AN ABSTRACT OF THE THESIS OF

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Title: Carbon Dynamics as a Function of Land Use in Eastern Kansas: Implications for Carbon Storage in Mollisols.

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Soils are recognized as an important source and/or sink for atmospheric CO_2. The role of soil in the carbon cycle is currently a topic of renewed focus, as causes of possible global climate change and the role of greenhouse gasses continue to be debated. In either capacity, source or sink, we have limited understanding of the effects of soil erosion and land use practices designed to enhance soil carbon assimilation at a variety of spatial scales.

Because eastern Kansas contains abundant carbon-rich soils (Mollisols) and holds a relatively short agricultural land use history (150+/- years), it presents an ideal environment for study of land use effects on soil carbon dynamics and erosion recovery. The site identified for this study (near Gridley, in Coffey County, Kansas) contains untilled soil with native prairie vegetation adjacent to an area that had been farmed with traditional agricultural tillage methods in the past. The land previously farmed (from the late 1880's) had been seriously eroded, abandoned from row crop agriculture, and

reseeded with native grasses and forbs. This portion of the site has remained unfarmed since the late 1940's. This study investigated the changes in soil carbon dynamics present at the site as a result of changes in land use practices.

Sixteen soil cores were described along two transects that traversed the previously tilled and untilled portions of the study area to characterize spatial changes in soil thickness and horizonation. Ninety-two sample sites provided 197 systematic and random soil samples. These samples were analyzed by the Kansas State University Soil Testing Laboratory for soil organic carbon, total carbon and soil nitrogen data. Surface bulk density data were gathered from the native and the eroded soil using the core method. Topographic data were determined with transit and stadia rod in seven transects spaced every ten meters. Bedrock data were determined from soil characterization core information. All data, including recorded GPS information, were entered into spreadsheet form for use in map making and graphing, as well as for statistical analysis.

Comparison of soil thickness data lead to the conclusion that erosion, accelerated by the activities associated with traditional farming methods, physically removed the original A horizon and the upper part of the original AB horizon from the northern (eroded) part of the study site. Concentrations of nitrogen, total carbon, and total organic carbon were found to be significantly higher ($\alpha = 0.05$) in samples from the upper 40 cm of the untilled soil than in samples from the upper 40 cm of the eroded soil. Concentrations of the same three components in samples taken from the 41-80 cm interval at each site yielded significantly higher concentrations of total organic carbon in the native soil. There were, however, no statistically significant differences in the nitrogen nor in the total carbon concentration between the two land uses. Comparisons were made of the 0-40 cm intervals of the eroded section with the 41-80 cm intervals of the untilled soil's samples to determine whether or not a statistically significant difference exists for the same three soil elements. The results indicated that the percent of the three elements from the surface horizons of the eroded soils were significantly different (higher) from the native soils. If erosional processes removed the original surface horizon from the northern portion of the study site, then the present surface there is actually the sub-surface (Bt) horizon of the original soil, and the concentrations of nitrogen, total carbon, and total organic carbon would be similar. Similarities or differences could be determined by comparing the surface horizon of the previously eroded area with the sub-surface (Bt) horizon of the untilled soil.

It is concluded that while traditional agriculture is responsible for many soil degrading impacts, it may have actually contributed to sub-surface soil quality by mixing surface soil with underlying horizons. It is also possible that erosion may not have removed all organic matter originally present prior to tilling activities. Additionally, it is concluded that the soil is showing clear signs of recovery since having been left unplowed for the past 50+ years.

CARBON DYNAMICS AS A FUNCTION OF LAND USE IN EASTERN KANSAS: IMPLICATION FOR CARBON STORAGE IN MOLLISOLS

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INTRODUCTION

The agricultural land use practices of the past hundred-plus years on prairie soils of eastern Kansas have yielded abundant crops. While this success has been enjoyed by many, it is these same anthropogenic practices that result in a noticeable acceleration of soil erosion. In one response to the visible loss of valuable soil, generations of farmers choose to remove the affected parcels from crop production, reseeding them to native or tame grasses. In addition to these voluntary practices, and beginning as early as 1956 with the Soil Bank programs, state and federal governments have offered programs with monetary incentives designed to protect cropland from the accelerated erosion caused by agricultural land use.

While these initial responses dealt with resolving the problems of the physical removal of soil, more recent environmental concerns have included other issues. Scientific interests in more clearly defining and more efficiently maintaining soil quality are related to efforts to preserve soil as a valuable natural resource. Debates about increasing amounts of greenhouse gasses and the possible resulting global climate change necessitate a better understanding of the global carbon budget, and these debates have prompted further research into the role of soil in this ongoing discussion. Soils are recognized as an important source and/or sink for atmospheric CO_2, with some estimates allowing that soil organic carbon accounts for approximately two thirds of the carbon pool in the entire terrestrial biosphere (Allmaras et al., 2000). In any capacity, seen as a source and/or as a sink, the reseeding of eroded or highly eroded soil can have significant effects, yet our understanding of these effects on the enhancement of soil quality and long term carbon dynamics is limited.

Because Eastern Kansas contains abundant carbon-rich soils (Mollisols), and holds a relatively short agricultural land use history (150 +/- years), it presents an ideal environment for further study of these land use effects on soil carbon dynamics and soil quality. It is a common practice to reseed at-risk acreage to grasses (either independently or under Government programs), and nearby fields offer ideal locations for studying areas of native soils directly adjacent to eroded and reseeded soils.

The purpose of this research is to study the differences in soil carbon content present at a site that are the result of the changes in land management practices. Changes in soil properties affecting soil quality, carbon storage, and rates of soil recovery may be more clearly understood by comparing soil organic carbon, soil horizon thickness, and surface bulk density data from untilled soil and from soils that have been eroded and that are currently recovering. Additionally, this may help to define carbon budgets on a field scale more accurately, thus enhancing our knowledge of global carbon budgets.

Chapter 2:

SOIL CARBON: WHY THE ATTENTION?

There is growing concern that anthropogenic activity has contributed, and continues to contribute to increasing amounts of greenhouse gases in our atmosphere, with possible impact on global climate (Potter et al., 1999; Feng et al., 2002). In addition to the impact of the Industrial Revolution and the burning of fossil fuels, the activities of culling forests, draining wetlands, and tilling grasslands for agricultural uses have released millions of tons of carbon into the atmosphere. Concurrently, trees that remove and store tons of carbon from the atmosphere each year have been harvested for use as lumber or simply burned to clear forested land for settlement and agriculture. These practices leave soil increasingly vulnerable to erosion. Tillage results in a decrease in soil organic carbon content as some carbon is physically removed with the detachment, transportation and deposition of eroded soils. Additional carbon is lost through exposure and oxidation of soil, ultimately reducing the amounts of carbon stored in terrestrial carbon pools (Lal et al., 1999). To fully appreciate the significance of these changes, a more complete discussion of the carbon cycle, the effects of erosion, the impacts of tillage and the implications of these processes for global climate concerns is helpful. Government policies and the findings of similar studies are also discussed.

The Carbon Cycle

It is becoming increasingly important to explore and understand carbon cycling. Smith et al. (2001: 697) stated that the "major processes accounting for carbon flux in the terrestrial biosphere (primary production and respiration) cycle carbon between organic matter and CO_2 at rates of ~60 gigatons per year globally". The carbon cycle is all-inclusive because it involves not only the soil and its teeming microscopic fauna and flora, as well as macroscopic plants of every description, but also all larger animal life, including humans (Brady, 1990). Carbon changes phase between gas (mostly carbon dioxide, CO_2, and methane, CH_4) and solid as it moves through its cycle, from the atmosphere to the earth and back. Plant production converts CO_2 from the atmosphere into chemical compounds in plant tissue (such as carbohydrates) through photosynthesis, with part of the gas being returned to the atmosphere through respiration. Humans and other higher animals obtain energy and body tissue from plant products, and their wastes, including exhaled CO_2, and residues join plant litter and can eventually return to the soil. Macro- and micro-organisms digest these organic materials, releasing nutrients for plants and releasing part of the remaining organic carbon into the atmosphere and soil as CH_4 and CO_2. The balance of this carbon is stored in the soils as soil organic matter, including humus, and is relatively stable.

Rice (2000) indicated the importance of the conversion atmospheric carbon to soil organic carbon and into soil humus, because humus then becomes part of the recalcitrant, or longer lasting, soil carbon pool. Studies have indicated that as a result of this process, soils that support living plants have the potential to sequester enough carbon globally, for a long enough time, to slow the rate of atmospheric CO_2 accumulation (Izaurralde et al., 2001). Soils are, therefore, potential carbon sequestration sinks (places where carbon might be stored after removal from the atmosphere) that might be managed for maximum benefits. Studies also indicate much of the naturally sequestered CO_2 lost from the soil carbon reservoir through agricultural and other land use practices might be retrieved most successfully when these land use practices are altered to mimic nature's patterns more closely (Uri, 2001). Eve, et al. (2002) wrote that it is critical for land managers to understand how management alternatives will impact soil carbon storage. Low- and no-till farming practices reflect a move toward this awareness, and these practices are discussed in further text.

Some carbonates and bicarbonates of calcium ($CaCO_3$ and $Ca(HCO_3)_2$), magnesium ($MgCO_3$ and $Mg(HCO_3)_2$), and potassium (K_2CO_3 and $KHCO_3$) commonly found in soil are removed through leaching or mineralization. Eventually some of this removed carbon returns to the cycle in the form of CO_2 released into the atmosphere where it is again available for plant assimilation (Brady, 1990). Another component of the cycle, but not included in this study, is aquatic plants. Specialized microorganisms decompose plant residue, with any carbon remaining in the plant residue accumulating in accordance with a given water body's characteristics. In addition, it should be mentioned that volcanic out-gassing is a natural source of atmospheric CO_2, though amounts and frequency of contributions are unpredictable, and that air laden with sulfur dioxide pollutants can produce acid rain which can also react with carbonate rocks releasing additional CO_2 into the atmosphere.

Figure 1 illustrates a simplified version of the global carbon cycle with emphasis placed on the pools of carbon that have major interaction with the atmosphere. In this figure, the numbers shown in the boxes represent gigatons (billion metric tons) of carbon stored in the various reservoirs while the numbers next to the arrows indicate gigatons of carbon flowing from one pool to another each year. The estimates used in this depiction show a clear imbalance between the amount of carbon entering the soil and that amount which leaves the soil. In addition, the burning of fossil fuel contributes to the imbalance of carbon into the atmosphere – an imbalance only partially offset by increased absorption by oceans. Although numbers vary slightly in each different published study, the trends reflect similar patterns (Brady and Weil, 2002; Delgado and Follett, 2002; Rosenzweig and Hillel, 2000; Lal et al., 1999; Eswaran et al., 1993; Bohn, 1976). The discrepancy in specific numbers of gigatons of carbon in each pool may be a result of the most recent information available to the authors at the time of publication.

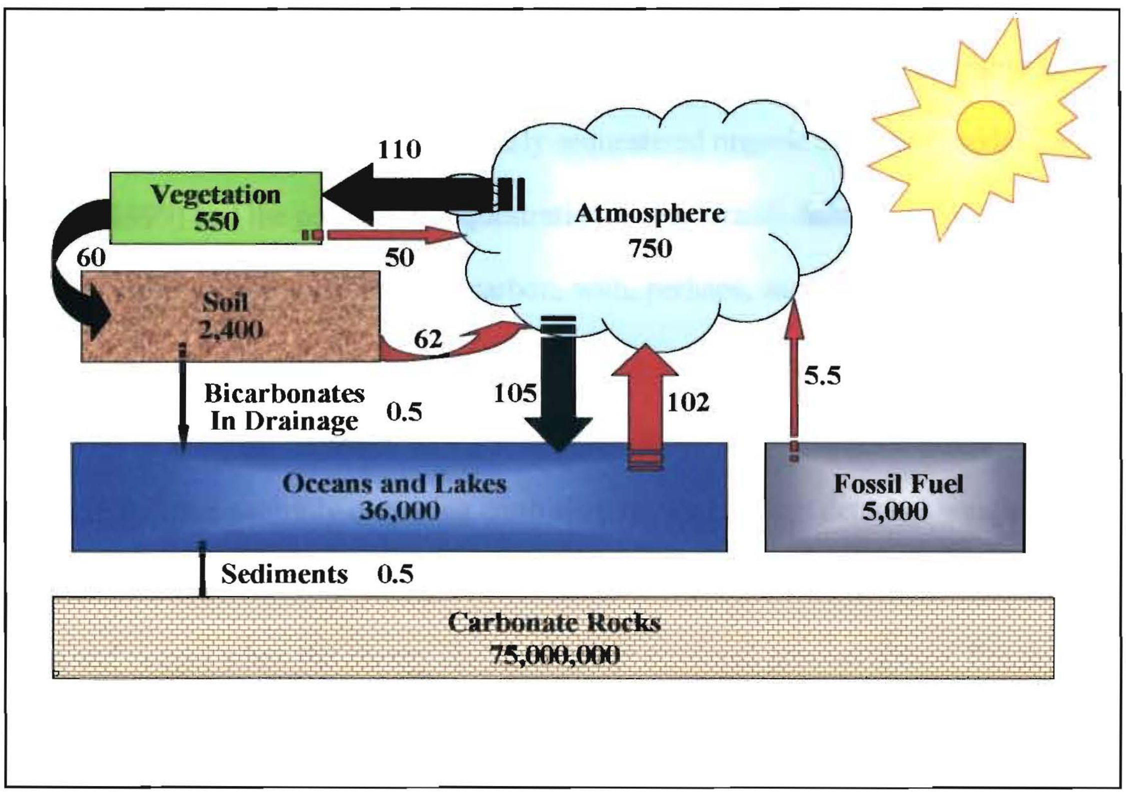

Figure 1. Global carbon cycle (redrawn after Brady and Weil, 2002:499). Amounts shown represent gigatons (billion metric tons) of carbon.

Not included in the description of the carbon cycle, but clearly of vital importance, are spatial variations in soil characteristics and climatic conditions, with their concurrent impacts on biochemical reaction rates, plant types, length of growing (or active) seasons, erosion rates, decomposition rates, as well as present land management practices including fertilization, tillage and water use (Brady and Weil, 2002). In addition, the carbon cycle can be interrupted by flood or fire, both events short-circuiting the carbon cycle through destruction of decomposers and consumption or drowning of plant material. Carbon originally destined for storage in the soil is released back into the atmosphere when plants are consumed by fire, though carbon left as residue ash can be incorporated. When the plant cover is destroyed by fire, the soil is left vulnerable to wind and water erosion, exposing previously sequestered organic carbon to oxidation (Lal et al., 1999) and the process of sequestration is temporarily halted. Thus soil can qualify as both a source and a sink for carbon, with, perhaps, surprising capacity.

The Effects of Natural Erosion

Erosion is a naturally occurring earth shaping process that detaches weathered particles and transports them some (any) distance. The process of deposition follows erosion and occurs when the energy involved in the erosional process abates. Erosion is constantly at work with tectonic processes, slope processes, and weathering processes to continually reshape Earth's surface. Weathering, erosion, and deposition, three separate but interconnected processes impact soils, and soils continue to be impacted by, contribute to, and benefit from these processes. Human activities throughout the history of civilization have caused the destruction of many fertile soils, resulting in extreme erosion from the loss of billions of tons of soil at a rate that is more accelerated than natural processes (Izaurralde et al., 2001). Within the discussion of soil carbon, it is the scale of this erosion, and the ability of humans and nature to mitigate the resulting losses, that draws our attention.

Soil erosion presents a greater problem than simply the physical removal of surface soils. During the erosion process, and without its surface vegetation cover, soil carbon, once bound in the clay fraction and therefore protected from decomposition, is exposed to air as aggregates (massed units of soil particles) are exposed at the surface and begin to break down (Lal et al., 1999). The very act of traditional cultivation begins the soil's degradation process as macroaggregates (larger clods of soil particles which often exhibit specific structural forms such as platy, prismatic, blocky, etc.) are destroyed and carbon begins to be oxidized at accelerated rates (Cambardella and Elliott, 1993). Additionally, part of the naturally occurring nutrient bank found in undisturbed soils is harvested with the removal of each yearly crop, and unless these nutrients are replenished, the steady state condition of the undisturbed soil becomes unbalanced. Though seemingly counter-intuitive, Izaurralde et al. (2001) found that in general, the ratio of carbon to mineral material, or the carbon content of the water-and wind-blown sediments to that of the contributing soils, is greater than one. Also, Lal (1976) observed that eroded sediments studied in Nigeria contained three to five times more carbon than the original soil, and Sterk et al. (1996), studying wind blown material in Niger, found 32 times more carbon in eolian sediments in samples trapped at 2m above the ground than in the original topsoil. While this re-distributed soil may enrich some areas, it clearly exposes additional soil organic carbon to oxidation losses into the atmosphere as CO_2. In addition, the donor soil is left with fewer nutrients to support soil building plants and organisms that may attempt to become established. Izaurralde et al. (2001) suggested that though the world's soils have lost ~24.9 gigatons of carbon to the atmosphere through erosion, most of the carbon can be recaptured through management practices that promote sequestration.

Studies indicate that grassland and forest soils converted to cropland and/or pasture tend to lose from 20 to 50% of the original soil organic content within the depth of cultivation within 40 to 50 years of land use change (Bruce et al. 1999). A number of estimates have been made concerning terrestrial carbon reservoirs and anthropogenic impacts on them. Lal et al. (1999) estimated that as a result of cultivation, 5,000 gigatons of carbon have been released from United States (U.S.) terrestrial sources to the atmosphere. While many such inventories of carbon have focused on the most obvious carbon pools (e.g., forests, oceans, etc.), recent research suggests that grassland soils are very significant carbon reservoirs as well. For instance, the tall grass prairie in the United States was originally 400,000 mile^2 (National Park Service, 2004). Calculations using the U. S. Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) data determined this area would have contained two to twelve gigatons of soil organic carbon in just the upper 25 cm of soil. With 60% gone, this loss alone would represent one to seven gigatons of soil organic carbon. Bruce et al. (1999) gave a range of 41 to 55 gigatons for the amount of carbon released worldwide from cultivated soils as a result of anthropogenic activity. Allmaras et al. (2000) reported that carbon levels in croplands converted from grasslands were reduced up to 40% by 1940, and the volume of carbon in tall grass prairie soils has been diminished by as much as 60% as a result of tillage. Since it has been estimated that soil organic carbon accounts for approximately two-thirds of the carbon pool in the terrestrial biosphere (Allmaras et al., 2000), the importance of these soils and their carbon dynamics as a function of land-use history cannot be underrated.

Agricultural Land Use Practices

Cropland is important for reasons beyond its role in sustaining human life on Earth. It comprises a great percentage of that part of the biosphere referred to as highly managed, Class I land (Brady and Weil, 2002). Traditional agricultural practices dictate soil be tilled, seeds planted, crops harvested, and the crop residue burned, tilled in, or removed. The outcome of this intensive tilling, along with compaction by farming equipment in repeated trips across fields, and crop residue removal or burning is to leave the soil vulnerable to increased erosion.

The Soil Bank Act of 1956 was the first major federal program designed to protect cropland from the erosional effects of poor conservation practices. This was clearly a response to the disaster of the 1930's Dust Bowl days, and probably to the drought of 1954. It also established a renewed awareness and re-commitment to stewardship of the land. During the ten years the Soil Bank program was in effect, 28.7 million acres of land were diverted to conservation practices on 306,000 farms (Farm Services Agency, 2004) with the United States Department of Agriculture (USDA) sharing the cost of conversion from production to protective cover crops. Similar long-term contractual programs were subsequently introduced with additional conservation incentives – the Cropland Conservation Program and the Cropland Adjustment Program in 1962 and 1965, respectively. In 1985, the federal government introduced the Conservation Reserve Program (CRP), using subsidies to encourage farmers to voluntarily set aside highly erodible lands using this reseeding technique. With a primary goal of reducing soil erosion, land enrolled in this program is kept out of row crop production for ten years, during which time a permanent cover is established. Brady and Weil (2002) submit that approximately 60% of the reduction in soil erosion in the United States since 1982 can be credited to government programs that pay farmers to practice CRP (p. 789). As these soils are rebuilt, carbon is being removed from the atmosphere into the soil. Though it remains vulnerable to a short-term turnover rate, the longer the soil is left undisturbed, the more carbon can be sequestered and the longer some carbon will remain.

Reseeding is not the only land-use practice being encouraged to mitigate against erosion. Since any disruption of the soil surface exposes accumulated humus and stored carbon to decomposition processes, conservation tillage practices have also been widely adopted (Uri, 2001a.). Conservation tillage refers to agricultural practices that cause minimal disturbance to the land during planting and harvesting. In 1977, the Soil Conservation Service (SCS, now part of NRCS, Natural Resource Conservation Service) defined this practice as a form of non-inversion tillage, retaining protective amounts of residue on the land surface throughout the year. By 1984, the definition included the requirement that at least 30% of the soil surface be covered with residue after planting to reduce erosion by water, and added requirements to prevent wind erosion (Uri, 2001b.). Upon meeting these requirements, farmers qualified for monetary subsidies from the federal government. Systems that leave 15-30% residue on the surface after planting are referred to as reduced-till systems.

While the focus of this research concerns the results of conventional agricultural practices on present local conditions, the Inter-governmental Panel on Climate Change (IPCC) has determined that up to two-thirds of the soil carbon released to the atmosphere since the mid-1800's can be recaptured with best land use practices such as reseeding, limited till, and no-till agriculture (Izaurralde et al., 2001). Bruce et al. (1999:385) observed that the obstacles to achieving pre-cultivation carbon content in soils fall into three general areas. They include:

1. Agricultural ecosystems having been designed either explicitly or implicitly to maximize exported (harvested) carbon so that the amount of carbon returned to the soil is often less than what was returned in "native" systems.

2. Because of an overall decrease in soil quality due to erosion, salinization, or other degradative processes, some soils can no longer be returned to the level of productivity achieved before cultivation.

3. Economic, social, and practical constraints limit the adoption of new management practices in some areas.

However, with the annual net release of carbon from agricultural soils being estimated at 14% of global fossil fuel emissions, the ability to sequester carbon in soils through better tillage and erosion management techniques serves to justify long-term soil conservation programs (Uri, 2001b). Best management practices can involve major changes in tillage activity, minor adjustments to present practices, or total cessation from tillage.

Several additional agricultural systems have evolved in response to soil depletion, including mulch-till, ridge-till, and no-till farming, with degrees of disturbance to the soil decreasing respectively. Shared advantages include economic benefits associated with reductions in labor, equipment, and fuel use. Other benefits include better overall soil quality including water holding capacity and aggregate formation, improved water, air, and wildlife habitat quality, and often a reduction in amendment requirements (Izaurralde et al., 2001). The amounts of carbon sequestered as a result of these practices varies with soil type, climate regime, choice of crop, cropping intensity, fertilizer application type and rate, crop rotations, land use history, and the original amount of depletion. Severely eroded soils often show great depletion, and may offer equally great potential for sequestration and reversal of degradation. Soils converted from traditional tillage to a no-till system and planted to a crop determined to be used as an alternative to fossil fuel would represent the greatest potential for CO_2 mitigation.

Potential Impacts On and Causes of Increased Atmospheric Carbon

The Kyoto Protocol is the most prominent outcome of a global assembly questioning the possible impacts of the enhanced greenhouse effect on global and regional climates. This subject continues to involve increased research and discussion by scientists, policy makers, and the world community at large. Although the degree to which global climates are changing continues to be debated, many nations of the world have acknowledged a definite measured increase in atmospheric greenhouse gases (Izaurralde et al., 2001), including three major gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Higher concentrations of greenhouse gases in Earth's atmosphere are likely to enhance trapping of infrared radiation, which would intensify the natural greenhouse effect of the atmosphere.

The warming trend following the last glaciations continues to be investigated to help determine whether or not the current rapid increase in greenhouse gases is entirely the result of anthropogenic activity or some combination of anthropogenic activity and the longer temporal scale (Rosenzweig and Hillel, 2000). Earth's history consists of many climate changes, including cycles of glaciations and warming, distinctive patterns of wet and dry periods, and climatic extremes. What differentiate our present concerns from those events are the contributions of anthropogenic activities to an accelerated rate of change.

Because atmospheric CO_2 is the gas most likely to be subject to some control through policy and land management activity, further examination and study will enhance development of potential solutions or mitigation plans. The continued increase in concentration of CO_2 and other greenhouse gases is likely to intensify the greenhouse effect and may impact the climate of the planet (Rosenzweig and Hillel, 2000). Increased CO_2 accelerates plant growth and thereby increases plant removal of CO_2 from the atmospheric pool. However, warmer soil temperatures will also increase decomposition rates for organic matter, and could further accelerate the accumulation of CO_2 into the atmosphere by increasing soil respiration of CO_2. In addition, extreme weather patterns being experienced now may be changing precipitation and wind regimes, increasing erosion and severe storm damage (Rosenzweig and Hillel, 2000).

Carbon Sources and Sinks

As stated previously, the Industrial Revolution with its concurrent increased use of fossil fuels and expanded agricultural activities amplified anthropogenic contributions to atmospheric CO_2 concentrations. This is not solely an historic reality. Ongoing industrialization and use of fossil fuels continues to contribute more than 3 billion tons of carbon to the atmosphere each year (Rice, 2002). The components of the natural carbon cycle, as in all Earth systems, work toward a state of equilibrium – in this case, a balance of sources and sinks. These human activities are, however, in many cases sources without counter-balancing sinks. Table 1 outlines values ascribed by Rosenzweig and Hillel (2000, p. 48) to various carbon pools and fluxes recognized as the major natural sources and sinks of atmospheric CO_2. Identifying and further developing the manageable sinks may mitigate the rate of increasing atmospheric CO_2.

	Source (+)	**Sink (-)**
Soils	+60.3	-60 (from biota)
Biota	+61.5	-120
Ocean Surface	+100	-102.5
Intermediate and deep-ocean	+35	-37.5 (from surface; 2.5 Gt/yr increase)

Table 1. Sources (CO_2 transferred to the atmosphere) and sinks (CO_2 transferred from the atmosphere) of atmospheric CO_2 in gigatons per year (after Rosenzweig and Hillel 2002).

An abundance of literature suggests that global inventories of carbon continue to be studied also. Reservoirs of carbon involved in the global carbon cycle fall into three general categories: the atmosphere, the oceans, and the planet's land masses. Geological reservoirs (excluding fossil fuels) are generally classified as permanent reservoirs (Eswaran et al. 1993), however, much of the terrestrial carbon is in soils, and at geologic time scales it is not permanent. As early as 1982, Hinrich Bohn wrote that "soil organic carbon (C) is the largest carbon reservoir at the earth's surface, but its mass is the least certain" (p.1118). The renewed attention on soils focuses, in part, on the complex interactions that occur between soils and the atmosphere, hydrosphere, biosphere and lithosphere.

Rosenzweig and Hillel (2000) determined global soils hold approximately 1,500 gigatons (Gt.) of carbon, with approximately 730 Gt. attributed to the atmospheric pool and approximately 560 Gt. found in the terrestrial biosphere. Similar numbers have been used by other authors: Rice (2002) credited soils (approx. 1,600 Gt.) with holding more than twice the carbon of the atmospheric pool (approx. 750 Gt.) and close to three times the amounts held in the terrestrial biosphere (approx. 560 Gt.). Delgado and Follett (2002) reported the soil organic carbon pool (approx. 1,600 Gt.) to be over twice the atmospheric carbon dioxide carbon pool (approx. 535 Gt.), and 4.5 times that of the carbon found in terrestrial land plants (approx. 400 Gt.). Soil inorganic carbon and soil organic carbon pools, together, can hold 3.2 times the carbon found in the atmosphere and four times the carbon found in terrestrial vegetation.

The problems with accurately estimating global carbon inventories logically stem from these facts: 1) there is high spatial variability in soil carbon, 2) soil surveys are generalized and of varying quality, 3) reliable data on bulk density is often unavailable, and 4.) temporal variations in land use and vegetation occur continually (Eswaran et al., 1993) causing temporal variability in soil carbon contents. All of the carbon estimates in literature cited in this paper are based on United Nations global carbon data as the source for budget modeling and research calculations. While this research project addresses these interactions at a field scale, and the masses of carbon are miniscule compared with the global soil organic carbon pool, it may contribute important information to address issues about a soil's recuperative abilities over time.

The Effects of Erosion and the Missing Sink

Smith et al. (2001) acknowledged that carbon inventories are being comprehensively reported, but suggested that between ~0.5 and 2 gigatons of carbon per year is being sequestered somewhere in the Earth system that is yet to be identified. They concluded that this missing sink is most likely terrestrial in nature. Other estimates of the missing sink are higher. McCarthy et al. (2002:423) estimated the missing sink to be as much as 110 gigatons of carbon. They based these estimates on the "distinct gap between the estimated net terrestrial emission (26 gigatons carbon) and land use change emissions (136 gigatons carbon)". They also agreed that a better understanding of the terrestrial component of the carbon cycle would likely help uncover the missing C sink.

Several theories have been put forth in attempts to solve this mystery. Schindler (1999) noted that annual oceanic flux had been considered by Tans et al. (1990) to be less than 0.5 gigatons carbon per year, or as little as one quarter of the carbon necessary to balance global budgets. Reforestation's role as the missing sink has been refuted in a study of temperate forests using carbon:nitrogen ratio tracing to determine carbon uptake (Nadelhoffer, et al., 1999). Schindler (1999:107) noted an estimate for the temperate forests of "the maximum contribution to the missing sink for atmospheric CO_2 to be a disappointing 0.25 gigatons of carbon per year". McCarty et al. (2002) cited data from the Intergovernmental Panel on Climate Change (IPCC, 1990) report indicating that 0.8 gigatons of carbon per year is labeled as terrestrial export (i.e., carbon in eroded soils which settles in oceans), which is only slightly more than that attributed to uptake by the land (0.7 gigatons per year). All of these estimates carry with them some amount of uncertainty.

Redistributed soils, or those soils which have been moved through erosion processes, have attracted attention as another possible explanation. Eroded soils do contribute to atmospheric CO_2 as aggregates are broken down and organic carbon in ped interiors from deeper horizons is exposed to oxidation, disrupting the steady state of the soil environment. However, by looking at budgets for bulk soil and soil organic carbon erosion and deposition, Smith et al. (2001) reported the total amount of soil carbon eroded and re-deposited across the United States to be ~0.04 gigatons per year. When applied globally, their calculations of the amount of carbon trapped in catchments such as lakes, ponds, bogs, etc. may account for some, but not all, of the missing sink. In addition, the soils which have been eroded and are re-forming with perennial vegetation are sequestering carbon previously lost to the atmosphere. Smith et al. (2001:697) wrote an apt description, noting "This 'missing sink' may represent a single unknown or improperly quantified reservoir; it may represent the summation of several smaller, unknown reservoirs; or it may represent summed errors (biased in one direction) in the standard reservoirs".

Soils become carbon sinks when land management practices (or natural processes) result in a positive balance of carbon being retained in the soil during carbon cycling processes; i.e., the input of plant residues and other organics versus the output resulting from decomposition, leaching, and erosion. While individual soil properties vary, the processes involved in carbon sequestration remain consistent: humification, aggregate formation, translocation within the soil profile, deep rooting, and calcification (Uri, 2001). Therefore, for traditionally tilled agricultural soils, translocation of carbon below the Ap horizon (the depth to which traditional plowing invades and turns over the soil) would be necessary to prevent exposure to further decomposition when soil is tilled.

It is important to understand the conditions under which carbon stays in the soil. Climatic factors influence soil properties more than any other component of the soil building process and have a profound affect on sequestration potential, including affecting the types of vegetation and decomposers present.

Warm, moist climates encourage plant productivity, whereas lack of sufficient water becomes a limiting factor in hot, dry climates, and cooler climates act to reduce growing season length and total plant growth. In addition to impacts on vegetation, temperatures affect microbial activity, slowing it in cooler temperatures and accelerating it as soil temperatures increase. Again, water can be a key component in this part of the carbon cycle. Microbial decomposition is slower and less complete in wet Inceptisols and Histosols; likewise, but at the other extreme, decomposition rates are also slow in dry soils, e.g. Aridisols (Miller and Gardiner, 2001).

Soil texture (usually expressed in terms of the relative percentages of sand, silt, and clay sized particles) as well as clay mineralogy also play an important role in carbon sequestration. Initially, soil texture (along with bulk density, soil chemistry, soil gases and reactive and stable forms of inorganic material) helps determine vegetation by impacting various soil properties including: water holding capacity and internal drainage, cation exchange capacity, ability to form aggregates, aggregate stability, ability to resist compaction, and the ability to provide a suitable environment for fungal and microbial growth as well as habitat for earthworms and other macro-invertebrates. Vegetation variety helps to determine other components of the ecosystem, thus influencing additional organic input and disruption patterns. As organics are introduced to the soil, the clay fraction adsorbs organic molecules, further building micro- and macro-aggregates. "SOC is transformed by bacterial action and stabilized in clay- and silt-sized organomineral complexes (HF-OC, heavy fraction organic carbons) where the majority of SOC is found" (Post, et al., 2000:318). Since soils with a higher percentage of clay have higher potentials for forming aggregates, they also have a higher potential for carbon sequestration, because organic carbon is trapped in aggregates and physically protected from microbial degradation (Rice, 2002).

Different organic compounds decompose at different rates, and organic carbon is held in the soil in different pools of availability. Rice (2002) referred to three recognized pools based on their residence times: 1) active (<5% SOC), 2) intermediate or slow (20-40% SOC) and 3) recalcitrant (60-70% SOC). He assigned turnover rates to each pool. The turnover rate is the amount of time organic carbon remains in the soil before it is affected by further microbial action and decomposition, allowing it to re-enter the carbon cycle. The active pool will turn over in just months to years, where as the slow pool may remain in the soil for decades and the recalcitrant pool may be sequestered for hundreds to thousands of years. Rice's research was conducted on the tall grass prairie and is, therefore, of particular interest to this study. Globally, it is important to consider soil type, climate regime, and land use management when reviewing these findings and applying them to historical losses and estimates of potential sequestration for particular soils.

Various estimates of the magnitude of the soil organic carbon pool have been made. In addition to those estimates mentioned in an earlier discussion of carbon pool comparisons, the following should be noted. Eswaran et al. (1993) used World Soil Resources of the USDA Soil Conservation Service (WSR-SCS, now the Natural Resources Conservation Service (NRCS)) data to calculate a global soil organic carbon pool of 1,576 gigatons. Bruce, et al. (1999:384) reported world soils "constitute a principal carbon pool of 1,500 to 2,000 gigatons as soil organic carbon and 800 to 1,000 gigatons as soil inorganic carbon". These estimates are for total soil carbon and do not differentiate as to turnover rates or residence times for organic or inorganic soil carbon.

Undisturbed soils hold a combination of organic carbon availability pools, always nearing a steady state. Logically, soil that has lost carbon as a result of erosion, fire, and agricultural and other human activities is more receptive to carbon sequestration as it moves toward re-establishing a new equilibrium (i.e., carbon additions equaling carbon emissions). Izaurralde et al. (2001) identified approximately 2 billion hectares of desertified and degraded lands worldwide (75% in the tropics) that might be utilized as sinks with appropriate land use regime changes. Schlesinger (1999) supported conservation tillage and reintroduction of native vegetation to abandoned farmlands, noting this practice might result in a substantial sink for carbon in soils.

Global Soils

A number of soil classification systems are in use throughout the world, each reflecting the requirements of the country or region to distinguish soil types and to calculate a soil's value for industry, agriculture, or other uses (Brady and Weil, 2002). As early as 1951, the USDA's Soil Survey Staff began developing a more comprehensive classification system that would move global information closer to an agreeable standard and enhance clear communication between scientists. Modifications have been made since 1965, and this system of Soil Taxonomy is now accepted in more than 55 countries globally (Brady and Weil, 2002 p. 77). In this system, soils of the world are divided into twelve Orders representing groupings based on measurable and/or describable soil characteristics. Miller and Gardiner (2001) summarized the characteristics of the twelve orders used in soil taxonomy (Table 2). From these 12 orders, soils are further sub-divided into sub-orders, great groups, sub-groups, families, and series that describe the characteristics of soils in greater and greater detail. Table 3 summarizes the criteria associated with each successively more distinctive grouping. In this table, the criteria are clearly influenced by the perceived agricultural value of each soil. Figure 2 illustrates global soil order distribution, with each order represented by a percentage of total ice-free land.

Soil Order	**Climate**	**Characteristic**
Histosols	Varied	Organic
Entisols	Varied	Undeveloped
Inceptisols	Varied	Slightly developed
Andisols	Varied	Volcanic material
Vertisols	Varied	Contain swelling clays.
Gelisols	Very Cold	Permafrost within top 2 meters
Mollisols	Semi-Arid to Sub-Humid	Usually naturally fertile; slightly leached; originally under grasses or broadleaf forests.
Alfisols	Good moisture	Fertile and productive; do not require irrigation.
Utisols	Long frost-free periods; warm climates.	Leached, acidic, low to moderate fertility, highly productive.
Aridisols	Arid regions	Often highly productive when irrigated.
Oxisols	Hot, wet tropics	Infertile; poor for crops, best left to evergreen forest.
Spodosols	Cool climates	Acidic, sandy, poor for cultivation without lime and fertilizers.

Table 2. Major orders of soil with descriptive definitions (after Miller and Gardiner 2001).

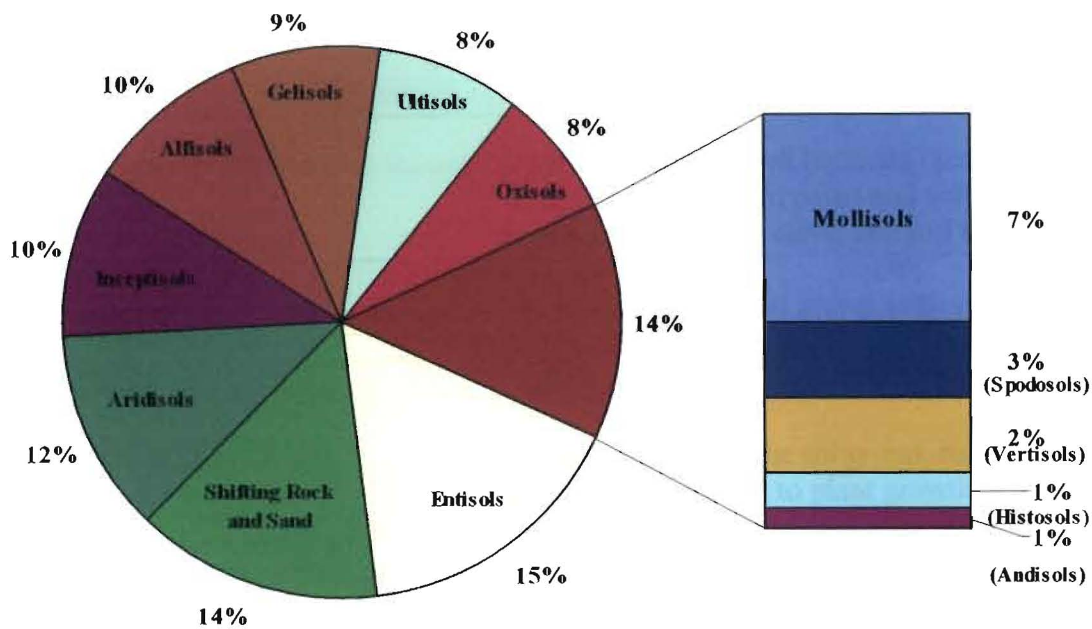

Figure 2. Global soil orders as percentages of ice-free land (Brady and Weil, 2002:91).

From these twelve orders, soils are further sub-divided into sub-orders, great groups, sub-groups, families, and series that describe the characteristics of soils in greater and greater detail. Table 3 summarizes the criteria associated with each successively more distinctive grouping. The criteria are clearly influenced by the perceived agricultural value of each soil.

Descriptive Group	Definitive Properties
Suborder (63)	Soil properties / horizons resulting from soil moisture, soil temperature, strong effects of chemical and textural features.
Great Group (319)	Differentiations in soil horizons (accumulated clay, iron, humus, and hard pans) and soil features (salt content, self-mixing clays, and soil temperatures).
Subgroup (2,484)	Greater detail of great group; indicates how closely soil represents great group features, indicates differences.
Family (~8,000)	Separations within the subgroup; based on soil properties important to plant growth or engineering purposes.
Series (~19,000 in U.S.)	Narrower range of family characteristics; based on observable and mappable soil characteristics.

Table 3. Characteristics used to specify individual soils (after Miller and Gardiner, 2001; Brady and Weil, 2002).

Mollisols

The soils that are the major focus of this study are classified in Soil Taxonomy as Mollisols. Figure 3 indicates the percentage of Mollisols on the Earth's surface. The largest body of Mollisols extends from central Europe through central Asia and continues to northern China. Argentina and parts of surrounding countries in South America constitute the next greatest expanse. The intermountain regions of the Pacific Northwest and the Great Plains define Mollisol distribution in North America. Mollisols are the most extensive soils in the United States, and represent approximately one-fifth of our soils (Miller et al., 2001). This vast area of naturally fertile soil has driven population expansion and nation building. It is responsible for some of the highest volumes of agricultural production in history, and its management continues to impact agricultural research and technological developments world-wide. Figure 3 illustrates the distribution of soil orders in the United States.

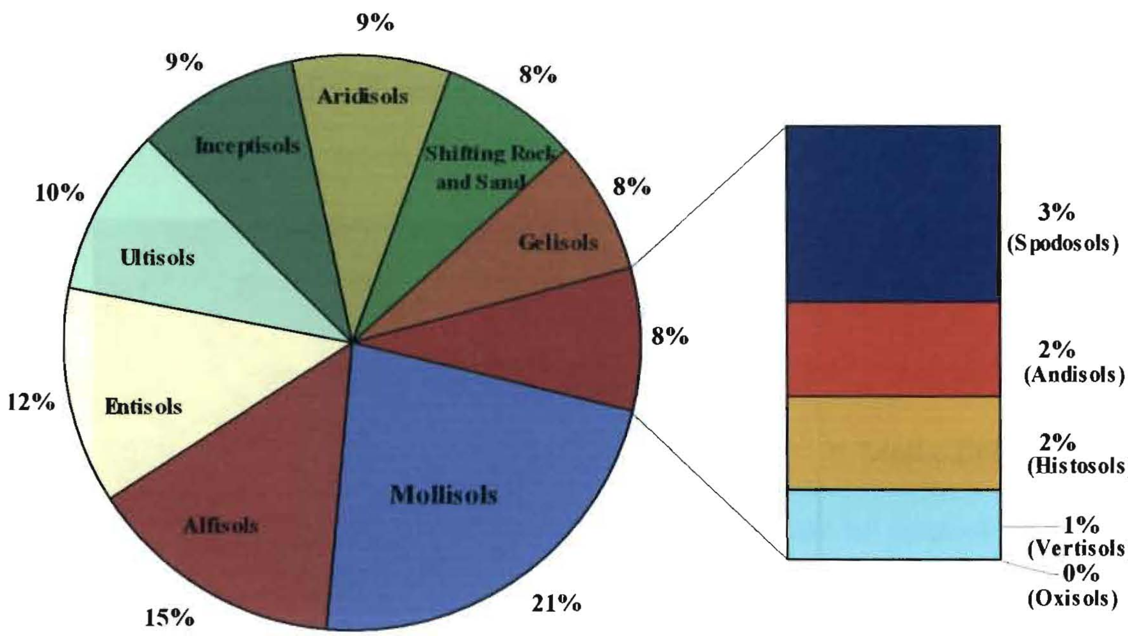

Figure 3. Soil orders as percentages of ice free land in United States (Brady and Weil, 2002:91).

Kansas' Mollisols represent a range of great groups and subgroups strongly influenced by the underlying geology (or parent rock), topography, weathering processes, vegetation, hydrology and climate over time. Common to these undisturbed, organic-rich mineral soils are Mollic epipedons that are, in pristine condition, deep and rich in soil organic carbon. Epipedons are surface horizons to which diagnostic descriptions are applied (Brady and Weil, 2002:79). The Soil Survey Staff (1992) description lists Mollic epipedons as having dark color and low chroma in 50% or more of its matrix, 50% or more base saturation, and at least 0.6% organic carbon content throughout its thickness. While the most common thickness requirement for classification as a Mollic epipedons is >25 cm, its thickness can range from at least 10 cm when directly above a lithic contact, to >25 cm when textures are loamy fine sand (with variations dictated by presence of duripans, fragipans, specific horizon boundaries, etc.). Thickness is 18 cm or more when no special conditions exist. Figure 4 represents a typical Mollic Epipedon.

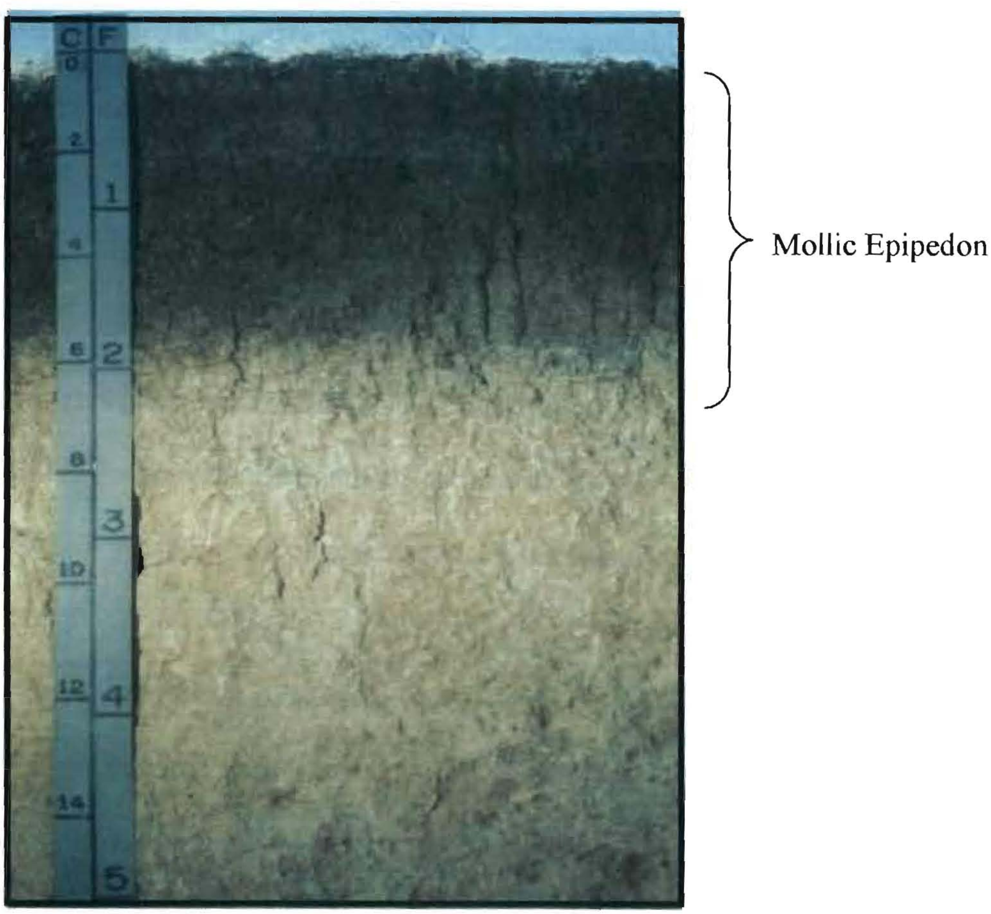

Figure 4. Profile of Mollisol showing Mollic epipedon (National Resources Conservation Service, 2004)

Brady and Weil (2002:500) noted that most of the carbon found in the soil profile is found in the upper one meter, with the upper 15 cm of soil, the soil surface representing the area "most readily influenced by land use and soil management". According to their data, Mollisols represent less than 4% of soil area globally but hold 5% of the world's soil organic carbon. With the exception of Histosols and Andisols, Mollisols provide the highest percentage of soil organic carbon in the upper 15 cm of soil.

The natural fertility of Mollisols has resulted in their successful use for agriculture, which has also led to the enormous impact of this success upon the ecosystems where Mollisols are common. Understandably, these valuable soils draw the attention of researchers. They are readily available for studies to determine anthropogenic land use and management impacts on soil properties. Kimble et al. (1999) studied four Mollisols in western Iowa, comparing soil organic carbon contents in slightly, moderately, and severely eroded sites. They reinforced the value of the Mollic epipedons reporting that its loss changed the structure of the soil, adversely impacting its water holding capacity and effectively destroying its fertility, thus resulting in a reduction of overall soil quality. As we have discussed, the full effects of erosion can be even more far reaching.

The literature consulted and referenced for this study supply a range of information from basic definitions to opinions and observations of recent research results. It is clear that we are confronted with global concerns that strongly emphasize the need to look at solutions with a holistic eye. This study focuses on a small but ideal site, using new technology with fundamental field work to understand what has happened to soils as a function of land use change over time. By comparing properties of soils which have been cultivated, eroded, reseeded and left in pasture to an undisturbed area of the same soil types, it may be possible to quantify the amount of previously contained soil organic carbon recovered by the reseeded soil. The knowledge gained from this small parcel will contribute to the collection of answers being gathered world-wide, and it may provide a better understanding of the questions being asked at a complex global scale.

Goals of This Study

Assembling data which reflects the effects of erosion on the integrity of soil structure and calculating what that represents, even on a field scale, may contribute to a better understanding of the importance of erosion control and a deeper appreciation for the role of soil in earth systems. By selecting a site that is comprised of rich Mollisols and that exhibits undisturbed and eroded soils side by side, valuable research can be performed about the effects of land use on carbon storage in soils.

The purpose of this study is to quantify the changes in the soil quality present in the northern, eroded, and recovering portion of the site as a result of human land management practices. Data will be collected to determine how much soil has been eroded, the possible changes in organic carbon contents, how the soil profile may have changed as a result of any erosion, and whether or not there is evidence for soil rebuilding having taken place.

Chapter 3:

SITE AND METHODS

Site Location and Description

The site used for this study is located near Gridley, Coffey County, Kansas. This parcel of land is ideal for a study of changes in organic matter as a function of land use change. The history of management practices, a component often missing from many similar studies, was supplied by the land's owners. The parcel has been in the family of the present owners for several generations, and management practices concerning the cessation of conventional agricultural practices are recent enough to be in personal, living memory. The northern half of the site's land shows dramatic signs of accelerated erosion along with evidence of recovery. The oral history indicates this portion of the site was tilled using conventional agricultural practices from the late 1800's to the late 1940's and then abandoned to pasture.

The southern half of the site has never been tilled and remains in undisturbed, native prairie vegetation. The site is small enough to be walked repeatedly (80 m x 240 m) and large enough to provide ample sampling for meaningful research. Additionally, the site's owners allowed easy access. Figure 5 presents the location of the study site.

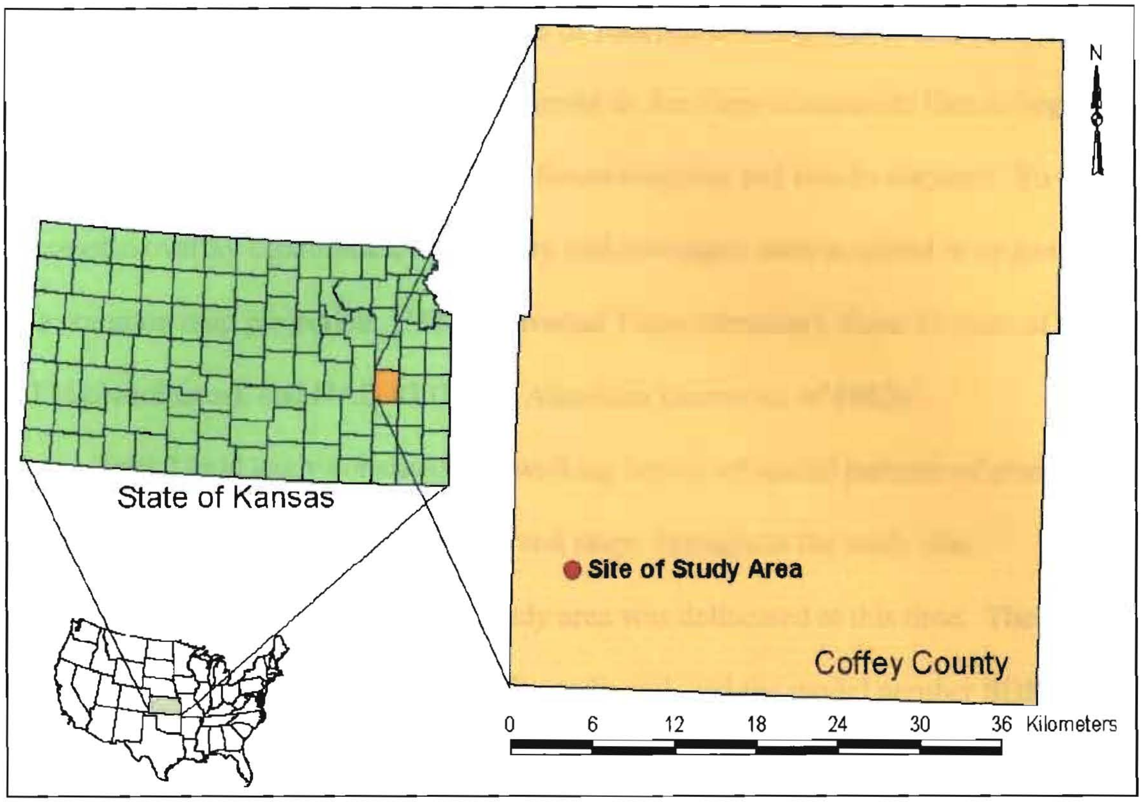

Figure 5. Locator map of study site, Gridley, Coffey County, Kansas.

Field Work

Before soil core characterization was begun, a Field Sample Data Sheet was designed for use with this study (Appendix 1). This form enabled soil characterization data (color, texture, horizon parameters, redoximorphic features, moisture condition, depth to bedrock, GIS location) to be recorded immediately after being determined in the field. Later, information on the completed forms was used to characterize each sample point, to accurately classify the soils within the eroded and non-eroded portion of the study site, and for comparison studies.

Digital orthophoto quarter-quadrangles (DOQQ's – digitized aerial photos with cameral tilt and terrain relief distortion removed), digital raster graphics (DRG's – scanned USGS 7.5 minute topographic quadrangles with 250 dpi providing 2.4 meter resolution), and soil coverages (directories of files representing spatial relations in points, lines and polygons) were located and retrieved to ArcView-compatible files to begin creation of a GIS database to be used for future mapping and results displays. To ensure successful overlay capabilities, all imagery and coverages were acquired in or converted to a common map projection: UTM (Universal Trans-Mercater), Zone 15 (part of the UTM coordinates), and NAD 83 (North American Datum set of 1983).

Initial field study consisted of a walking survey of spatial patterns of plant colonies, moisture state, rock exposure, and slope throughout the study site. Observations were recorded, and the study area was delineated at this time. The study's initial boundaries were set using a transit, stadia rod, and the model number SDR 8100 back-pack GPS unit with Sokia Axis 3 receiver (Figure 6).

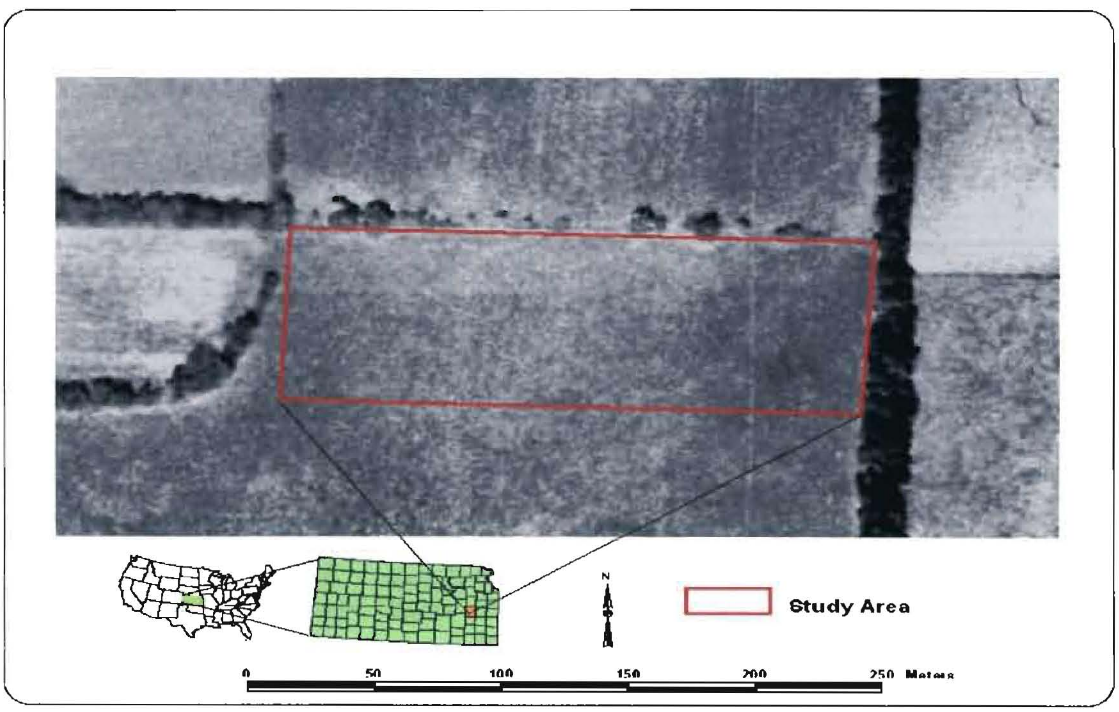

Figure 6. Boundaries of study site as determined by initial survey.

Soil Coring

Sixteen sites were identified for initial coring and description to compare actual soil morphology to descriptions given in the Coffey County Soil Survey for the soils mapped at the study site. Cores were extracted along paired transects (eight cores in the eroded soil and eight in the undisturbed soil) that were equidistant from the field boundary between eroded and undisturbed soils. At each core location, a small circular "plug" of surface soil was removed using a Montana spade. A Back-Saver soil probe was then pushed into the soil until bedrock was encountered. Each sample site was assigned a number, and its location was recorded using GPS. Each core was laid in a wooden core box and described using techniques outlined by the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) (Soil Survey Staff, Schoeneberger, et al., 2002). Cores were measured, and horizon boundaries and thicknesses were identified. Data was recorded on field data sheets (Appendix 1). Figure 7 identifies sample coring locations.

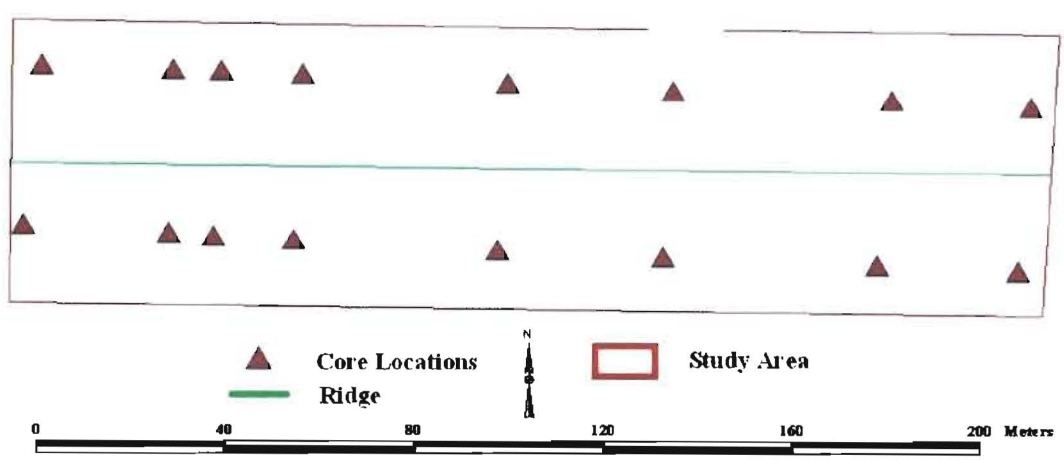

Figure 7. Core locations for soil characterization sampling. Paired locations reflect differences in soil profiles at similar slope positions.

Soil Texture

A soil's texture can reveal much about its composition, history, and stage of soil development. It can also help to determine soil horizon boundaries. Textures were estimated using hand texturing methods for each horizon identified in the field. There are several ways to hand texture, and often a soil scientist will develop a personal technique as a result of his/her experiences. The method used for this study was based on the teachings of Larry Hepner of Delaware Valley College of Science and Agriculture through personal contact, and were derived from a flow diagram developed by Steven Thien (1979). Placing a small sample of soil from a horizon in the palm of one hand, water is slowly added and the soil kneaded to wet all aggregates. When the soil is the consistency of putty, it is formed into a ball and gently extruded between the thumb and forefinger in an attempt to make a ribbon of uniform thickness and width, extending until it breaks of its own weight. Soil that does not form a ball is considered sandy; soil that forms a ball but does not form a ribbon is considered sandy loam. Only the presence of sufficient clay will enable the soil to be extruded, and the texturing process to continue. The length of ribbon produced by any horizon's sample is measured and recorded. Next, an additional pinch of a horizon's soil is placed in the palm, mixed with excessive water, and rubbed with the forefinger of the opposite hand, and the texture noted.

The resulting information combines to determine the soil's texture as follows: A sample of a soil producing a ribbon 2.5 cm or less in length with a predominately gritty feel is considered a sandy loam; a predominately smooth feeling identifies a silt loam, and a neutral feel identifies a loam. Likewise, a soil with a ribbon from 2.5 – 5 cm in length with a predominately gritty feel is identified as a sandy clay loam, a predominately smooth feel indicates a silty clay loam, and a neutral feel indicates a clay loam. As the soil's percentage of clay content increases, its ability to make a ribbon >5 cm becomes greater. Thus a sample from such soil that feels predominately gritty is classified as a sandy clay soil, as a silty clay soil if the predominate feeling is smooth, and simply as a clay soil if neither descriptive term applies.

Soil Color

The color of a soil can also contribute to understanding its history and condition, and it is a factor in determining horizon boundaries, leaching activities, and aerobic or anaerobic conditions. Soil colors were described using a Munsell color book, an internationally recognized coded set of colors. A soil sample was held in one palm under a page of color chips, each chip having a hole above it and a number below it. By moving the sample behind the holes associated with each color chip, a match could be found and the color recorded. As colors can change with degrees of dampness, field conditions were noted. Oxidation-reduction (or, redoximorphic) features were also noted. The USDA's Keys to Soil Taxonomy (1992) describes these features (p. 27) as being associated with wetness and resulting from the reduction and oxidation of iron and manganese compounds in the soil after saturation with water and desaturation respectively. The reduced iron and manganese ions are mobile and may be transported through the soil. Redoximorphic patterns are significant in that they indicate whether or not a soil is well-aerated (oxidized states of minerals) or has indication of poor drainage (minerals in a reduced state). Poorly drained Mollisols are less likely to successfully support plant life normally associated with this soil, and would be available for plants better suited for such conditions, thus possibly impacting a soil's carbon sequestering capacities.

Though initial classifications were performed in the field, more precise soil classifications were determined later using USDA – NRCS Agricultural Handbook #436 (Soil Survey Staff, 1999).

Relief of Land Surface

Topography at the site was surveyed using seven transects. Two transects – one a meter north and one a meter south of the east-west ridge axis marking the field's agricultural activity boundary - were used to give more precise measurements of soil loss. This information was used to create a topographic map of the site and to help determine the natural slope of the site for calculating volume of soil lost due to erosion (Figure 8).

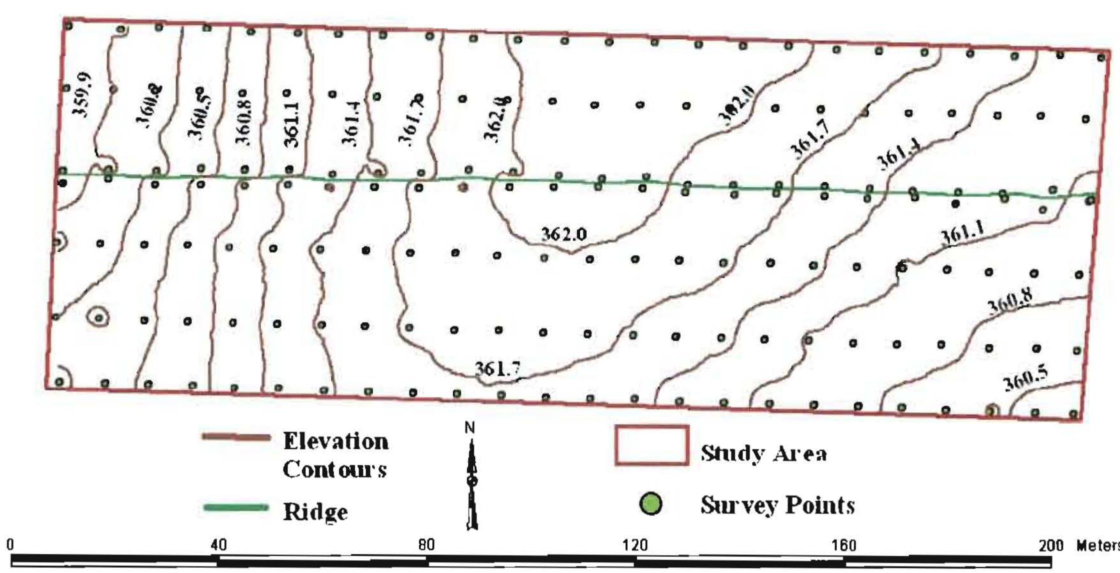

Figure 8. Topographic map of study site. Elevation contours are shown in meters; contour interval is 0.3 meters.

Soil Sampling

Using a measuring tape and a generalized formula based on, but not equal to the Pythagorean Theorem, a sampling grid was laid out and marked with flags, dividing the study site into 15m x 10m (N/S x E/W) plots. A total of 48 sample points were identified within this grid system, four sample points to each row (N/S), with twelve rows total (E/W). The north-south pattern was mirrored on either side of the ridge. The east-west pattern alternated between points ten and thirty meters from the ridge, and five and twenty meters from the ridge. In addition, 44 random points were sampled. These locations were determined by blindly throwing a nylon covered ring, Frisbee-like, within each grid square and flagging each landing spot. Each sampling site was labeled with grid coordinates or a random site number, and locations were recorded with GPS. Figure 9 illustrates the coverage obtained by the combination of both systems.

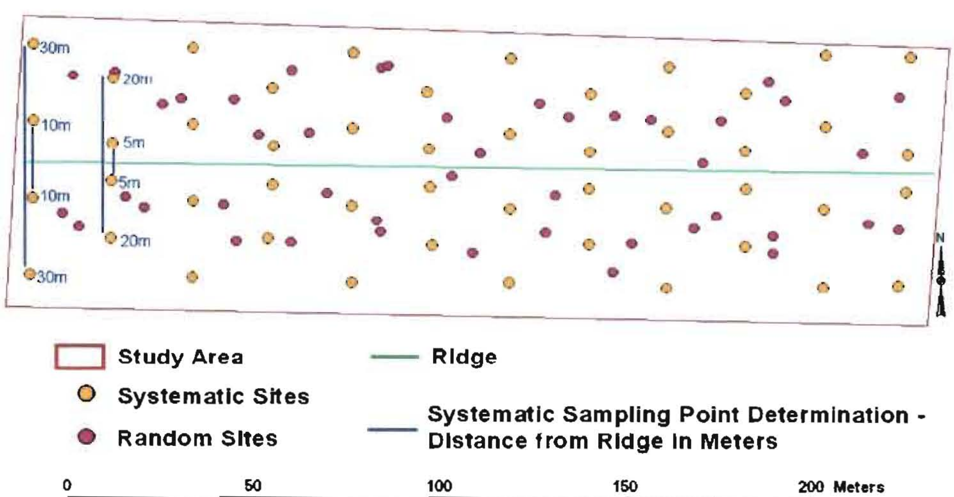

Figure 9. Coverage obtained by systematic and random sampling schemes.

Once the sampling pattern was determined, sampling was begun. A single core was taken at each sampling point using the Back-Saver hand coring tool, with three core barrels of decreasing diameter and length to a total depth of 114 cm or to bedrock, whichever came first. Ideally, each core retrieved consisted of three complete samples from each site. Each section was placed in a plastic bag that was then labeled and sealed. If sufficient soil depth existed, then three depth intervals were sampled. Using a knife, each core sample was trimmed to remove any residue from the outside of the barrel. Samples were categorized according to depth intervals as follows: 0-40 cm, 41-80 cm, and 81-114 cm. The length of the terminal sections were recorded when lithic contact (encountering solid rock which prevents further sampling to greater depth) was made anywhere before 114 cm, thus possibly reducing the last depth interval. Ideally, lithic contact refers to contact with bedrock (R horizon) beneath the soil being sampled. It is possible, however, for a piece of rock large enough to impede further probing to be encountered. The greater the diameter of the probe, the less likely this is to occur. The total number of samples collected was 197 from a total of 92 core locations, and details of the data recorded for each sample are shown in Appendix III.

Bulk Density Sampling

Using the original map and sampling grid, 20 bulk density samples were taken from the surface soil horizons. These samples were taken at selected sample points which had been used for carbon sampling in a pattern representative of the overall study area. The 20 samples were deemed to amply represent the variability in surface soils present at the study area, and they provided data for calculating carbon masses and for statistical analysis. To obtain each sample, a small area near a carbon core location was brushed clear of vegetation, and a metal cylinder (4.95 cm diameter x 5.0 cm height) was carefully hammered into the soil. Soil surrounding the cylinder was carefully dug away until the cylinder was exposed on all sides. Using a knife, the cylinder sides were cleaned, and the bottom of the soil column dug out, enabling a clean cut to be made along the bottom of the sample. Thus, an undisturbed cylinder of soil was collected. Each sample was put into a plastic bag, sealed and labeled for return to the lab. Figure10 shows the locations of the bulk density sampling sites.

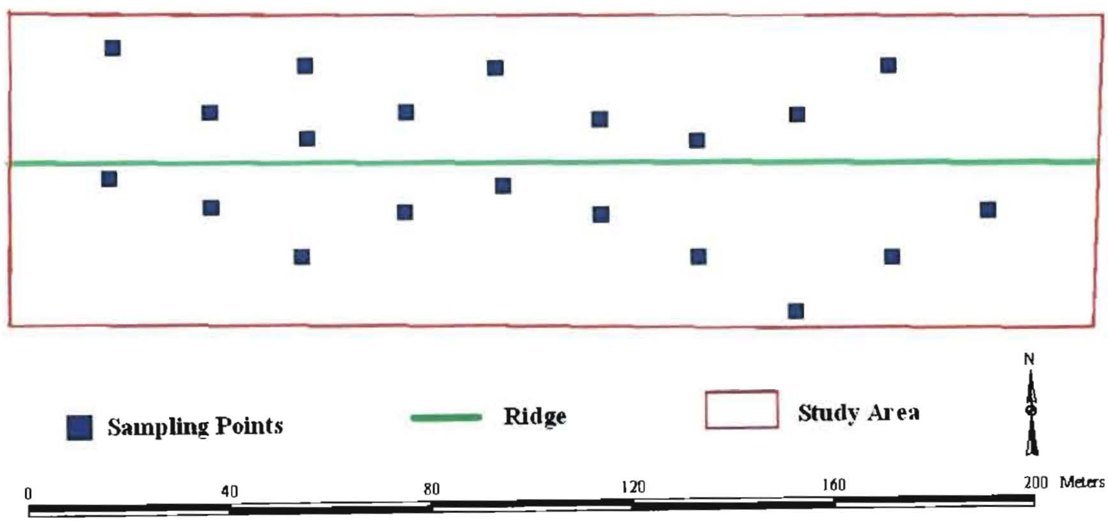

Figure 10. Location of bulk density sampling points.

Non-Computer Aided Lab Work

Soil Samples

The soil samples were returned to the lab for preparation and analysis. Each sample bag was opened and roots and rock pieces were removed by hand. Each sample was thoroughly broken up and allowed to air dry. A soil grinder was used to produce uniform sample size (i.e., approximately 2 mm), and it was cleaned thoroughly between each sample's grinding to prevent contamination. Each sample was then passed through a sieve (2 mm), oven dried, and re-numbered for shipment to the Kansas State University Soil Testing Laboratory for organic carbon testing. This lab uses a LECO CN2000 combustion analyzer to measure soil carbon content. According to LECO Corporation's literature for this model analyzer, the process uses a 0.5-g sample of prepared soil that is subjected to high temperatures; total levels (inorganic and organic) of carbon and nitrogen are determined on a dry weight percent basis. A second sample is then pretreated with dilute hydrochloric acid (HCl) to remove calcium carbonates and magnesium carbonates in any calcareous soils, leaving only total organic carbon remaining in the soil samples. These samples are then re-run through the analyzer to determine the organic carbon and nitrogen contents. The total inorganic carbon is the difference in the treated and untreated soil carbon values. The percentage of carbonates expressed as $CaCO_3$ can also be calculated. Test results (Appendix III) were added to the spreadsheet of sample points and used to study spatial variations in organic carbon within the site.

Bulk Density Determination

In the lab, samples were weighed, oven dried for 24 hours and re-weighed, with each sample's bulk density calculated using the sample's weight and the volume of the cylinder. Bulk density is a soil's mass per unit volume. The volume of a soil's natural state includes solids and pores, and thus the higher the bulk density, the lower the area taken by pore space. This test can reveal the comparative compaction of soils being sampled, and it is often used to demonstrate a soil's comparative value for water storage and plant production. The results of the bulk density tests are summarized in Appendix II.

Computer Aided Lab Work

The data gathered from the measurements of surface elevation, depth to bedrock, surface layer bulk density, and carbon analysis of surface soils were combined in a Microsoft Excel 2002 spread sheet format with appropriate data assigned to each sample point. The spreadsheet was used to create a shapefile using ArcView 3.3 (Environmental Systems Research Institutes, Inc., ESRI). This shapefile, along with the delineation of the study site area, was then used to interpolate grids to indicate the approximate amount of soil present, the approximate amount of soil lost to erosion, and to determine and display differences in bulk density and soil carbon findings. It should be noted that all research proceeded upon the basic assumption of a continual catena having been present at the site before the introduction of traditional agriculture. That is to say, the original soil present on the northern section of the study site would have formed in response to the underlying geology in the same way as did the southern section of the study site, including the slight rise (trending north to south) as the site is traversed west to east. The Spatial Analyst Module in the ArcView 3.3 was used to interpolate grids using an inverse distance weighted to a power algorithm, and a grid cell size of 0.5 m^2. By subtracting the depth to bedrock from surface elevation measurements, soil thickness was determined. The resulting interpolation was then divided into a 132-unit grid overlay (66 units north of the east-west trending ridge and 66 units south of the ridge), with the average thickness of each unit calculated using the information from all 0.5 m^2 cells located within the unit and assigned to a point applied to the center of each "fishnet" unit. Figure 11 illustrates this grid overlay.

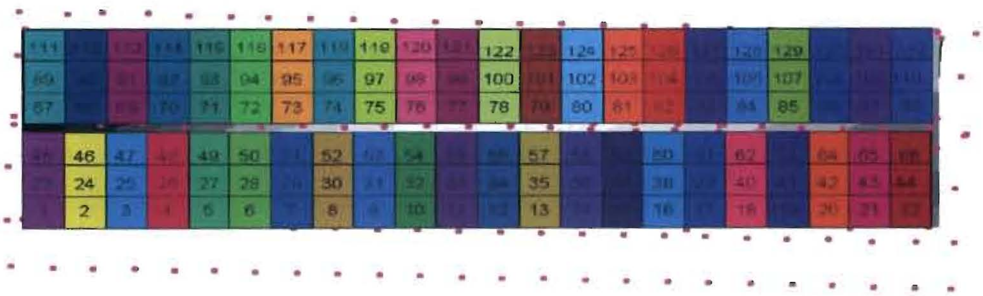

Figure 11. Computer generated grid overlay used to calculate soil lost to erosion.

A point shape file was created, calculating and recording the average depth to bedrock for each cell in the fishnet. Average soil thickness of each cell in the northern (eroded) side of the ridge was compared to the average thickness of each three-celled strip, or summarized zone, of cells in the south (undisturbed soil) to determine approximate volume of soil lost to erosion. Maps illustrating outcomes of these procedures appear in the Results chapter of this study.

Graphing and Statistical Methods

The soil properties data were graphically compared using Microsoft Excel 2002. Descriptive statistics were calculated in spreadsheets and analyzed using box plots. The

Mann-Whitney U test was used to determine if differences in soil properties between eroded and non-eroded soils were statistically significant. The Mann-Whitney U test is the nonparametric equivalent of the T-test. It was selected because the soil data are non-normal in distribution, the sample numbers are relatively small, and our sampling methods were not entirely random. The Anderson-Darling normality test, performed using the Minitab Release II program, was used to determine that the data was non-normal.

Chapter 4:

RESULTS

Soil Cores

The results of the initial soil core descriptions taken at the study site were entered into a spreadsheet, compared, and graphed. Figures 12 and 13 represent the findings.

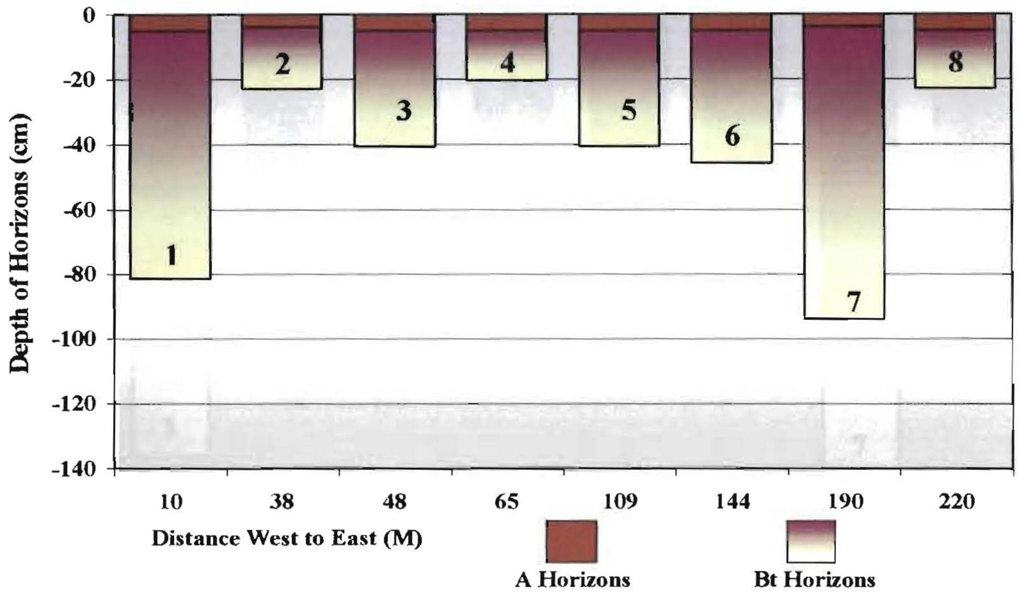

Figure 12. Horizon depths of eroded soils along transect; north of ridge axis.

The graph in Figure 12 represents horizon depths determined from soil core samples taken along an east to west transect in the northern portion of the study site. It clearly illustrates the shallow depth and uniformity of the A horizons across this entire portion of the site. Additionally, the underlying bedrock topography is easily distinguished. Everything else being equal, the depths of the Bt horizons will be greatest where they formed over easily weathered bedrock, i.e. shale. Sampling cores represented by columns numbered 1 and 7 correspond with the soil depth map in Figure 15. Columns

2, 4, and 8 represent cores of soil formed over a more resistant underlying limestone, also indicated on Figure 15. Columns 3, 5, and 6 are of relatively medium depth and represent areas of transition between the weathering rocks beneath the surface. All Bt horizons appear to be nearer to the surface than the Bt horizons determined to be present south of the ridge axis, and there is an absence of an AB horizon.

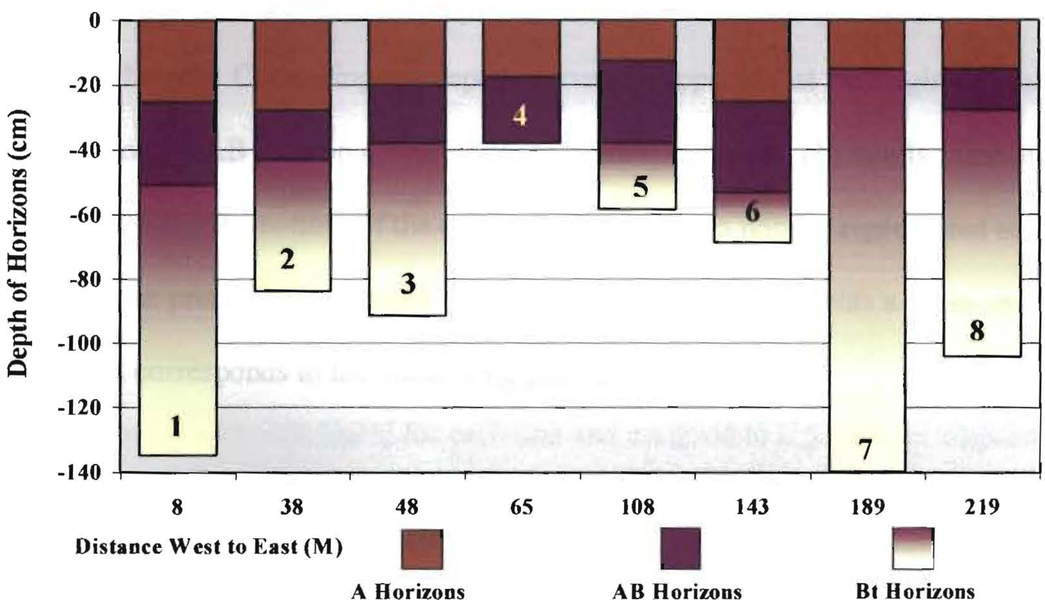

Figure 13. Horizon depth of untilled soil along transect; south of ridge axis.

The graph in Figure 13 represents horizon depths determined from soil core samples taken along an east to west transect in the undisturbed, southern portion of the study site. It illustrates the depth of the A horizons, the presence of an AB horizon, and the depth of the Bt horizon across this area. Here, too, the underlying bedrock topography is easily distinguished. Everything else being equal, the depths of the Bt horizons are interpreted to be greatest where they are forming over easily weathered bedrock, i.e., shale. Sampling cores represented by columns numbered 1, 2, 3, 7, and 8 correspond with the soil depth map in Figure 14. Columns 4 and, possibly, 5 indicate the underlying limestone, also clearly shown on Figure 14. Columns 5 and 6 indicate possible areas of transition between the weathering rocks beneath the surface. The presence of an AB horizon reflects a more fully developed and undisturbed soil, and Bt horizons begin to be distinguished at greater depths.

Most of the A and AB horizons are conspicuously missing from the northern section of the site. Comparing the depth intervals, it appears that the original A and upper part of the AB horizon on the northern section have been physically removed by erosion, allowing the bottom of the original AB horizon to now be represented at the surface by the presently designated A horizon. Each graph represents a cross-section of the site and corresponds to the underlying geology.

Soil Thickness

Figure 14 graphically displays present soil thickness at the study site. This grid was created using surface elevations and depth-to-bedrock grids. It reflects the influences of the underlying geology at the site and indicates the area most affected by erosion (the western third of the northern half of the site), with evidence of some deposition, or less severe erosion, in the extreme northwest corner.

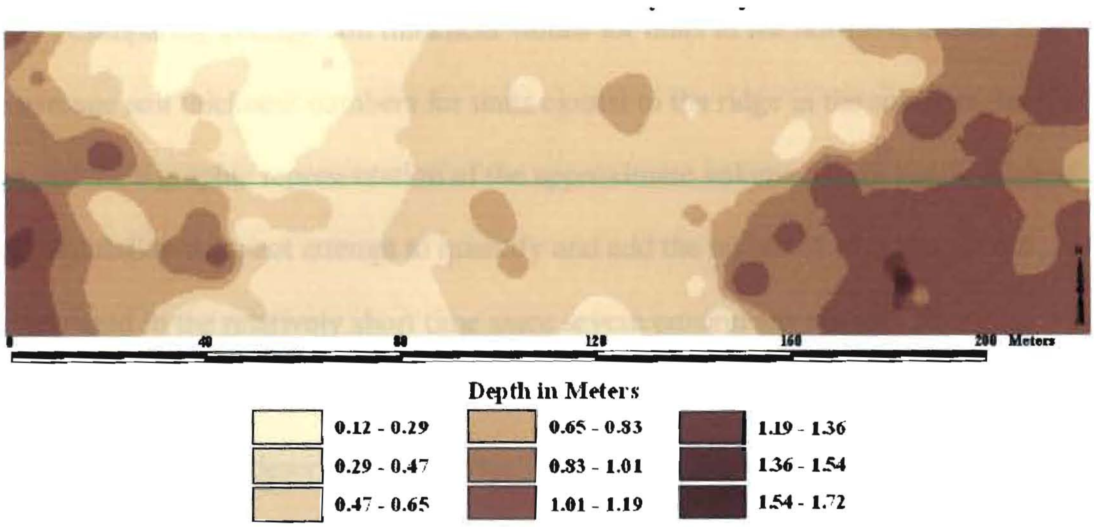

Figure14. Soil thickness interpolated grid. Green line indicates location of ridge axis.

Using the fishnet-like grid overlay described in the previous chapter, average thickness values were calculated for each unit and assigned to a point superimposed on the center of each unit. Figure 15 represents this initial overlay.

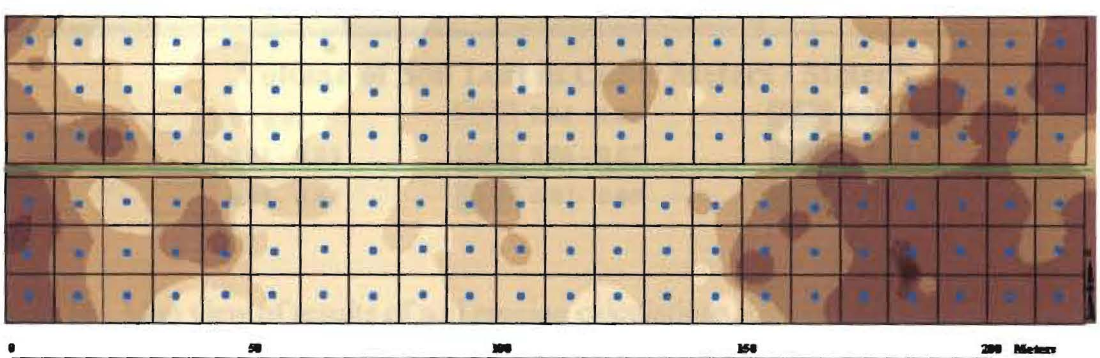

Figure 15. Soil thickness map with "fishnet" overlay. Green line indicates location of ridge axis.

Comparing average soil thickness values for units in the northern, eroded area to the average soil thickness numbers for units closest to the ridge in the southern, native area yielded a graphic representation of the approximate volume of soil lost to erosion. This calculation does not attempt to quantify and add the regenerated and recovering soil accumulated in the relatively short time since severe erosion has ceased. This data will be used and further described in the Conclusions chapter. Figure 16 shows the results of this calculation. The described ridge which developed as a result of erosional events remains clearly visible though unmarked graphically on this map. The process for this procedure is described in the Chapter 3, Site and Methods.

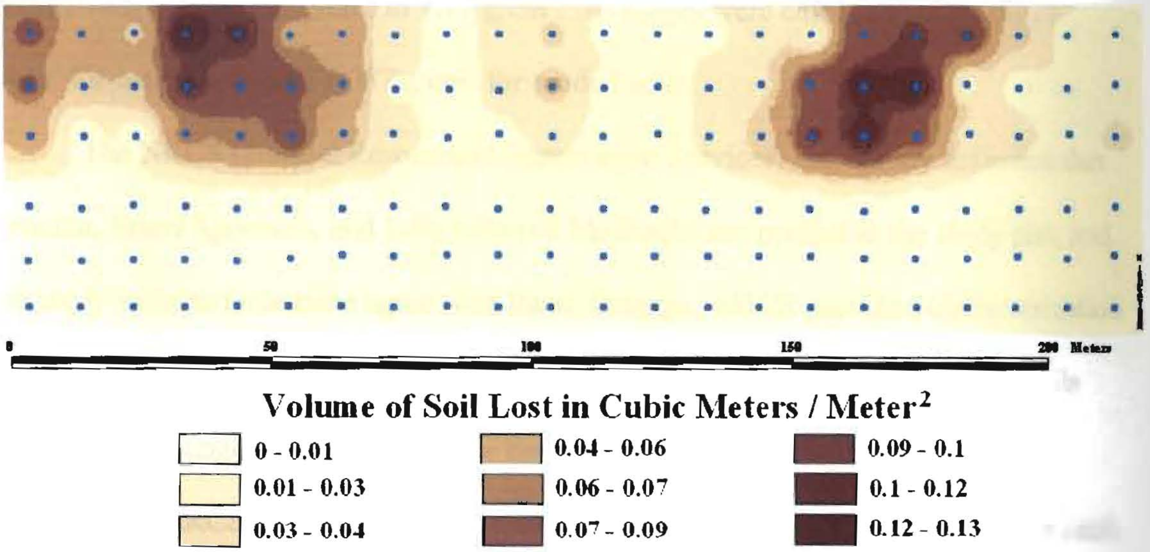

Figure 16. Map view of results of soil erosion calculations. Unmarked ridge remains clearly defined.

Bulk Density

Bulk density is a soil's mass per unit volume, and in Mollisols, it tends to increase with depth. The volume of a soil's natural state includes solids and pores, and thus the higher the bulk density, the lower the area taken by pore space. This test can reveal the comparative compaction of soils being sampled, and it is often used to demonstrate a soil's comparative value for water storage and plant production. This study tested the upper 25 cm of soil because that was the area for data appropriate to the research being done. The results of the sampling for bulk density of the site's soils are shown in Appendix 2. The range of bulk density numbers for the samples taken from the native soil is from 0.79 g/cm^3 to 1.05 g/cm^3. Samples taken from eroded soils yielded a bulk density range from 0.91 g/cm^3 to 1.17 g/cm^3. Averages were calculated to be 0.919 g/cm^3 for native soils and 1.087 g/cm^3 for eroded soils.

The NRCS (Natural Resources Conservation Services) soil survey indicates that Kenoma, Eram/Apperson, and Lula soils (all Mollisols) are present at the study site, and this study's characterizations agree with those findings. NRCS provided characterization data for eleven Kenoma soil samples, but only two bulk density figures for these soils within a depth range of 0-12 cm. These figures are 1.53 g/cm^3 and 1.34 g/cm^3. Additionally, NRCS data for Apperson and Eram soils consisted of two samples for each soil. All four records contained bulk density information and reported 1.35 g/cm^3 for each Apperson sample and 1.64g/cm^3 and 1.40 g/cm^3 for the Eram soils tested. Lacking knowledge of the methods used to determine these findings, and absent a standardization of this test when used for research, it was decided to forego using this data for significant comparisons.

Figure 17 represents the interpretation of bulk density data, and shows greater bulk density indicated on the eroded (northern) portion of the study site. These samples represent surface bulk density findings and reflect the erosion patterns displayed on map Figure 17. It is expected that bulk density increases with depth. It is also possible to increase bulk density (both surface and at depth) through anthropogenic activity, i.e. traditional agricultural practices, deliberate road building, repeated foot or vehicle crossings in confined pathways. The ridge that developed as a result of erosional events is unmarked on this map, and yet remains visible in the field and on the map.

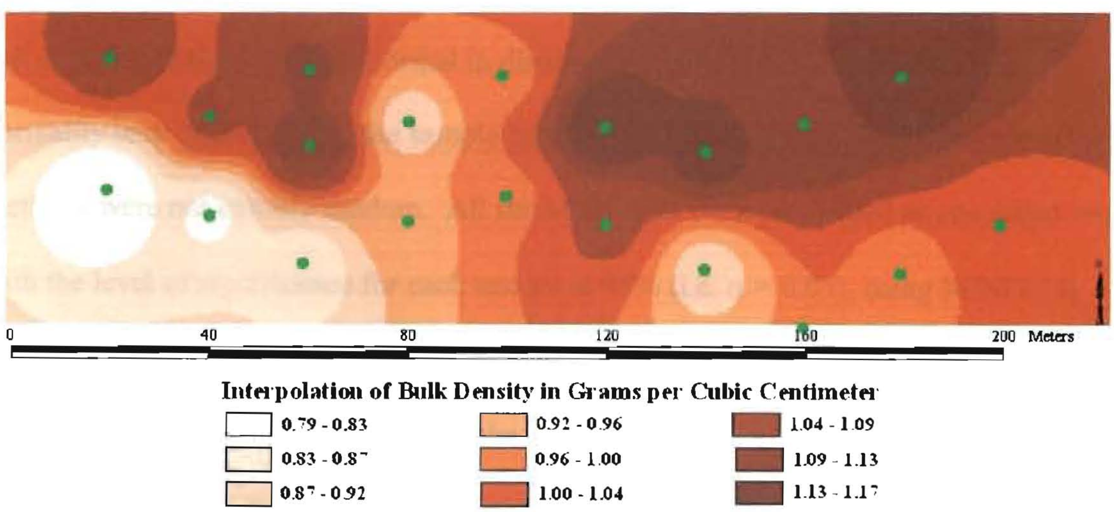

Figure 17. Bulk density interpolation at study site. Green dots identify sampling points.

Statistical Analysis of Soil Properties

The complete results of the laboratory soils analyses for nitrogen and carbon were received from Kansas State University Soils Lab in spread sheet form. Descriptive used to graphically compare soil carbon and nitrogen data between eroded and native soils and to establish formal hypotheses to test. In general these hypotheses can be stated as follows:

H_{null} – there is no statistically significant difference in soil carbon and nitrogen concentrations between untilled and eroded soils.

$H_{alternative}$ – soil carbon and nitrogen concentrations are significantly higher in untilled soils than in eroded soils.

The Mann-Whitney U test was used to test the above hypotheses. The Mann-Whitney U test is the non-parametric equivalent of the T-test. It was selected because the soil data was determined non-normal in distribution using the Anderson-Darling normality test. Additionally, the sample numbers are relatively small, and the sampling methods were not entirely random. All statistical tests were performed as one tailed tests with the level of significance for each test set at 95% (i.e. $\alpha = 0.05$), using MINITAB Release 11 program for Windows.

Figure 18 represents data from the upper 40 cm of soil on both the northern and southern portions of the site. Concentrations of soil nitrogen, total carbon, and total organic carbon appear to be higher in native soils than in eroded soils. In all three cases the results of the Mann-Whitney U tests indicated that these apparent differences were, in fact, statistically significant, and the alternative hypothesis is accepted.

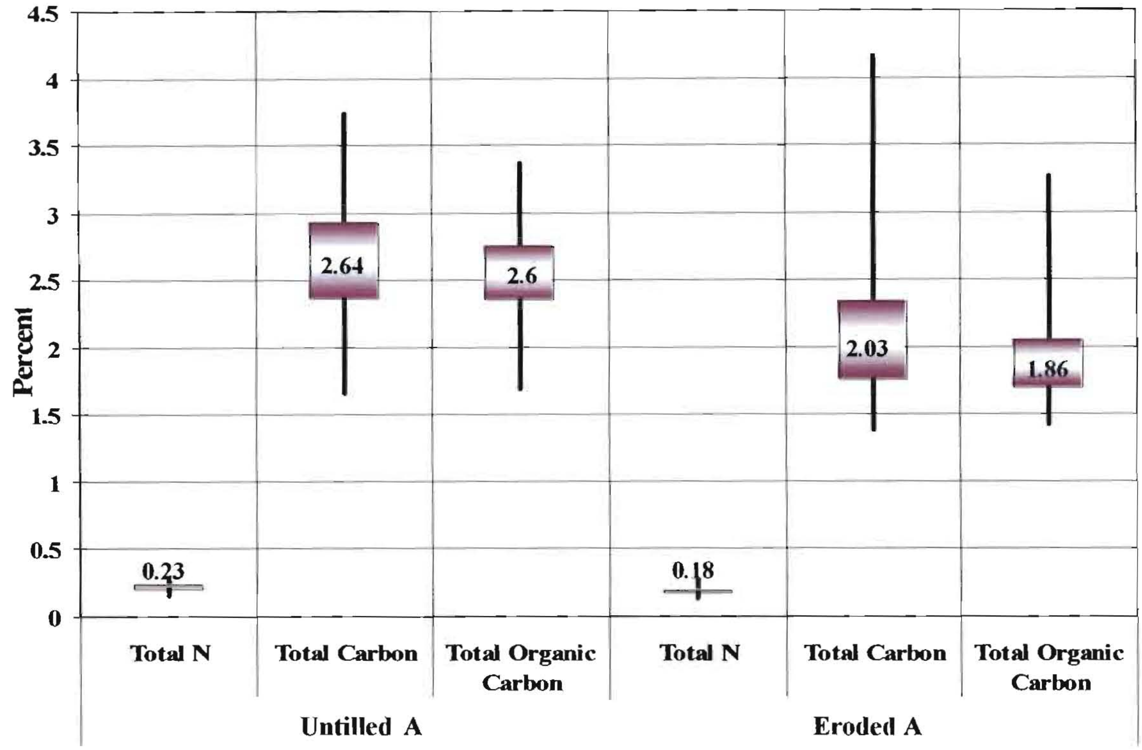

Figure 18. Results of analysis in the upper 40 cm of soil. Untilled samples (46) are compared with 46 samples from eroded area. Percentages shown are median values.

Figure 19 represents data from the 41-80 cm depth interval of soil on both the northern and southern portions of the site. Concentrations of soil nitrogen, total carbon, and total organic carbon appear to be higher in untilled soils than in eroded soils. However, with the parameters of our hypotheses, the results of the Mann-Whitney U tests indicated that there is no statistically significant difference between the percentage of nitrogen present in the untilled soil and the percentage of nitrogen present in the eroded soil at this depth, so we accept the null hypothesis. Additionally, within the parameters of our hypotheses, the results of the Mann-Whitney U tests indicated that there is no statistical significance between the percentage of total carbon present in the native soil and the percentage of total carbon present in the eroded soil, so the null hypothesis is accepted for this test as well. When comparisons of the percentage of total *organic* carbon present in each soil were made, the Mann-Whitney U tests resulted in finding the amount of total *organic* carbon in the native soil to be significantly different from the amount in the eroded soil, and we accept the alternative hypothesis.

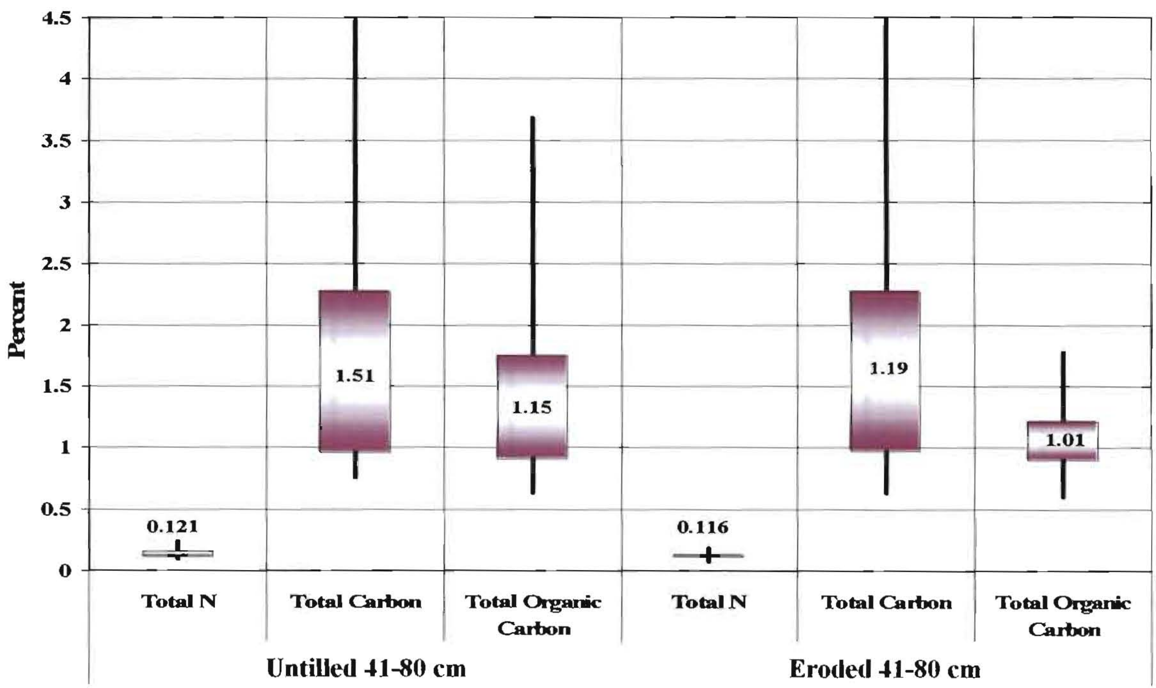

Figure 19. Results of analysis of soil in the 41-80 cm level. Untilled samples (40) are compared with 35 samples from eroded area. Percentages shown are median values.

Additionally, the upper 40 cm of the northern, eroded section of the site was compared with the 41-80 cm layer of the southern, undisturbed section. If erosional processes removed the original surface horizon from the northern portion of the study site, then the present surface there is actually the sub-surface (Bt) horizon of the original soil, and statistically similar concentrations of nitrogen, total carbon, and total organic carbon would be present. Similarities or differences could be determined by comparing the surface horizon of the previously eroded area with the sub-surface (Bt) horizon of the untilled soil. Figure 20 represents this data.

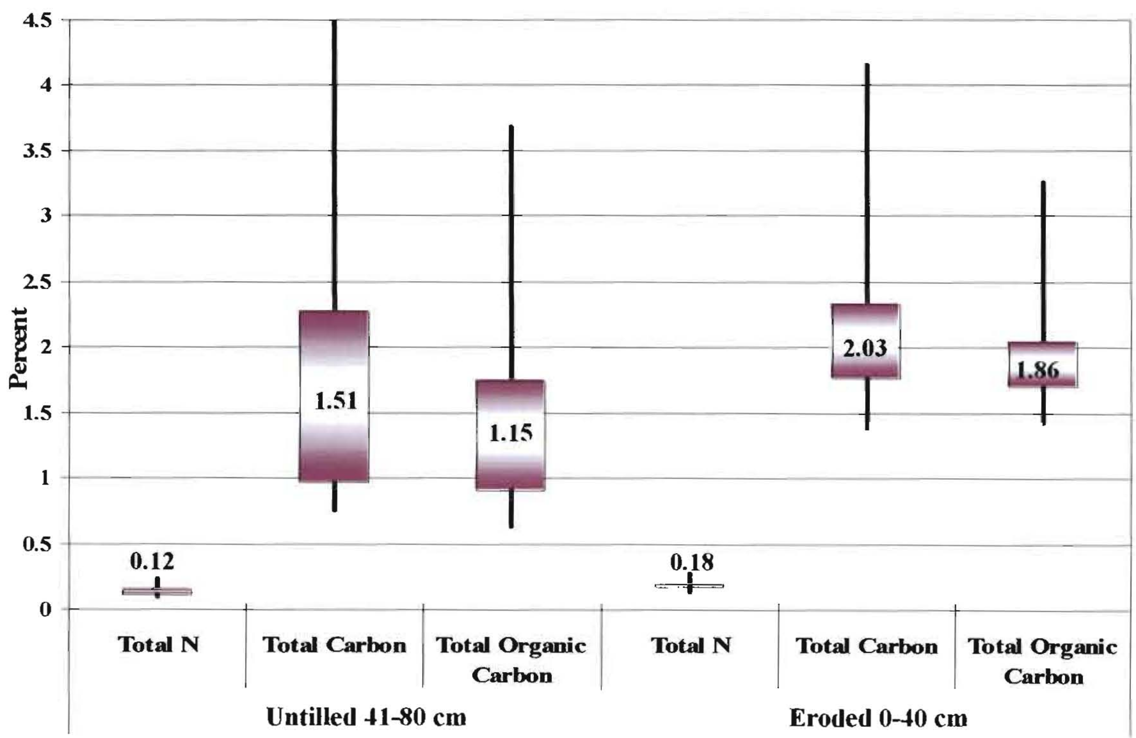

Figure 20. Results of analysis comparing upper 40 cm of eroded soil with 41-80 cm layer of adjacent untilled soil.

For this comparison, a two tailed test was run. Because equal horizons were not being compared, it was deemed necessary to change the hypotheses to reflect only whether the percentage amounts for nitrogen, total carbon, and/or total organic carbon in these two areas were the same or different, without assumptions of greater than or lesser than being applied.

H_{null} – there is no statistically significant difference in soil carbon and nitrogen concentrations between native and eroded soils.

$H_{alternative}$ – soil carbon and nitrogen concentrations are significantly different in native soils than in eroded soils.

The Mann-Whitney U tests indicated that the concentrations of soil nitrogen, total carbon, and total organic carbon are different in eroded soils than in native soils, and that in all three cases the results were, in fact, statistically significant. The alternative hypothesis for these findings was accepted.

SUMMARY AND CONCLUSIONS

In this study, analyses of soil samples from a site in Coffey County, Kansas were used to compare properties of a native, undisturbed soil to the properties of the adjacent, eroded soil. These results were used to determine the impacts of anthropogenic activity (i.e., traditional agricultural activities) and erosion on the properties of the native soil. Past studies (Huang, et al., 2002; Kimble, et al., 2001; Allmaras, et al., 2000; Knops and Tilman, 2000; Pulleman, et al., 2000; Cambardella and Elliot, 1993; L. K. Mann, 1986; and Bauer and Black, 1981) have concluded that traditional agricultural activities result in soil compaction, increased vulnerability to erosion, and diminished soil structural stability and reduced overall soil thickness and quality. Because the study site in eastern Kansas contains abundant carbon-rich soils (Mollisols) that have been influenced by a relatively short agricultural land use history (150 +/- years), it presents an ideal environment for a region-specific study of land use effects on soil properties. By comparing soil horizon thickness, soil depth to bedrock, surface bulk density data, and soil nutrient characteristics from untilled soil to corresponding data from soils that have been tilled and eroded and that are currently recovering, changes in soil nitrogen, soil carbon and overall soil quality were identified. In addition, the data collected were used to explore the volume of soil lost to the erosional process and the changes in soil profile characteristics that exist in the eroded soils.

Soil Horizon Thickness

The horizons of the untilled prairie soils were generally more highly developed and of greater individual thickness than the horizons of the soils that had been eroded. Figure 12 graphs the horizon thicknesses of the eroded soils and shows the thickest A horizon to be <8 cm, an absence of an AB horizon, and the deepest Bt horizon to be <100 cm from the surface, with the majority of Bt horizon depths to be <50 cm from the surface. Figure 13 graphs the horizon depths of the native soils and shows the majority of A horizon thicknesses to be >20 cm, clear evidence of a developed AB horizon, and a majority of Bt horizons beginning to be distinguished at greater depths and reaching >80 cm from the surface with three samples determined to have Bt horizons reaching >100 cm from the surface. It is concluded that erosion has physically removed the original A horizon and the upper part of the original AB horizon from the northern part of the study site. While it is generally known that the rates of natural processes of erosion, transportation and deposition are accelerated by the activities associated with traditional agricultural methods of plowing, tilling, and disking, this study quantifies the effects of such land use activity. Also, the land used in this particular study exhibits an additional component – the current evidence (ridge) of the boundaries of these activities.

Soil Depth to Bedrock

By establishing the depth from the soil surface to the underlying bedrock, soil volumes were calculated and used to determine soil loss. Figure 14 reflects this calculation. Figure 16 illustrates the volume of soil lost to erosion in cubic meters per square meter of surface as are distributed across the northern half of the study site. The evidence interpreted on this map, combined with land use history, supports the conclusion that soil in the northern half of the site was physically removed as a result of erosion and transportation. There is some evidence of deposition or less severe erosion in the northwestern corner. Areas in the extreme northeastern corner also appear to be of greater depth, and this may be due in some part to deposition from erosion or from a greater rate of recovery. However, since there is less discrepancy between the soil depth at the ridge in the eastern portion of the site, it is also possible the topography of this area helped to prevent extensive transportation of disturbed soil. Further, this may be a result of the weathering of the underlying bedrock (shale). These calculations emphasize the negative impacts of accelerated erosion of organic soils, and give quantitative values for discussion and debate.

Bulk Density

Given that bulk density increases with depth, it is tempting to use the results of surface bulk density testing as evidence to support the determination that the present A horizon on the eroded (northern) half of the study site was originally an AB and/or a Bt horizon before erosion exhumed it. This alone is not sufficient, however, since the land use history for this portion of the site includes repeated cross field trips by tractors and farm implements which can also cause compaction of soil and thus increase bulk density as well as mixing of surface and subsurface soil. When compared to the native soil, it is, however, conclusive evidence that one or both of these processes contributed to the increased bulk density of the soil north of the present ridge.

Soil Nutrient Characteristics

Concentrations of soil nitrogen, total carbon, and total organic carbon were found to be significantly higher ($\alpha = 0.05$) in samples taken from the upper 40 cm of the native soil when compared with their mirrored samples taken from upper 40 cm of the eroded soil (Figure 18). This evidence points to the conclusion that higher quality of soil is in the undisturbed, native portion of the site. It also supports the conclusion that the effects of erosional processes on surface soil in the northern portion of the site are detrimental to soil quality as defined by this study.

Concentrations of soil nitrogen, total carbon, and total organic carbon appear to be higher in samples taken from the 40-80 cm depth intervals of the native soil when compared with their mirrored samples taken from the 40-80 cm depth interval of the eroded soil (Figure 19). Total organic carbon present in the native soil was found to be significantly higher as compared with the eroded soil ($\alpha = 0.05$). It can be concluded, therefore, that although the visible roots included in each sample were removed by hand, the presence of residue from extensive plant root structures (root hairs, increased amounts of decomposed root parts) adds to the total percentage of carbon in an undisturbed soil at this depth. It was found, however, that there is no statistically significant difference between the percentage of nitrogen present in the native and eroded soils, nor is there a statistically significant difference between the percentages of total carbon present in these soils at these depths. It is concluded that this indicates the effects of surface erosion have less impact at this depth, and that the carbon contributed by the underlying weathering rock and the nitrogen present at this depth are at a relatively steady state across the site.

Additionally, it should be noted that some nutrients continue to be removed from the native soil at each year's hay harvest.

Concentrations of soil nitrogen, total carbon, and total organic carbon appear to be significantly higher in samples taken from the 40-80 cm depth intervals of the native soil when compared with their mirrored samples taken from the 0-40 cm depth interval of the eroded soil (Figure 20). Since this comparison involved two distinctly different horizons (the A horizon of the eroded soil vs. the AB-Bt horizon of the native soil), the statistical testing was performed to simply determine whether or not there was a difference. If the soil in the original A horizon of the northern part of the site had simply been eroded and transported, the values for the nutrients present in what would then be the surface or A horizon should be the same as those found in the original AB-Bt horizon. This original horizon is still in tact in the native soil, and it was used for comparison. As seen in the results, we found there is a statistically significant difference between the two samplings, with the eroded soil's A horizon actually showing higher values for these nutrients. These are statistics from which several conclusions can be drawn.

First, it is possible that the erosional process did not remove the entire original A horizon from the northern part of the site. Secondly, the traditional agricultural activities to which repeated reference has been made are also responsible for mixing and churning what is left of the original A horizon into the original AB and, possibly, the original upper Bt horizon together. While this exposes once protected soil to the surface environment, it also works to distribute organically rich surface soil and plant residue throughout near-surface and sub-surface horizons. Thirdly, increased nutrients in the eroded soil's A could be the result of the plants that have colonized the soil since farming practices ended. If so, it can be concluded that the soil in the northern, eroded side of the ridge has begun to heal and regenerate. This process may be changing the site from a carbon source to a carbon sink as CO_2 is taken from the atmosphere and sequestered in the now undisturbed but recovering soil.

This site holds great value and potential for future studies. Its advantages, outlined in earlier text, remain unchanged. Added to these advantages now is a baseline of sorts for monitoring changes in the soil. It is hoped that the site will be revisited for further, perhaps more in-depth, research on soil recovery and carbon sequestration rates every five years. It is also hoped that it be made available for interdisciplinary studies, as a record of plant and animal successions may prove valuable also.

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Field Sample Data Sheet

Sample Number:

Date: Location: Mapped Series: Vegetation:

Horizons / Parameters	Texture	Munsell Color	Mottles / Color	Mollic	Soil Thickness	Moisture / Conditions

Comments:

Sample Number:

Date: Location: Mapped Series: Vegetation:

Horizons / Parameters	Texture	Munsell Color	Mottles / Color	Mollic	Soil Thickness	Moisture / Conditions

Comments:

Bulk Density Sample Data
Gridley, Kansas - 2003

Sample # and Location	Weight: Sample Plus Container	B=Beaker Wt. b=bag Wt.	Wet Sample Weight	Dry Weight: Sample Plus Container	Empty Cup Weight	Dry Sample Weight	Sample Volume	Bulk Density
(U) **1** (2, 2.5)	287.12 g	(B) 186.0 g	101.12 g	86.36 g	10.14 g	76.22 g	96.22 cm3	0.79g/cm3
(E) **2** (2, 5)	142.87 g	(b) 8.75 g	134.12 g	112.59 g	9.97 g	102.62 g	96.22 cm3	1.07g/cm3
(U) **3** (**4**. 2)	112.78 g	(b) 8.27 g	104.51 g	89.36 g	9.79 g	79.57 g	96.22 cm3	0.83g/cm3
(E) **4** (4, 4)	139.19 g	(b) 8.33 g	130.86 g	110.80 g	9.81 g	100.99 g	96.22 cm3	1.05g/cm3
(U) **5** (6, 1)	123.85 g	(b) 8.45 g	115.40 g	91.92 g	10.12 g	81.8 g	96.22 cm3	0.85g/cm3
(E) **6** (6, 3.5)	145.52 g	(b) 8.35 g	137.17 g	118.76 g	10.11 g	108.65 g	96.22 cm3	1.13g/cm3
(E) **7** (6, 5)	143071 g	(b) 8.68 g	135.03 g	116.27 g	10.41 g	105.86 g	96.22 cm3	1.10g/cm3
(U) **8** (8, 2)	120.95 g	(b) 8.52 g	112.43 g	100.12 g	10.10 g	90.02 g	96.22 cm3	0.94g/cm3
(E) **9** (8, 4)	122.75 g	(b) 8.44 g	114.31 g	98.18 g	10.59 g	87.59 g	96.22 cm3	0.91g/cm3
(U) **10** (10, 2.5)	134.06 g	(b) 8.41 g	125.65 g	106.82 g	10.47 g	96.35 g	96.22 cm3	1.00g/cm3
(E) **11** (10, 5)	131.53 g	(b) 8.37 g	123.16 g	106.45 g	10.15 g	96.30 g	96.22 cm3	1.00g/cm3
(U) **12** (12, 2)	138.86 g	(b) 8.40 g	130.46 g	110.54 g	9.90 g	100.64 g	96.22 cm3	1.05g/cm3
(E) **13** (12, 4)	152.38 g	(b) 8.48 g	143.90 g	123.62 g	10.66 g	112.96 g	96.22 cm3	1.17g/cm3
(U) **14** (14, 1)	120.49 g	(b) 8.59 g	111.90 g	97.84 g	10.60 g	87.24 g	96.22 cm3	0.91g/cm3
(E) **15** (14, 3.5)	149.78 g	(b) 8.28 g	141.50 g	120.42 g	10.14 g	110.28 g	96.22 cm3	1.15g/cm3
(U) **16** (16, 0)	112.98 g	(b) 8.59 g	104.39 g	87.45 g	10.10 g	77.35 g	96.22 cm3	0.80g/cm3
(E) **17** (16, 4)	146.63 g	(b) 8.42 g	138.21 g	117.88 g	10.45 g	107.43 g	96.22 cm3	1.12g/cm3
(U) **18** (18, 1)	132.08 g	(b) 8.68 g	123.40 g	105.73 g	10.12 g	95.61 g	96.22 cm3	0.99g/cm3
(E) **19** (18, 5)	149.41 g	(b) 8.39 g	141.02 g	122.45 g	9.86 g	112.59 g	96.22 cm3	1.17g/cm3
(U) **20** (20, 2)	139.69 g	(b) 8.57 g	131.12 g	109.82 g	10.56 g	99.26 g	96.22 cm3	1.03g/cm3

Bulk Density = oven dried mass weight divided by volume of sample.

Samples dried @105 degrees C for 24 hours.

Untilled Soil (in g/cm3)		Eroded Soil (in g/cm3)	
0.79	1.05	1.07	1.00
0.83	0.91	1.05	1.17
0.85	0.80	1.13	1.15
0.94	0.99	1.10	1.12
1.00	1.03	0.91	1.17

Untilled Soil Average Bulk Density: 0.919 g/cm3

Eroded Soil Average Bulk Density: 1.087 g/cm3

			0-40 cm Data: Eroded Soil				
					Total	Inorganic	
CoreID	Depth Interval	KSU SampleID	Total N	Total Carbon	Organic Carbon	Carbon	CaCO3
0, 4	0 - 40	192	0.149	1.75	1.66	0.09	0.8
0, 6	0 - 40	189	0.138	1.63	1.62	0.01	0.1
10, 3.5	0 - 40	155	0.142	1.46	1.45	0.01	ND
10. 5	0 - 40	153	0.183	2.10	1.88	0.22	1.8
12, 4	0 - 40	148	0.196	2.07	2.03	0.04	0.3
12, 6	0 - 40	146	0.195	2.16	2.14	0.02	0.2
14, 3.5	0 - 40	140	0.181	2.07	2.05	0.02	0.2
14, 5	0 - 40	138	0.182	2.02	2.04	-0.02	ND
16, 4	0 - 40	130	0.199	2.16	2.17	-0.01	ND
16, 6	0 - 40	129	0.160	1.74	1.69	0.05	0.4
18, 3.5	0 - 40	121	0.160	1.72	1.74	-0.02	ND
18, 5	0 - 40	118	0.203	2.35	2.40	-0.05	ND
2, 3.5	0 - 40	182	0.177	2.23	2.09	0.14	1.2
2, 5	0 - 40	179	0.141	1.71	1.74	-0.03	ND
20, 4	0 - 40	110	0.167	1.69	1.67	0.02	0.2
20, 6	0 - 40	107	0.211	2.29	2.20	0.09	0.7
22, 3.5	0 - 40	98	0.176	1.64	1.62	0.02	0.2
22, 6	0 - 40	96	0.193	1.78	1.75	0.03	0.3
4, 4	0 - 40	173	0.159	2.23	1.88	0.35	2.9
4, 6	0 -8	171	0.282	3.37	3.26	0.11	0.9
6, 3.5	0 - 27	167	0.174	4.16	1.65	2.51	20.9
6, 5	0 - 24	166	0.221	2.42	2.28	0.14	1.2
8, 4	0 - 40	162	0.154	1.54	1.56	-0.02	ND
8, 6	0 - 35	160	0.201	2.59	2.03	0.56	4.7
R 11	0 - 40	75	0.177	1.80	1.81	-0.01	ND
R 13	0 - 40	71	0.167	1.84	1.86	-0.02	ND
R 15	0 - 40	67	0.180	1.92	1.90	0.02	0.2
R 17	0 - 40	62	0.190	2.11	2.05	0.06	0.5
R 2	0 - 40	90	0.182	1.94	1.87	0.07	0.6
R 20	0 - 40	53	0.181	1.97	1.94	0.03	0.3
R 22	0 - 40	48	0.147	1.38	1.42	-0.04	ND
R 24	0 - 40	42	0.147	1.39	1.44	-0.05	ND
R 25	0 - 40	39	0.173	1.86	1.84	0.02	0.2
R 28	0 - 40	30	0.177	1.87	1.86	0.01	ND
R 3	0 - 40	88	0.159	3.23	1.47	1.76	14.7
R 30	0 - 40	27	0.156	1.68	1.74	-0.06	ND
R 32	0 - 40	23	0.185	2.03	2.02	0.01	ND
R 33	0 - 40	21	0.169	1.82	1.84	-0.02	ND
R 35	0 - 40	17	0.171	2.71	1.69	1.02	8.5
R 37	0 - 33	13	0.203	3.21	1.80	1.41	11.8
R 39	0 - 18	11	0.224	3.24	2.23	1.01	8.4
R 41	0 - 34	1	0.175	2.44	1.68	0.76	6.3
R 43	0 - 40	6	0.167	1.77	1.75	0.02	0.2
R 6	0 - 9	82	0.244	2.62	2.51	0.11	0.9
R 7	0 - 30	81	0.227	3.13	2.25	0.88	7.3
R 9	0 - 40	79	0.194	2.23	1.93	0.30	2.5
					Total		
			Total N	Total Carbon	Organic Carbon		
		average	0.181	2.154	1.902		
		Median	0.177	2.025	1.860		
		Minimum	0.138	1.380	1.420		
		Maximum	0.282	4.160	3.260		
		1st Quartile	0.16175	1.755	1.69		
		3rd Quartile	0.19475	2.335	2.0475		
					Total		
			Total N	Total Carbon	Organic Carbon		
		3rd Quartile	0.19475	2.335	2.0475		
		Maximum	0.282	4.16	3.26		
		Minimum	0.138	1.38	1.42		
		1st Quartile	0.16175	1.755	1.69		

			0-40 cm Data: Untilled Soil				
					Total		
CoreID	Depth Interval	KSU SampleID	Total N	Total Carbon	Organic Carbon	Inorganic Carbon	CaCO3
0, 0	0 - 40	198	0.151	1.86	1.97	-0.11	ND
0, 2	0 - 40	195	0.197	2.49	2.38	0.11	0.9
10, 1	0 - 40	159	0.213	2.41	2.31	0.10	0.8
10, 2.5	0 - 40	157	0.219	2.47	2.47	0.00	ND
12, 0	0 - 40	151	0.234	2.62	2.76	-0.14	ND
12, 2	0 - 40	150	0.237	3.61	2.58	1.03	8.6
14, 1	0 - 40	144	0.228	2.57	2.62	-0.05	ND
14, 2.5	0 - 40	142	0.236	2.73	2.80	-0.07	ND
16, 0	0 - 40	136	0.207	2.38	2.35	0.03	0.2
16, 2	0 - 40	133	0.242	2.78	2.84	-0.06	ND
18, 1	0 - 40	127	0.164	1.70	1.69	0.01	0.1
18, 2.5	0 - 40	124	0.200	2.09	2.11	-0.02	ND
2, 1	0 - 40	186	0.205	2.78	2.75	0.03	0.2
2, 2.5	0 - 40	184	0.223	2.89	2.85	0.04	0.3
20, 0	0 - 40	116	0.181	1.95	1.93	0.02	0.2
20, 2	0 - 40	113	0.182	1.87	1.87	0.00	ND
22, 1	0 - 40	104	0.241	2.58	2.63	-0.05	ND
22, 2.5	0 - 40	101	0.187	1.99	2.00	-0.01	ND
4, 0	0 - 33	177	0.246	3.39	3.37	0.02	0.2
4, 2	0 - 40	176	0.223	3.13	2.74	0.39	3.3
6, 2.5	0 - 40	169	0.195	3.57	2.71	0.86	7.2
6, 1	0 - 40	170	0.213	3.65	2.64	1.01	8.4
8, 0	0 - 30	165	0.241	3.74	2.65	1.09	9.1
8, 2	0 - 40	164	0.230	3.49	2.38	1.11	9.3
R 1	0 - 40	93	0.217	2.42	2.42	0.00	ND
R 10	0 - 40	77	0.254	2.78	2.67	0.11	0.9
R 12	0 - 40	73	0.264	2.63	2.55	0.08	0.7
R 14	0 - 40	69	0.207	2.34	2.35	-0.01	ND
R 16	0 - 40	65	0.255	2.82	2.76	0.06	0.5
R 18	0 - 40	59	0.226	2.50	2.47	0.03	0.2
R 19	0 - 40	56	0.172	1.75	1.77	-0.02	ND
R 21	0 - 40	51	0.200	2.08	2.06	0.02	0.2
R 23	0 - 40	45	0.169	1.66	1.74	-0.08	ND
R 26	0 - 40	36	0.184	1.81	1.83	-0.02	ND
R 27	0 - 40	33	0.238	2.64	2.65	-0.01	ND
R 29	0 - 40	29	0.233	2.74	2.75	-0.01	ND
R 31	0 - 40	25	0.210	2.50	2.40	0.10	0.8
R 34	0 - 40	19	0.202	2.35	2.35	0.00	ND
R 36	0 - 40	15	0.241	3.31	2.41	0.90	7.5
R 38	0 - 40	12	0.257	3.36	3.02	0.34	2.8
R 4	0 - 40	86	0.250	2.96	2.91	0.05	0.4
R 40	0 - 40	10	0.239	2.85	2.93	-0.08	ND
R 42	0 - 40	8	0.236	2.93	3.25	-0.32	ND
R 44	0 - 40	4	0.226	2.75	2.74	0.01	ND
R 5	0 - 40	84	0.260	2.94	2.92	0.02	0.2
R 8	0 - 40	80	0.246	2.87	2.65	0.22	1.8
			Total N	Total Carbon	Total Organic Carbon		
		average	0.219	2.646	2.500		
		Median	0.225	2.635	2.600		
		Minimum	0.151	1.660	1.690		
		Maximum	0.264	3.740	3.370		
		1st Quartile	0.2005	2.3575	2.35		
		3rd Quartile	0.2405	2.92	2.75		

			41-80 cm Data: Eroded Soil				
					Total		
CoreID	Depth Interval	KSU SampleID	Total N	Total Carbon	Organic Carbon	Inorganic Carbon	CaCO3
12, 6	40 - 52	145	0.119	5.48	1.22	4.26	35.5
R 9	40 - 61	78	0.116	4.81	0.84	3.97	33.1
R 35	40 - 58	16	0.081	4.89	1.24	3.65	30.4
R 3	40 - 53	87	0.111	3.49	0.68	2.81	23.5
R 33	40 - 54	20	0.125	3.87	1.09	2.78	23.2
10, 5	40 - 55	152	0.103	3.92	1.18	2.74	22.8
12, 4	40 - 55	147	0.144	3.79	1.20	2.59	21.6
4, 4	40 - 53	172	0.116	2.87	1.09	1.78	14.8
16, 6	40 - 60	128	0.114	2.27	1.00	1.27	10.6
R 11	40 - 56	74	0.137	2.25	1.01	1.24	10.3
R 43	40 - 44	5	0.156	2.29	1.48	0.81	6.8
R 30	40 - 54	26	0.120	1.64	1.03	0.61	5.1
R 32	40 - 52	22	0.150	1.86	1.45	0.41	3.4
10, 3.5	40 - 60	154	0.101	1.02	0.66	0.36	3.0
14, 3.5	40 - 48	139	0.186	2.01	1.78	0.23	1.9
R 13	40 - 80	70	0.092	0.92	0.71	0.21	1.8
2, 5	40 - 50	178	0.098	1.04	1.00	0.04	0.4
R 25	40 - 80	38	0.097	0.63	0.60	0.03	0.3
18, 5	40 - 55	117	0.141	1.32	1.29	0.03	0.3
R 20	40 - 46	52	0.132	1.18	1.15	0.03	0.3
0, 4	41 - 80	191	0.072	0.71	0.68	0.03	0.2
8, 4	40 - 48	161	0.117	0.98	0.96	0.03	0.2
0, 6	41 - 80	188	0.080	0.78	0.75	0.03	0.2
18, 3.5	40 - 80	120	0.089	0.65	0.63	0.03	0.2
R 24	40 - 80	41	0.114	0.94	0.93	0.01	0.1
R 15	40 - 57	66	0.166	1.37	1.36	0.01	ND
R 22	40 - 80	47	0.116	0.93	0.93	0.00	ND
2, 3.5	40 - 80	181	0.088	0.98	0.97	0.00	ND
20, 4	40 - 80	109	0.102	0.83	0.85	-0.02	ND
22, 6	40 - 80	95	0.123	0.94	0.96	-0.02	ND
20, 6	40 - 80	106	0.113	0.98	1.00	-0.02	ND
22, 3.5	40 - 80	97	0.150	1.20	1.23	-0.03	ND
R 2	40 - 58	89	0.136	1.19	1.23	-0.04	ND
R 17	40 - 80	61	0.118	1.03	1.07	-0.04	ND
14, 5	40 - 63	137	0.122	1.07	1.13	-0.06	ND
			Total N	Total Carbon	Total Organic Carbon		
		Average	0.118	1.89	1.04		
		Median	0.116	1.19	1.01		
		Eroded	Total N	Total Carbon	Total Organic Carbon		
		3rd Quartile	0.134	2.28	1.21		
		Maximum	0.186	5.48	1.78		
		Minimum	0.072	0.63	0.6		
		1st Quartile	0.102	0.96	0.886		

			41-80 cm Data: Untilled Soil				
					Total		
CoreID	Depth Interval	KSUSampleID	Total N	Total Carbon	Organic Carbon	Inorganic Carbon	CaCO3
R 36	40 - 45	14	0.124	7.03	3.68	3.35	27.91667
8, 2	40 - 52	163	0.0944	5.31	3.28	2.03	16.91667
R 5	40 - 46	83	0.239	2.38	2.39	-0.01	ND
14, 1	40 - 43	143	0.218	2.23	2.28	-0.05	ND
R 29	40 - 45	28	0.205	2.06	2.06	0	ND
R 40	40 - 50	9	0.188	2.23	1.88	0.35	2.916667
R 16	40 - 80	64	0.199	2.24	1.81	0.43	3.583333
R 34	40 - 52	18	0.182	1.78	1.79	-0.01	ND
12, 2	40 - 58	149	0.135	5.98	1.77	4.21	35.08333
R 31	40 - 50	24	0.167	1.7	1.76	-0.06	ND
2, 2.5	40 - 58	183	0.141	1.89	1.74	0.15	1.25
R 4	40 - 61	85	0.171	1.69	1.73	-0.04	ND
R 42	40 - 62	7	0.166	1.67	1.64	0.03	0.25
R 14	40 - 57	68	0.169	2.71	1.59	1.12	9.333333
14, 2.5	40 - 66	141	0.154	1.53	1.49	0.04	0.333333
R 44	40 - 80	3	0.128	1.35	1.32	0.03	0.25
R 10	40 - 56	76	0.12	6.35	1.3	5.05	42.08333
2, 1	40 - 76	185	0.122	1.36	1.21	0.15	1.25
16, 2	40 - 80	132	0.142	1.4	1.2	0.2	1.666667
10, 1	40 - 54	158	0.0969	4.89	1.17	3.72	31
R 21	40 - 80	50	0.131	1.09	1.12	-0.03	ND
10, 2.5	40 - 70	156	0.127	1.49	1.09	0.4	3.333333
22, 2.5	40 - 80	100	0.127	1.06	1.09	-0.03	ND
22, 1	40 - 80	103	0.118	1.02	1.06	-0.04	ND
20, 0	40 - 80	115	0.113	0.97	0.992	-0.022	ND
0, 0	41 - 80	197	0.0908	0.96	0.989	-0.029	ND
R 23	40 - 80	44	0.12	1.02	0.951	0.069	0.575
R 1	40 - 80	92	0.109	0.93	0.947	-0.017	ND
20, 2	40 - 80	112	0.105	0.919	0.923	-0.004	ND
0, 2	41 - 80	194	0.0885	0.942	0.905	0.037	0.308333
R 18	40 - 80	58	0.0989	0.834	0.876	-0.042	ND
R 27	40 - 80	32	0.101	0.852	0.872	-0.02	ND
R 26	40 - 80	35	0.105	0.844	0.864	-0.02	ND
R 19	40 - 80	55	0.113	0.844	0.85	-0.006	ND
R 12	40 - 61	72	0.0967	5.96	0.848	5.112	42.6
18, 2.5	40 - 80	123	0.0985	0.755	0.786	-0.031	ND
16, 0	40 - 80	135	0.101	0.809	0.751	0.058	0.483333
18, 1	40 - 80	126	0.092	0.775	0.746	0.029	0.241667
4, 2	40 - 80	175	0.0915	2.93	0.731	2.199	18.325
6, 2.5	40 - 54	168	0.0924	3.48	0.632	2.848	23.73333
			Total N	Total Carbon	Total Organic Carbon		
		Average	0.132	2.157	1.378		
		Median	0.121	1.51	1.145		
		Untilled	Total N	Total Carbon	Total Organic Carbon		
		3rd Quartile	0.157	2.275	1.745		
		Maximum	0.239	7.03	3.68		
		Minimum	0.0885	0.755	0.632		
		1st Quartile	0.100475	0.9555	0.89775		

			81-114 cm Data: Eroded Soil				
					Total		
CoreID	Depth Interval	KSU Sample ID	Total N	Total Carbon	Organic Carbon	Inorganic Carbon	CaCO3
R 25	80 - 101	37	0.179	1.75	1.81	-0.06	ND
2, 3.5	80 - 101	180	0.077	0.64	0.59	0.04	0.4
R 17	80 - 105	60	0.107	2.21	0.50	1.71	14.2
20, 6	80 - 95	105	0.086	2.27	0.46	1.81	15.1
0, 4	81 - 94	190	0.050	1.12	0.40	0.72	6.0
0, 6	81 - 105	187	0.058	2.33	0.40	1.93	16.1
R 22	80 - 103	46	0.079	0.45	0.33	0.12	1.0
R 24	80 - 105	40	0.076	0.37	0.32	0.05	0.4
20, 4	80 - 106	108	0.075	0.38	0.32	0.07	0.6
18, 3.5	80 - 102	119	0.069	2.27	0.26	2.01	16.7
22, 6	80 - 105	94	0.079	0.64	0.25	0.40	3.3
		Eroded	Total N	Total Carbon	Total Organic Carbon		
		Average	0.085	1.31	0.51		
		Median	0.077	1.12	0.4		
		Eroded 81-114	Total N	Total Carbon	Total Organic Carbon		
		3rd Quartile	0.083	2.24	0.48		
		Maximum	0.179	2.33	1.81		
		Minimum	0.05	0.37	0.25		
		1st Quartile	0.072	0.54	0.32		

			81-114 cm Data: Untilled Soil				
					Total		
CoreID	Depth Interval	KSU Sample ID	Total N	Total Carbon	Organic Carbon	Inorganic Carbon	CaCO3
22, 1	80 - 103	102	0.111	0.87	0.88	-0.02	ND
4, 2	80 - 86	174	0.059	3.76	0.87	2.89	24.1
18, 1	80 - 104	125	0.098	0.81	0.74	0.07	0.6
R 18	80 - 98	57	0.087	0.65	0.66	-0.01	ND
20, 0	80 - 100	114	0.082	0.60	0.61	-0.01	ND
R 27	80 - 103	31	0.078	0.57	0.57	0.00	ND
R 19	80 - 100	54	0.077	0.56	0.57	0.00	ND
R 1	80 - 104	91	0.078	0.50	0.50	-0.01	ND
16, 2	80 - 100	131	0.097	3.14	0.50	2.64	22.0
R 44	80 -100	2	0.068	0.46	0.49	-0.03	ND
R 26	80 - 93	34	0.070	0.69	0.45	0.25	2.1
22, 2.5	80 - 106	99	0.076	0.41	0.42	-0.01	ND
0, 2	81 - 110	193	0.058	0.47	0.42	0.06	0.5
R 16	80 - 104	63	0.081	3.54	0.39	3.15	26.3
R 21	80 - 107	49	0.056	0.37	0.35	0.02	0.2
R 23	80 - 94	43	0.056	0.32	0.33	0.00	ND
16, 0	80 - 100	134	0.075	0.32	0.32	0.00	ND
0, 0	81 - 110	196	0.051	0.35	0.32	0.03	0.3
18, 2.5	80 - 100	122	0.075	0.40	0.31	0.09	0.8
20, 2	80 - 108	111	0.051	0.36	0.29	0.07	0.6
		Untilled	Total N	Total Carbon	Total Organic Carbon		
		Average	0.074	0.96	0.5		
		Median	0.075	0.53	0.47		
		Untilled	Total N	Total Carbon	Total Organic Carbon		
		3rd Quartile	0.081	0.72	0.58		
		Maximum	0.111	3.76	0.88		
		Minimum	0.051	0.32	0.29		
		1st Quartile	0.059	0.39	0.34		

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Mary Susan Pachuta Hirsh, Author

13 May 2005

Date

Carbon Dynamics as a Function of Land Use in Eastern Kansas: Implications for Carbon Storage in Mollisols

Title of Thesis

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