil's capacity to sustain and nurture plant growth (Carter et al., 1997). Thus, from the perspective of agricultural crop production, soil quality can be defined as "*the soil's capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment*" (Gregorich and Acton, 1995). Although the basic concept behind soil quality is fitness of a soil for specific use, there is an ongoing attempt to more fully define soil quality. Based mainly on a definition of soil fertility introduced by Leopold (1949), Anderson and Gregorich (1984) proposed that soil quality could be defined as "*the sustained capability of a soil to accept, store and recycle water, nutrients and energy*." However, over the last decade, there has been a definitive shift in the way agricultural activities are perceived. No longer it is viewed as a closed operation, but rather as part of a much broader ecological system. This development is expressed in the expanded concept of soil quality evident in the work of Larson and Pierce (1991). They defined soil quality *as "the capacity of soil to function within its ecosystem boundaries and interact positively with the environment external to that ecosystem*."

A more detailed definition has been developed by the Soil Science Society of America (1995) and is stated as follows: "*soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation*"[79]. This definition is similar to that of Doran and Parkin. (1994) in which soil quality is the "*capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health*". These definitions imply that soil quality has two parts: an *intrinsic* part covering soil's inherent capacity for crop growth and a *dynamic* part influenced by the soil user or manager. Generally, dynamic soil quality changes in response to soil use and management (Larson and Pierce, 1994).

Inherent soil quality can be assessed by using national land resource or soil survey inventories (MacDonald et al., 1995; Soil Survey Staff, 2000). Huddleston (1984) indicated that the primary reason for initiating soil survey in U.S.A. was for the evaluation of soil productivity, which involves a blend of qualitative and quantitative rating models. Such databases can be analyzed in a computerized geographic information system (GIS) to develop broad regional assessments of inherent soil quality and landscape quality (Petersen et al., 1995). The USDA Natural

Resources Conservation Service (2000) has developed a national framework of inherent soil quality for application with the digital soil surveys (Soil Survey Geographic Database; SSURGO), which is termed the Soil Ratings for Plant Growth (SRPG; Sinclair et al. 1999). This arraying of soil map units draws upon physical, chemical, mineralogical, and landscape properties of soils to provide greater resolution to potential soil productivity.

Procedures for land resource assessment and evaluation of crop production potentials and risks have undergone many changes in the past several decades. The new concepts of land evaluation (Food and Agriculture Organization, 1974; 1976), integration of soil, climate, and land use information through Geographic Information Systems (GIS; Dumanski et al., 1996), and applications of models (Burrough, 1993), have made the information much more user-friendly and effective. To date, however, many land resource assessment studies have not fully capitalized on the opportunities presented by these new techniques in geospatial analysis and information management.

The objectives of this research were to: 1) test the geospatial context of a soil productivity assessment and new index of inherent soil quality (the SRPG); 2) define areas at a sub-county level where landscapes of similar soils and climate characteristics (agronomic behavior) that can be used to convey potentials and risks for crop production, 3) and identify landscapes vulnerable to water erosion and potential loss of productivity. More specifically, the research addresses the following applications of inherent soil quality and erosion modeling at the subcounty scale:

- How would a Soil Rating for Plant Growth be used with Landsat TM to define soil productivity regions at the sub-county level?
- How do potential crop yield potentials of soil landscapes derived by MUIR correlate with SRPG?
- How do erosion and cropping patterns at the detailed soil survey scale relate to SRPG?
- What interpretive maps of SRPG, Landsat TM-derived land cover, and terrain-modeling of erosion can be developed for decision support of conservation needs and practices.

The methods developed in this study will integrate existing digital datasets of soil, elevation, satellite imagery, climate, and infrastructure for assessing potential crop production, inherent soil quality, and soil-loss. Many of these data sets would be typically available for USDA Service Centers located in each county across the conterminous U.S. Polk County, Nebraska, served as the prototype study because of the availability of geospatial databases and its relevance to Nebraska's agriculture.

MATERIALS AND METHODS

Geographic Setting

Polk County is located in the east-central Nebraska (Figure 1) and falls within three Major Land Resource Areas (MLRA) (USDA-SCS, 1983). It is representative of the western Corn Belt, which largely consists of deep loess soils and dominantly irrigated agriculture. Sixty-nine percent of Polk County is associated with MLRA 75, the Central Loess Plains. The remainder of the county has parts of MLRA 102B, the Loess Uplands and Till Plains (26%), and the Nebraska Loess Hills (6%); MLRA 71. The county covers a total area of 282,287 acres (114,240 ha), in which corn-soybean rotations dominate the cropland. Corn is grown in an area of nearly 152,000 acres, of which about 71 percent is irrigated. In Polk County, about 54% (152,000 acres) of the total area is irrigated. The combination of deep loess soils coupled with an average of 3,372 growing degree-days (GDD) and 704 mm (27.71 in) of precipitation and supplemental irrigation, collectively contribute to highly productive environment for corn and soybeans (USDA/NASS, 1999). Polk County has a market value of agricultural production that exceeds $165 million, with livestock receipts totaling more than $100 million (USDA/NASS, 1999).

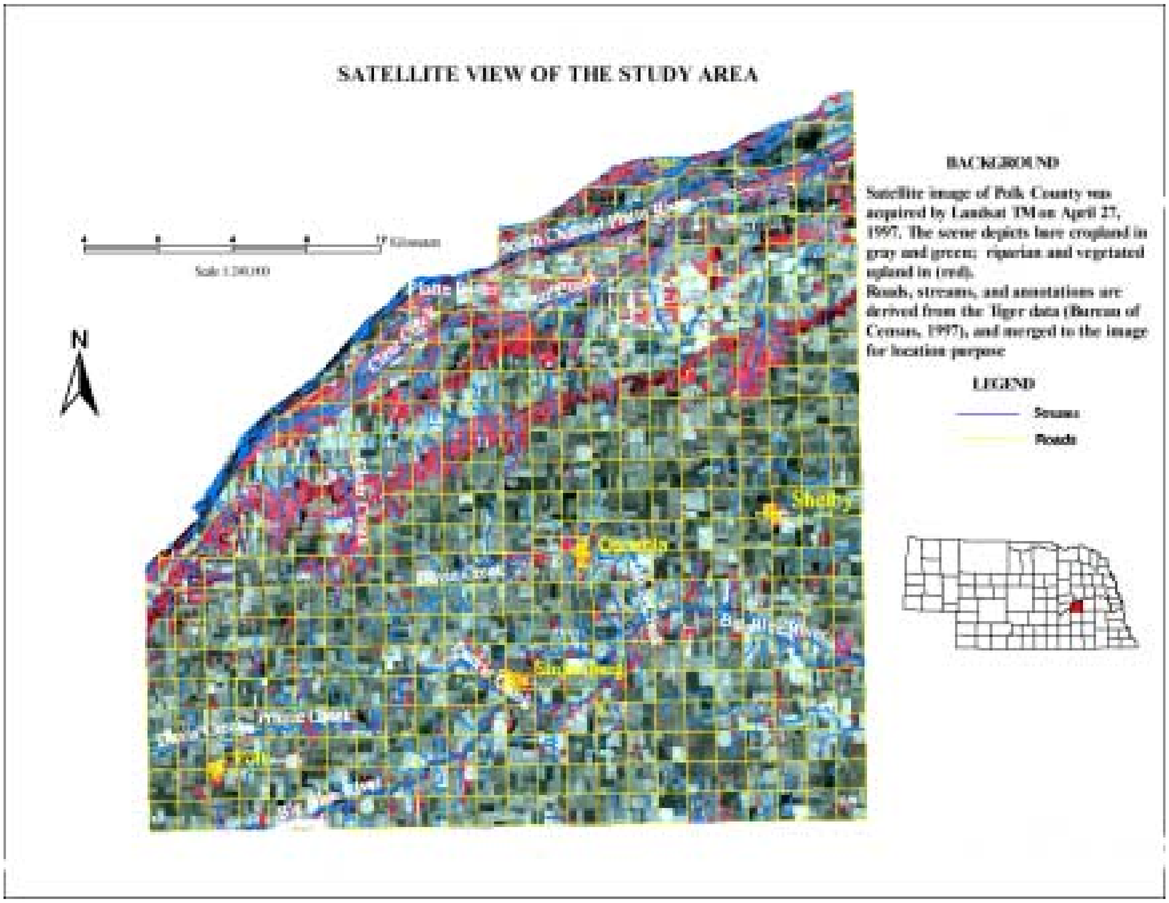


Figure 1. Landsat image of Polk County, Nebraska (inset).

Polk County's mid-continent location, elevation, and topography relative to the highly irrigated Platte River Valley is characteristically variable and a challenge to sustained high yields. About 74% (521 mm) of the mean annual precipitation falls during the growing season of April to September. Cooperative weather stations are located at the towns of Polk and Osceola. The Polk station has precipitation measurements available from 1948 to the present, while Osceola has a similar period of record with both temperature and precipitation data and therefore, was suitable for modeling soil climate regimes over the past 50 years.

The Osceola climate record would be representative of the Mesic, Typic Udic soil climate regime from the long-term averages. Figure 2 presents the Osceola climograph for the period of 1948 to 1997, as derived from the Newhall Simulation Model (Van Wambeke et al., 1992). The Osceola station has an annual water balance deficit of 20 mm (~1 in) and approximately 154 days where the soil moisture control section is moist and above 5^{o}C. The October to April recharge period fails to completely refill the soil profile. Drought events are an important part of the climate record in Polk County, particularly during the growing seasons of 1955, 1956, 1966, 1974, 1976, 1980, and 1989, when mean annual precipitation was less than 500 mm (20 in). The Soil Survey of Polk County, Nebraska (Seevers and Pollock, 1974), also provides some indication of the climatic variability as the Hastings soil series is classified as an Udic Argiustoll, or Udic/Ustic soil moisture regime. However, the dominant soil moisture regime is Typic Udic (46%) and Udic (Typic Udic plus Dry Tempudic) environments represent 56% of the total record. The Osceola weather station would fall fairly close to the pedocal/pedalfer line (where precipitation equals evapotranspiration) as described by Jenny (1941). Given the period of record for the Osceola weather station, mean annual precipitation ranged from 394 mm (15.5 in) to 1,056 mm (41.59 in). The 1988 to1989 period was the last extended drought in Polk County. In terms of growing season, Polk County has a lengthy frost-free period (158 days) and sufficient heat units (3,372) to support diversified cropping systems. Longer maturing corn hybrids and soybean varieties are well-adapted to these growing windows, given additional irrigation inputs.

The mean elevation of Polk County is 497-m (1,274 ft) and the degree of dissection is relatively limited, with elevations ranging from 437 to 543m. Most of the relief is constrained to the "breaks" or bluffs on the south border of the Platte River Valley. The bluffs make up a rough, steep area dissected by many intermittent drainageways and form a continuous band that varies from 0.3 to 2.5 km wide, with a maximum relief of approximately 47 m (150 ft). South of the breaks to the Platte River Valley is the nearly level, broad, loess-mantled upland that represents MLRA 75, the Central Loess Plains.

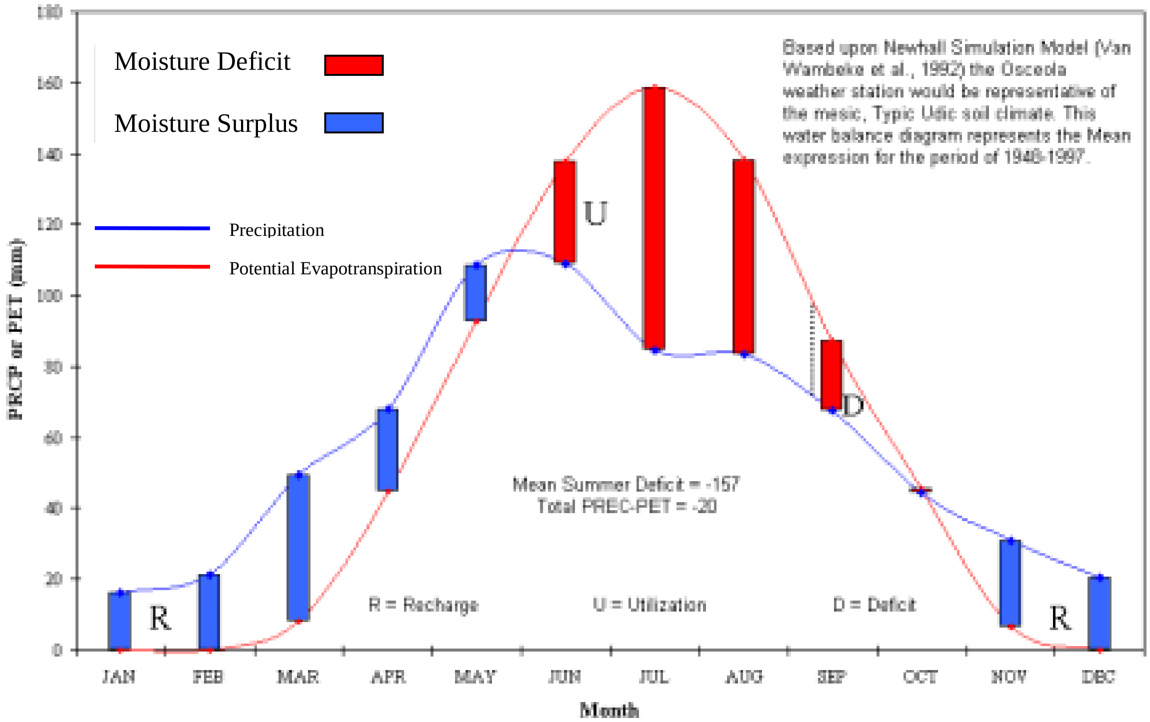


Figure 2 Climograph of the Osceola, Nebraska, weather station for the period of 1948 to 1997.

The soils in Polk County formed in three kinds of parent materials: loess, alluvium, and eolian sand. Loess is the most extensive soil parent material across the county (Seevers and Pollock, 1974). It is a light-gray or very pale brown, silty, windblown material that mantles all of the upland and a part of the Platte and Big Blue River Valleys. Across Polk County, loess thickness ranges from 25 to 45 feet. In the Platte River Valley, the loess deposits are thinner (generally range from 3 to 25 feet thick) and coarser-textured. In small areas on breaks to the Platte River Valley, an older pre-Wisconsinan windblown deposit known as the "Loveland Loess" is often exposed under the Wisconsinan Peoria Loess (Seevers and Pollock, 1974). Most of the soil material in the Platte River bottomland consists of sandy alluvial deposits on the floodplains and stream terraces. Re-worked sandy alluvium also occurs in the Platte River Valley forming small dunes on stream terraces.

Soil Productivity

While efforts to define and quantify soil quality and productivity are not new, establishing a consensus with regard to a set of standard conditions (soil properties) to be used for evaluation remains difficult (Karlen and Stott, 1994). USDA-NRCS staff developed the SRPG to quantify or rate soils suitability for plant growth at a county level (Soil Survey Staff, 2000). In this study SRPG is derived for SSURGO. The model calculations followed the "Storie Index Soil Rating" which was based on soil characteristics that govern the land's potential utilization and productive capacity (Storie, 1978). SRPG is based on twenty-five soil properties and landscape features. The system rates the major soil characteristics (physical, chemical, and biological) that are important for crop growth, and then combines the ratings into a soil rating, ranging form 0 to 100 (from low to high quality). The model recognizes extreme cases where a single soil characteristic can severely impact the suitability or productivity of the soil; such characteristics override all others.

The rating system, or the model, is unique in placing heavy reliance on combinations of geography, numerical and categorical soil property data, soil classification/taxonomy, and interpretations that are components of the SSURGO database. The SSURGO database (scale 1:24,000; Soil Survey Staff, 1995) was obtained from the Nebraska Natural Resource Commission (http://www.dnr.state.ne.us/). The soils data have been digitized and made available on the Internet for download in Arc export format. The SSURGO data and thematic maps were developed in the Universal Transverse Mercator projection, with a North American Datum of 1983. Then, tables of the inherent soil quality, root zone available water-holding capacity, and the effective rooting depth of soils derived as subcalculations from the SRPG (Soil Survey Staff, 2000) were processed and joined to the SSURGO database. MUIR data were obtained from Iowa Sate University Statistical Laboratories (http://www.statlab.iastate.edu/soils/muir/). Crop yield potentials of soils landscapes derived from this data were developed from a combination of field observations, site descriptions, and laboratory analyses (Soil Survey Staff, 1995). Irrigated and non-irrigated corn and sorghum potential yield data were extracted from their tabular format, and merged into SSURGO coverage. The crop yield interpretions derived from MUIR and SSURGO databases represent a static concept based on normal climatic conditions and long-term productivity.

Landsat TM Data Classification

Landsat TM images were obtained from EROS Data Center. Subsets of the study area were extracted from images obtained on April 27th, July 16th and October 4th 1997. These images were rectified and projected to Universal Transverse Mercator (UTM). Multiple dates were used to extract land cover/ land use information of the growing season of 1997. The U.S Geological Survey Land Use/Land Cover classification scheme is adopted in this study, and the classification process followed the methodology developed by CALMIT for the Cooperative Hydrology Study (COHYST) in 1999. The COHYST approach of classification depends on both *in situ* observations and interpretation of remote sensing data. Digital image processing included the use of the supervised classification process, whereby training sites that were representative of the land cover classes of interest were acquired through *in situ* information and on-screen seeding. The optimum spectral bands for land use/land cover classification; determined through graphic methods of feature selection such as bar graph spectral plots; included the green, red, and near infrared bands of each image. These bands were extracted from each image and merged into a single 9-band data set for use in the classification procedure. The maximum likelihood algorithm was applied to assign an unknown pixel to one of a number of classes, resulting in a classified image-map of Polk County (Fig. 3).

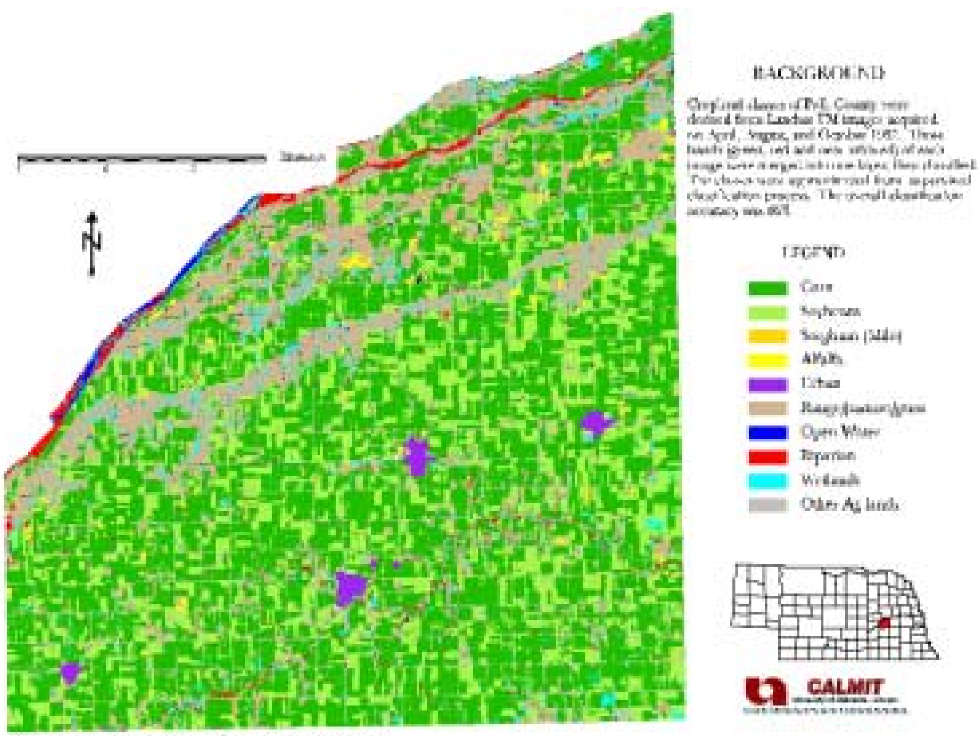


Figure 3 Land cover classes of 1997 growing season

Classification accuracy assessment was performed to compare the classified remotely sensed map and the reference test information. The relationship between these two sets of information is summarized in Table 3.4. The producer's accuracy is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data. The result is a probability of a reference pixel being correctly classified and is a measure of omission error. The user's accuracy is the total number of correct pixels in a category divided by the total number of pixels that were actually classified in that category; the result is a measure of commission error. The overall obtained classification accuracy is about 86%.

Soil Erosion Analysis

Effective control of soil erosion requires ability to quantitatively predict the amount of soil loss that would occur under alternate management strategies and practices. The model with the greatest acceptance and use is the Revised Universal Soil-Loss equation (RUSLE; Renard et al., 1997), which has its origin in the work by Wischmeier and Smith (1965;1978). The RUSLE states that the field soil-loss in tons per acre is the product of six causative factors:

$$A = R*K*LS*C*P \qquad (1)$$

Where, A = soil loss in tons per acre per year;
R = rainfall factor; K = soil-erodibility factor; L = slope-length factor;
S = slope-gradient factor; C = cropping-management factor; P = Conservation practice factor

This study implemented the RUSLE model geospatially by assigning each cell (30 x 30 m) a value for each causative factor and then computing the soil-loss in tons per acre per year. The input parameters to RUSLE were derived from the USGS National Elevation Dataset (1999), SSURGO (Soil Survey Staff, 1995), and the Landsat land cover and projected to the UTM coordinate system.

RESULTS AND DISCUSSION

Geospatial Analysis of Soil Resources

Inherent soil quality layer, and potential corn and sorghum yield layer were converted from vector to raster so as to perform some spatial and statistical analysis. The raster layers were analyzed to calculate areas of inherent soil quality and corn or sorghum production (Table 1; Figure 3.9). Simple regression analysis is conducted on the soil quality ratings, and the potential crop yields data to estimate the relationship between the two data sets (Table 1). Areas with similar soils and climate characteristics to predict potentials and risks of crop production were defined, and the analysis for SRPG and SSURGO data was useful in classifying the county soils into quality classes and assesses its crop yield potentials. The inherent soil quality map shows about 63% of the county soil landscapes have been rated between 70 to 100. About 90% of the county has 10 to 14 inches of root zone available water-holding capacity, and about 95% of the county lands have effective rooting depth between 41 to 60. The study found that there were significant relationships between soil quality rated by SRPG and potential crop yield estimated by MUIR record ($r^2 \cong 0.7$) (Figures 4a and 4b; Table 1), based on long-term records.

Some soil survey map units in the county were not rated and consisted of water bodies, gravel pits, and others, which cover an area of about 2,089 acres (Figure 4a). In addition, some soils in the northern part of the county within the Platte River Valley and a few small, scattered patches were rated very low, between 25-29 and cover an area of about 13,889 acres. The highest soil quality class rated by SRPG system ranges between 95 to 100. Only one soil map unit is found in this category; the Hord silt loam, 0 to 1 percent slope (Hd). This map unit covers an area of 13,307 acres (approximately 4% of the county total area) and consists of deep, well-drained, medium-textured soils formed in alluvium on stream terraces in the Platte River Valley and the Blue River Valley. Risks of crop production on these soils are few, therefore nearly all the acreage is under cultivation. Most of Polk County soils (176,878 acres; 63% of the county) were rated over 70 by the SRPG index, and about 25% of the total county area (69,337 ac) was rated between 85 to 89.

Table 1. Relationship between SRPG indices and MUIR-derived corn and sorghum yields under irrigated and nonirrigated management.

Relationships	R^2 Values
SRPG indices and MUIR records for non-irrigated corn yield	0.7327
SRPG indices and MUIR records for irrigated corn yield	0.7379
SRPG indices and MUIR records for non-irrigated sorghum yield	0.6793
SRPG indices and MUIR records for irrigated sorghum yield	0.7316

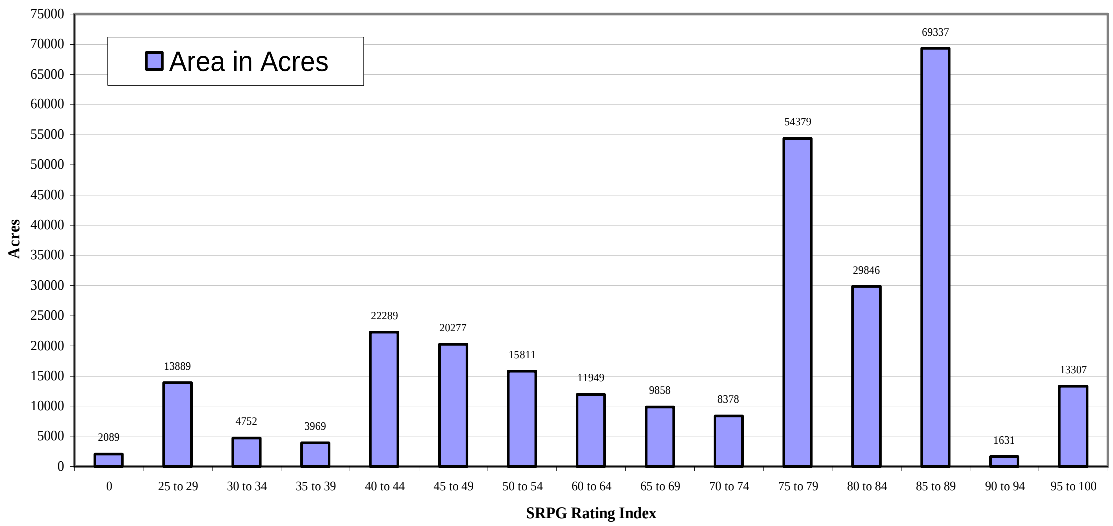
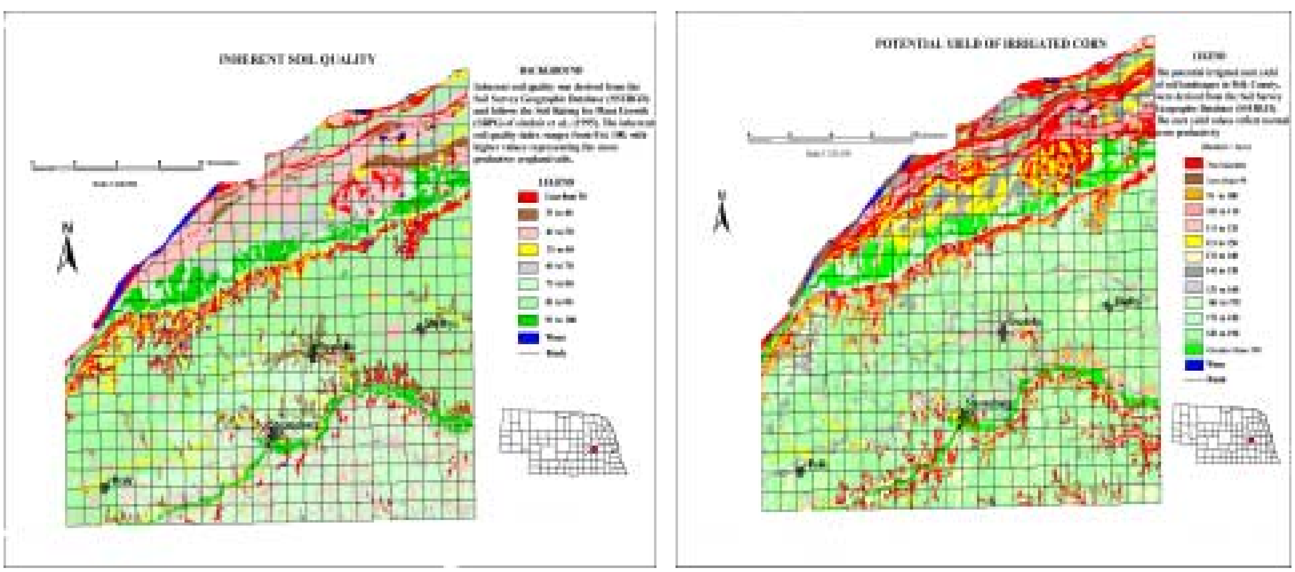


Figure 3.9. Distribution of soil landscapes as rated by SRPG



(a) (b)

Figure 4a and 4b. Inherent soil quality (SRPG) and potential yield of irrigated corn in Polk County, Nebraska.

The comparative evaluation between inherent soil quality and areas of crops grown in 1997, derived from the classified Landsat TM image shows that very small patches (7%) of soils rated less than 30 by SRPG were cultivated in 1997, whereas, most of the areas rated between 90 to 100 were used for crop production. In general, corn was produced on areas rated more than 70. Soils rated 60 or less, were mainly cultivated with irrigation management, particularly in areas of sandy alluvium by the Platte River Valley where root zone available water-holding capacity is low. From the classified TM data and MUIR records for potential irrigated corn yield, the carrying capacity of land grown in corn in 1997, was estimated 21,714,250 bushels. This is within 5% of the actual corn production reported by USDA's National Agricultural Statistics Service (NASS, 1999) for Polk County, which was about 20,871,400 bushels. Based upon the 1997 TM-derived land cover, most of the county land was used for corn and soybeans production, about 150,000 and 61,000 acres respectively.

The SSURGO database also provides tools for identifying soil characteristics and qualities associated with riparian ecosystems. For instance, in Polk County, there are about 7,332 acres of high quality soils (rated 70 or higher). On the other hand, about 6,055 acres of riparian areas were associated with poorer soil quality (SRPG > 30) on the alluvial plain of the Platte River. The riparian areas with low quality soils could be targeted to USDA programs for buffer strips.

Potential Erosion of Landscapes

The K factor values, which quantify the cohesion of a soil and its ability to resist being dislodged and transported due to raindrop energy, were obtained from SSURGO data (Figure 5a). In general, K-factors range from 0.03 to 0.69 for major soil types, and are inherently tied to the soil parent materials. For example, alluvial sands have values of 0.10, whereas loess-derived surfaces (silt and loams) have values of 0.38, and are more susceptible to erosion.

The R-factor or the erosivity index is calculated from the annual summation of rainfall energy in every storm (correlates with raindrop size) times its maximum 30-minutes intensity. The erosivity index varies geographically and temporally, and for Polk County an average erosivity index for the period 1961 to 1990 was developed using values derived from 10 precipitation stations around and within the study area. The Inverse Distance Weighting (IDW) interpolation algorithm was used to create the R-factor coverage because orographic and topographic effects were not significant in Polk County.

The slope length and the slope steepness factors (LS) are defined as the topographic factor. Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or runoff becomes concentrate in a defined channel (Wischmeier and Smith, 1978). Steeper slopes produce higher overland flow velocities. Both slope length and steepness substantially affect sheet and rill erosion estimated by the RUSLE, and are usually evaluated together for predicting erosion. In this study, these values were computed for each soil type from the following functional relationship:

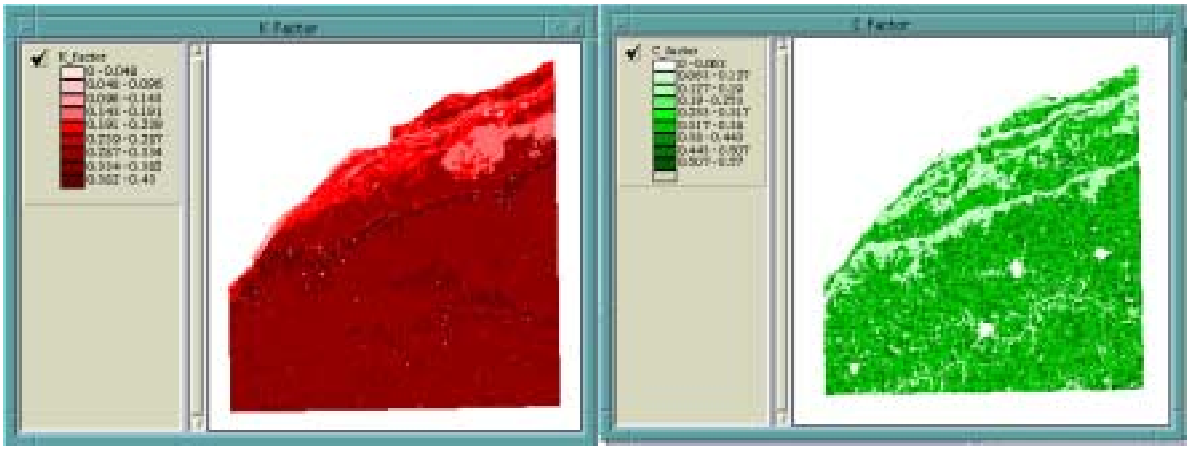
$$LS = \left(\frac{\lambda}{72.6}\right)^{0.3}\left(65.41\sin^2\theta + 4.56\sin\theta + 0.065\right) \qquad (2)$$

Where, λ = slope length, and θ = slope degree.

The slope length and the slope coverages were combined to produce a final LS-factor coverage.

The C factor or the crop management factor in RUSLE is the ratio of soil loss from land cropped under specified conditions (crop type and tillage management) to the corresponding loss from continuously fallow or tilled-land (Renard et al., 1996). This factor measures the combined effect of all the interrelated cover (leaf area and its phenology) and management variables. To derive a spatial distribution map of the C-factor, the land cover classes of the crops grown in 1997 were obtained from the classified Landsat TM image, and assigned to their corresponding C-factors (Figure 5b; Table 2).

The Conservation Practice Factor (P-factor) describes the reduction in soil erosion attributable to conservation structures, such as contour strip cropping and terracing. In this study, a P-factor was set equal to 1.0, assuming inherent erosion rates without major conservation practices. Although there were no digital data sets that captured conservation structures on the landscape, the digital orthophotographs can serve as a background image for interpreting terraces and contour strips, which could be manually digitized to modify P-factor assumptions.



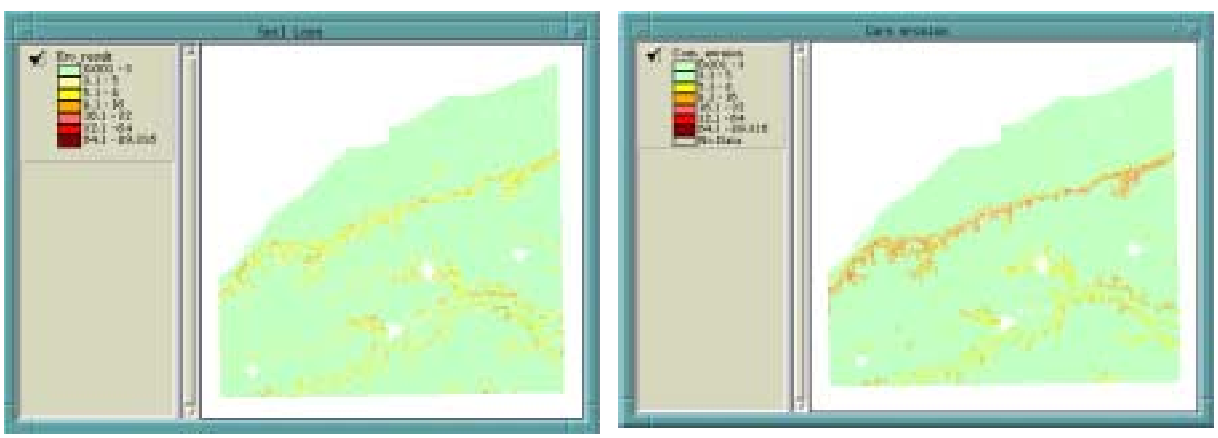
Figures 5a and 5b. Comparison of K-factor and C-factor maps of Polk County, Nebraska.

Table 2. RUSLE C-factor values for specific crops in Polk County, Nebraska.

Land Cover	C-Factor Value
Corn	0.31
Soybeans	0.41
Alfalfa	0.20
Range / Grass / Riparian	0.13
Wetland	0.003

Once the data for all five factors were produced in a geospatial format, the soil-loss (tons/ acre/year) was computed (Fig. 6a). In addition, soil-loss potential was also calculated assuming that a single crop was grown throughout the county - e.g., corn or soybeans (Fig. 6b). Areas that exceed soil-loss tolerance (T) or usually more than 5 tons/acre/year would require additional conservation practices, while those exceeding 8 tons/acre/year would be considered highly-erodible lands (HEL).

From the RUSLE calculations, the Clear Creek Watershed which covers an area of 72,434 acres was predicted to generate about 368,482 tons of soil/acre/year if the land was used for mixed-crop production, such as corn, soybeans, and alfalfa. This watershed has the highest potential for soil erosion in Polk County due to the length and the steepness of the slopes (LS-factor) and the highly erodible soils (K-factor). Soybean production contributes to the highest soil-loss in all watersheds within Polk County. Watersheds (14-digits) were delineated from the digital elevation model (USGS; 1999) and soil erosion was summarized across individual drainage basins.



(a) (b)

Figure 6. Soil-loss (tons/acre/year) based upon current crop cover (a) and if the cropland was planted in corn (b).

SUMMARY AND CONCLUSIONS

Procedures for land resource assessment and evaluation of crop production potentials and risks have undergone many changes in the past several decades. However, many land resource assessment studies have not fully capitalized on the opportunities presented by the available spatial data and the techniques in spatial data modeling, such as in GIS. This study integrated spatial data for land resource evaluation and production risks proved that the Soil Rating for Plant Growth (SRPG) model, in conjunction with Soil Survey Geographic Database (SSURGO) could provide an improved methodology for soil quality and productivity assessment. Using these data and other ancillary spatial information in a GIS environment, it was possible to identify similar soil characteristics that can be used to predict potentials and risk of land for specific crop production. This methodology can be useful to land use planners, seed companies, crop insurance companies, county assessors, and other users to obtain information about the soil productive capacity of any specific geographic area and identify risks of land use.

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