# Effects of cultivation history and current grassland management on soil quality in northeastern Kansas

C.A. Murphy, B.L. Foster, M.E. Ramspott, and K.P. Price

**ABSTRACT:** Management regimes of varying types and intensities can have profound impacts on grassland soil quality. Plus, there has recently been increased interest in finding soil quality indicators that are reflective of historical and current land management. We surveyed soil quality of privately owned grasslands in northeastern Kansas differing in their cultivation histories and current land-use (cool-season hay and grazed, warm-season native hay and grazed, and Conservation Reserve Program). We found significant differences in individual soil characteristics among management regimes when using both chemical and physical soil quality indicators. Principal components analysis showed that cultivation history and current land-use of these fields could be reflected by overall soil quality. Also, within cultivated fields, overall soil quality significantly increased with time since last cultivation. Our results suggest that using soil quality indicators such as nitrogen, carbon and organic matter are reflective of historical land use, but are not as useful when trying to determine current land use.

**Keywords:** Conservation Reserve Program, cultivation, grassland, grazing, hay, land-use, prairie, soil quality

**Soil quality is the soil's capacity to function within an ecosystem in order to sustain and promote the health of biological organisms and maintain environmental quality (Karlen et al., 1997; Islam and Weil, 2000).** Because soil quality cannot be measured directly, it must be inferred from measurable soil properties, termed soil quality indicators (Islam and Weil, 2000; Brady and Weil, 2002). Soil quality indicators have typically been divided into three categories: chemical, physical, and biological (Doran et al., 1996).

Chemical indicators have been used to gain insight into the quantities of plant available nutrients, nutrient leaching potentials, thresholds for biological activities and potential nutrient storage capabilities (Doran et al., 1996). Physical indicators, such as texture, have been useful for indicating erosion potential and capacity to immobilize nutrients. In addition, soil bulk density is highly correlated with texture, soil aeration, and cultivation and management history (Doran and Jones, 1996; Doran et al., 1996; Elliott et al., 1999; Brady and Weil, 2002; Murphy et al., 2004), making this a good indicator of historical and current land-use management. Potentially mineralizable nitrogen and microbial biomass are examples of biological indicators that can reflect a soil's productivity and can warn of management effects on soil quality (Doran et al., 1996; Brady and Weil, 2002). Use of these measures of soil quality is important when exploring how land-use change can impact soils.

Changing land use patterns can have large impacts on soil quality (Gebhart et al., 1994; Post and Kwon, 2000). For example, shifting land use from cropland to pasture can result in significant gains in soil carbon and altered nutrient dynamics. Land in northeastern Kansas can serve as a good example for this shift. Land in this region has been used for a variety of agricultural purposes, including cropland, pasture and haying, following settlement in the 1800's. Long-term cultivation will increase soil bulk density through depletion of soil organic matter, weakened soil structure, and compaction by farm equipment (Lyon et al., 1952; Tiessen et al., 1982; Dormaar et al., 1989; Naeth et al., 1990; Douglas et al., 1992; Ford and Grace, 1998; Villamil et al., 2001; Donkor et al., 2002). In addition, cultivation can promote soil erosion and loss of topsoil leaving the subsoil exposed, which typically has higher soil bulk density and lower nutrient and biotic contents (Dormaar et al., 1989; Brady and Weil, 2002), and subsequently, changing soil quality. Since the mid 1900's, there has been a trend towards decreasing the amount of land in cash crops and converting it back into grasslands (Dickey et al., 1977). These various agricultural changes (historically), along with current management practices, have likely had profound impacts on soil quality.

Though soils under conservation practices, such as no-till, exhibit higher soil organic matter contents, microbial biomass, soil moisture, soil aggregation, and soil nutrients when compared to tilled soils (Islam and Weil, 2000; Pulleman et al., 2000; Seybold et al., 2003), these soil quality indicators benefit even more when historically cultivated grasslands are reseeded to permanent cover (Burke et al., 1995; Gardi et al., 2002; Brye and Kucharik, 2003). However, soils under re-seeded conditions can still require decades to recover to levels assumed to be present before cultivation (Burke et al., 1995; Kindscher and Tieszen, 1998; Pulleman et al., 2000; Sparling et al., 2003).

Furthermore, current management practices that involve grazing and/or haying can alter soil quality by exerting pressure onto soils through animal hooves (up to 200 kPa) and tractor wheels (30 to 150 kPa), creating higher bulk densities (Proffitt et al., 1993). The subsequent removal of vegetation can also change the return of nutrients to the soil, impacting soil quality further (McNaughton, 1979; Turner et al., 1993).

Land use history and current land management effects on soil quality can be reflected through a single soil quality indicator such as

**Cheryl A. Murphy** is a Ph.D. student in the Department of Ecology and Evolutionary Biology at the University of Kansas in Lawrence, Kansas. **Bryan L. Foster** is an associate professor in the Department of Ecology and Evolutionary Biology at the University of Kansas in Lawrence, Kansas. **Matthew E. Ramspott** is a Ph.D. student in the Department Geography, Kansas Remote Sensing Program at the University of Kansas in Lawrence, Kansas. **Kevin P. Price** is an associate professor at the Kansas Remote Sensing Program at the University of Kansas in Lawrence, Kansas.

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organic matter content or soil bulk density (Pulleman et al., 2000; Murphy et al., 2004). However, because soil properties interact extensively, using multiple indicators and assessing soil properties in their entirety could generate a better understanding of overall soil quality (Larson and Pierce, 1991; Seybold et al., 1997; Brejda et al., 2000). Multivariate ordination statistics, such as principal components analysis, provide techniques useful for analyzing such data; principal components analysis concurrently analyzes highly correlated variables and explains those variables in a smaller set of underlying dimensions (components) (McGarigal et al., 2000). This procedure eliminates data redundancy by forming new and fully uncorrelated variables expressed as a few dominant gradients of variation (McGarigal et al., 2000). From analyses such as principal components analysis, one can examine soil responses in aggregate and determine the most influential soil quality indicators with the absence of high correlations (Brejda et al., 2000). The scores generated can also be used in additional analyses, such as analysis of variance, to compare different land-use management regimes (McGarigal et al., 2000).

For this study, we examined soils from five grassland management regimes, varying in cultivation history and current management, in northeastern Kansas in 2001 and 2002. We had three objectives: 1) to determine if there were soil property differences among the management regimes by using chemical and physical soil quality indicators; 2) to examine soil quality indicators via principal components analysis to generate an estimate of overall soil quality; and 3) to determine if overall soil quality could be explained by cultivation history and/or current management of these grasslands.

## Materials and Methods

***Study sites.*** We studied 32 privately owned grasslands in northeastern Kansas representing five management regimes: 1) cool-season hay (C-H); 2) cool-season grazed (C-G); 3) warm-season native hay (W-NH); 4) warm-season native grazed (W-NG); and 5) warm-season Conservation Reserve Program (W-CRP). Cool-season fields were historically cultivated and later converted into grasslands (dominated by either *Bromus inermis*: Smooth Brome or *Festuca arundinacea*: Tall Fescue) in the mid 1900's (cool-season fields averaged 28 years since abandonment from cultivation). These fields obtain their highest productivity during June and are used for either hay or grazing (Dickey, 1977; Dickey et al., 1977; Zavesky and Boatright, 1977).

Warm-season native grasslands were located on soils that have never been plowed (i.e. native prairie remnants) and have been used for either hay or grazing during the past 20 to 50 years. These fields are dominated by native grasses [*Andropogon gerardii* (big bluestem), *Schizachyrium scoparium* (little bluestem), and *Sorghastrum nutans* (indiangrass)], in which highest productivity occurs during late July to August.

In 1985, through the Food Security Act, Congress established the Conservation Reserve Program (Title XII). This program provides participants an annual per acre rent and half the cost of creating a permanent cover with native vegetation (e.g. grasses) for periods of ten years in exchange for retiring cropland that is highly erodible (Agapoff et al., 2003). The main goals for creating this program was to reduce the amount of soil erosion on cropland, curb surplus production, support farmer income and improve the environmental quality of the land (Diebel et al., 1993; Agapoff et al., 2003). In the grasslands used for our study, native warm-season grasses (*A. gerardii, S. scoparium, S. nutans, Panicum virgatum,* and *Bouteloua curtipendula*) and native forbs (*Cassia chamaecrista, Helianthus maximilianii, Desmanthus illinoiensis* and *Dalea purpueum*) were seeded, which created recently cultivated, warm-season grasslands (Jefferson County Conservation District: personal communications; unpublished data, landowner communications). Warm season-CRP fields included in our study have been out of cultivation for an average of 15 years.

***Data collection.*** When selecting fields, and sites within each field, we minimized differences in soil types by using upland grasslands with minimal slopes and similar soil series (Table 1). This helped eliminate potential confounding effects of differences in vegetation and soils between upland and lowland areas. In addition, sites were chosen near the center of each field such that results would not be confounded by edge effects.

In June 2001, 10 fields (two replications for each regime) were sampled within Douglas and Jefferson Counties, Kansas (Table 1). Within each field, six 20 x 20 m (66 x 66 ft) plots were established within an area of 160 x 90 m (525 x 295 ft) based on the criteria listed above. Within each plot, three sample locations were chosen in a diagonal arrangement (northwest corner, center and southeast corner) in an attempt to sample across the widest range of soil variability within each plot. At each location, two soil samples were taken, one for chemical analyses and the other for soil bulk density. For each soil quality indicator, 18 soil cores per field were sampled. Each soil sample was taken with a 36 in tube sampler to a depth of 15 cm (6 in), with all analyses based on the entire 15 cm (6 in) core and a diameter of 2.54 cm (1 in).

In October and November 2002, 30 fields were sampled in Douglas, Leavenworth and Jefferson Counties, Kansas, establishing six replicates for each grassland regime. Unlike the plot system in the previous year, transects were used within each field to expedite the sampling process. Three parallel transects, each 50 m (164 ft) long and separated by 50 m (164 ft), were positioned on the upland areas (sites based on the criteria listed above). Two soil samples were taken at the 5, 25, and 45 m (16, 82, and 148 ft) locations along each transect, generating nine soil samples per field for each soil quality indicator. One soil sample was used for chemical analyses and the other for physical soil properties. As in 2001, samples were taken at these locations in order to sample across the widest range of soil variability within the study site. Soil cores were taken in the same way as the previous year. Unlike 2001, however, soil cores used for soil bulk density were examined to determine if the core contained multiple horizons.

Soil data was taken as supplementary data to a larger plant biodiversity and remote sensing study. In 2001, extensive plant biodiversity data was taken in permanent plots that only allowed the sampling of 10 fields. In 2002, an effort was made to increase the number of fields in the study, compromising the time capable of being spent in any one field. Because of this, transects were used rather than permanent plots. Furthermore, only chemical and physical soil quality indicators (excluding biological indicators) were used due to the main study focus and time and equipment constraints.

Soils collected for chemical analyses were air dried and sent to the Ecosystems Analysis Lab (School of Biological Sciences; University of Nebraska-Lincoln) in 2001 and the Soil Testing Laboratory at Kansas State University in 2002 for the following analyses: 1.) Total percent nitrogen (N) and carbon (C); determined by

**Table 1. Soil and field characteristics and management history by field.**

| Management regime[1] | Year in study | County | Soil series name and texture[2] | Slope (%)[3] | Time since last cultivation (Year)[4] | Soil survey notes[5] | Observations[6] |
|---|---|---|---|---|---|---|---|
| Warm season-CRP (W-CRP) | 2001 2002 | Douglas | Martin silty clay loam | 1.7 | 14 (1988) | | Clayey |
| W-CRP | 2001 2002 | Jefferson | Oska silty clay loam | 3.1-5.8 | 17 (1985) | | Clayey |
| W-CRP | 2002 | Jefferson | Grundy and Oska silty clay loam | 0-5.2 | 14 (1988) | | Several samples = in road/ mowed area |
| W-CRP | 2002 | Jefferson | Vinland complex | 3.5-7.0 | 17 (1985) | Erosion | Clayey; Erosion? |
| W-CRP | 2002 | Douglas | Martin silty clay loam | 1.7 | 14 (1988) | Erosion | Clayey |
| W-CRP | 2002 | Jefferson | Martin silty clay loam | 3.5-7.0 | 14 (1988) | Erosion | Clayey |
| Cool-season hay | 2001 | Jefferson | Pawnee clay loam | 0-6 | 20 (1982) | | |
| C-H | 2001 2002 | Jefferson | Oska and Martin silty clay laom | 1.7-8.7 | 37 | Erosion | |
| C-H | 2002 | Jefferson | Vinland complex | 3.5 | 37 (1965) | Erosion | |
| C-H | 2002 | Jefferson | Shelby Pawnee complex | 1.7-3.5 | 7 | Erosion | Clayey; Erosion? |
| C-H | 2002 | Jefferson | Shelby Pawnee complex | 0.9-3.5 | 5 (1997) | Erosion | |
| C-H | 2002 | Leavenworth | Pawnee clay loam | 5.2-7.0 | 42 (1960) | Erosion | |
| C-H | 2002 | Leavenworth | Grundy silty clay loam | 0-1.7 | 33 | | |
| C-G | 2002 | Jefferson | Vinland complex | 0.9-3.5 | 33 | Erosion | |
| C-G | 2001 2002 | Jefferson | Martin silty clay loam | 7.0-8.7 | 35 | Erosion | Some samples = clay; Area has slopes |
| C-G | 2001 2002 | Jefferson | Martin-Oska silty clay loam | 0-3.5 | 7 | | Some samples clay; Slopes = erosion? |
| C-G | 2002 | Jefferson | Vinland complex | 0-3.5 | 35 | Erosion | Erosion: B horizon? Clayey |
| C-G | 2002 | Jefferson | Pawnee clay loam | 5.2-7.0 | 35 | | |
| C-G | 2002 | Jefferson | Martin silty clay loam | 0.9-2.6 | 37 | Erosion | |
| Warm-season native hay | 2001 2002 | Jefferson | Martin-Oska silty clay loam | 0 | NC | Rock outcrops | |
| W-NH | 2001 | Jefferson | Martín-Oska silty clay loam, Shelby complex, Vinland complex | 4-7 | NC | Vc = rock outcrops | |
| W-NH | 2002 | Jefferson | Pawnee clay loam | 0.4-1.3 | NC | | |

**Table 1 continued on next page**

**Table 1. Continued.**

| Management regime[1] | Year in study | County | Soil series name and texture[2] | Slope (%)[3] | Time since last cultivation (Year)[4] | Soil survey notes[5] | Observations[6] |
|---|---|---|---|---|---|---|---|
| W-NH | 2002 | Leavenworth | Shelby loam | 3.5-8.7 | NC | | |
| W-NH | 2002 | Jefferson | Shelby Pawnee complex | 1.7-7.0 | NC | | |
| W-NH | 2002 | Leavenworth | Sharpsburg silty clay loam | 1.7-5.2 | NC | | |
| W-NH | 2002 | Douglas | Sibleyville loam | 1.7-3.5 | NC | | |
| Warm-season native grazed | 2001 2002 | Jefferson | Martin-Oska silty clay loam | 0.5-1.7 | NC | | |
| W-NG | 2001 2002 | Jefferson | Martin-Oska silty clay loam | 2.6 | NC | | |
| W-NG | 2002 | Jefferson | Martin silty clay loam | 1.7-5.2 | NC | | |
| W-NG | 2002 | Jefferson | Pawnee clay loam | 0-3.5 | NC | | |
| W-NG | 2002 | Jefferson | Shelby Pawnee complex | 2.6-3.5 | NC | Rock outcrops | |
| W-NG | 2002 | Jefferson | Shelby Pawnee complex | 0 | NC | | |

[1] Management regime: W-CRP = warm-season Conservation Reserve Program; C-H = cool-season hay; C-G = cool-season grazed; W-NH = warm-season native hay; W-NG = warm-season native grazed.

[2] Soil Series that underlies each field as determined by soil surveys and digitized soil maps (Dickey, 1977; Dickey et al., 1977; Zavesky and Boatright, 1977; USDA-NRCS, SSURGO 1998, 1999a, 1999b).

[3] Each plot/transect that was established in each field had a slope measurement taken. This data is showing the range of the percent slope that was found in each field.

[4] Time Since Last Cultivation (Year): the number of years since the abandonment of cultivation and seeded with permanent cover (based from the year 2002). NC = never cultivated, these fields are native prairie remnants.

[5] Soil survey notes = description of comments found in the field area on soil survey maps (Dickey, 1977; Dickey et al., 1977; Zavesky and Boatright, 1977).

[6] Observations = any notes about the texture, position and other observations when taking the soil sample that could be relevant to interpreting soil bulk density data.

a Costech Analytical ECS 4010 (2001) and a LECO CN 2000 dry combustion analyzer (2002) (Kirsten, 1983;Yeomans and Bremner, 1991; University of Missouri, 1998); 2.) Soil pH (2002); measured directly by using a 1:1 slurry of 5 g (0.18 oz) of soil with deionized water with an automated system (McLean, 1982; University of Missouri, 1998); 3.) Plant available phosphorus (P) (ppm) (2002); measured with the Bray-1-P test in which HCl-ammonium fluoride extractant and a colorimetric assay was used (Bray and Kurtz, 1945; University of Missouri, 1998); and 4.) Percent organic matter (2002); measured with the Walkley-Black procedure in which sulfuric acid and dichromate digests the prepared soil and a direct colorimetric measurement of reduced $Cr_2O_2^{-2}$ ion was taken (Walkley and Black, 1934; University of Missouri, 1998).

All soils collected for soil bulk density were dried at 90°C (194°F) to a constant weight. Bulk density was calculated as the dry soil weight (g) divided by the soil volume (76.01 $cm^3$) and converted to $Mg/m^3$. The bulk density soil samples from 2002 were subsequently submitted to the Soil Testing Laboratory at Kansas State University for particle size analysis via the sodium hexametaphosphate hydrometer method (Gee and Bauder, 1986).

***Statistical analyses.*** Data analyses were performed using SPSS 11.5.0 (LEAD Technologies Inc., 2002). Field averages for each soil quality indicator were tested for normality using the Shapiro-Wilk test ($\alpha$ = 0.05). In addition, equal variances were tested using the Levene homogeneity of variance test. If normality and homogeneity of variance assumptions were met, one-way analyses of variance were used to test for management effects. Least significant difference tests were used to determine management regime effects on each soil variable separately ($\alpha$ = 0.05) (Sokal and Rohlf, 1995). For those soil quality indicators not conforming to analyses of variance assumptions, Kruskal-Wallis (Sokal and Rohlf, 1995) non-parametric tests were performed to test for management effects ($\alpha$ = 0.05). If differences were detected, further analyses to separate means were done using Mann-Whitney procedures (Sokal and Rohlf, 1995) ($\alpha$ = 0.05).

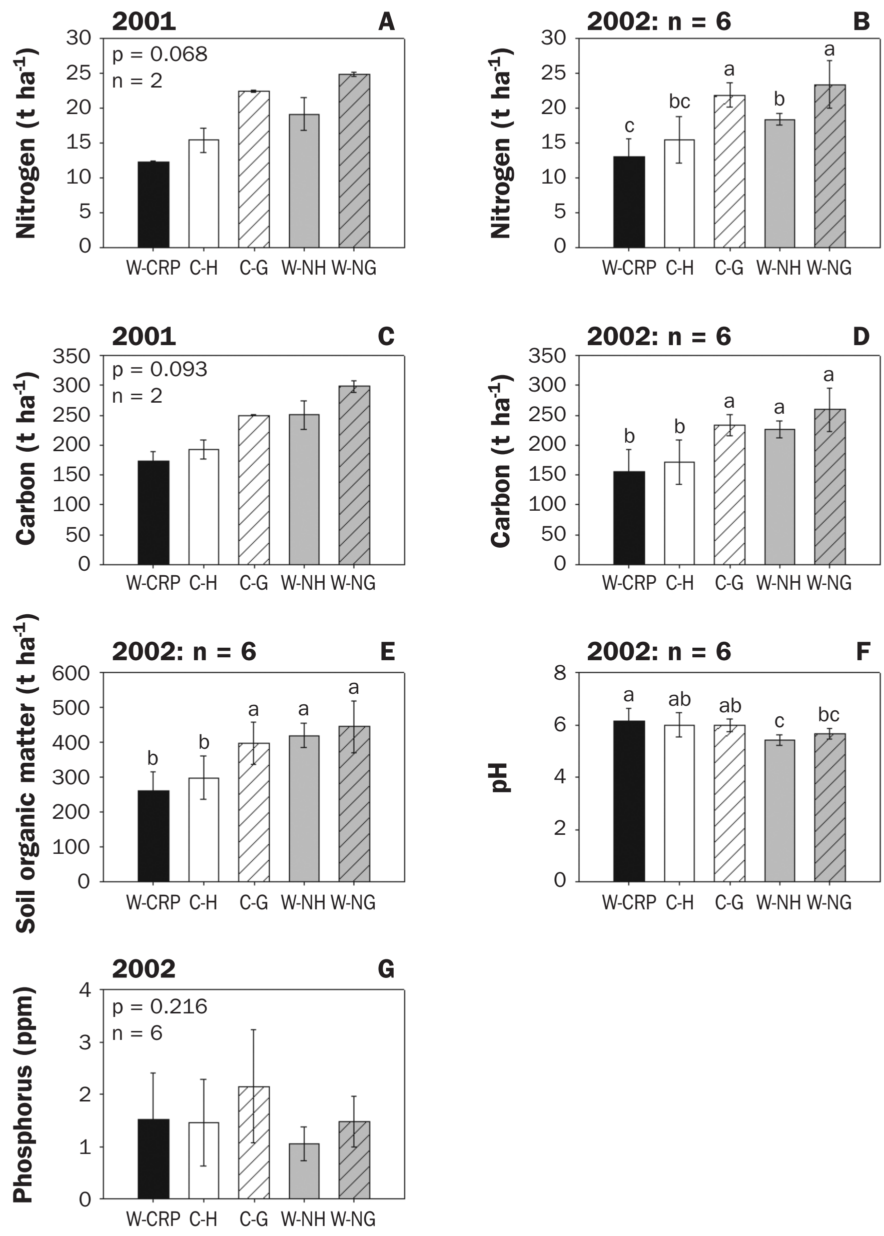
To examine overall soil quality, principal components analysis was performed in Minitab (Minitab, Inc. 1996). Only soil quality indicators from 2002 were used for principal components analysis because more indicators were sampled and because of larger sample sizes. Soil quality indicators included in the analyses were: N, C, organic matter, P, pH, bulk density, and percent clay. Only percent clay was included (vs. percent sand and percent silt) because analyses indicated that only this particle size had differences among the management regimes. When testing for normality of soil quality indicators (Ryan-Joiner test, Minitab, Inc., 1996) (regardless of management regime), natural log transformations of soil pH, P, and organic matter were necessary for normal distributions. A correlation matrix was used during analysis.

***Cultivation history and current management.*** For each field, data estimating the time and year since last cultivation were gathered from landowner communications when initial contacts were being established (Table 1). In addition, surveys were distributed to land owners in February 2004 to determine more precisely when each field was cultivated. If a range of years was given by the landowner, the average was selected as the time (in years) since last cultivation. For those fields in which surveys were not returned, time since last cultivation was estimated by the average time within that field's management regime. Time since last cultivation was based from 2002, the final year that soil data was obtained.

Each field was categorized as non-cultivated (managements including warm-season native hay and warm-season native grazed) or cultivated (managements including warm season-CRP, cool-season hay, and cool-season grazed), according to the first principal component axis. Principal component scores from the first axis were analyzed using one-way analysis of variance based on cultivation category. To further examine if time since last cultivation could be used to predict overall soil quality on the first axis, simple linear regression was performed on only those fields that had been cultivated historically. One-way analysis of variance was used to determine if the second principle component axis, which described current land management, was statistically detectable. Non-cultivated and cultivated fields were analyzed separately.

**Figure 1**

Chemical soil quality indicator averages with standard deviations for each management regime. W-CRP = Conservation Reserve Program; C-H = cool-season hay; C-G = cool-season grazed; W-NH = warm-season native hay; and W-NG = warm-season native grazed. Differing letters signify significant differences at $\alpha = 0.05$ level using least significant difference tests. The n is the number of samples represented in the calculated mean presented in each graph.

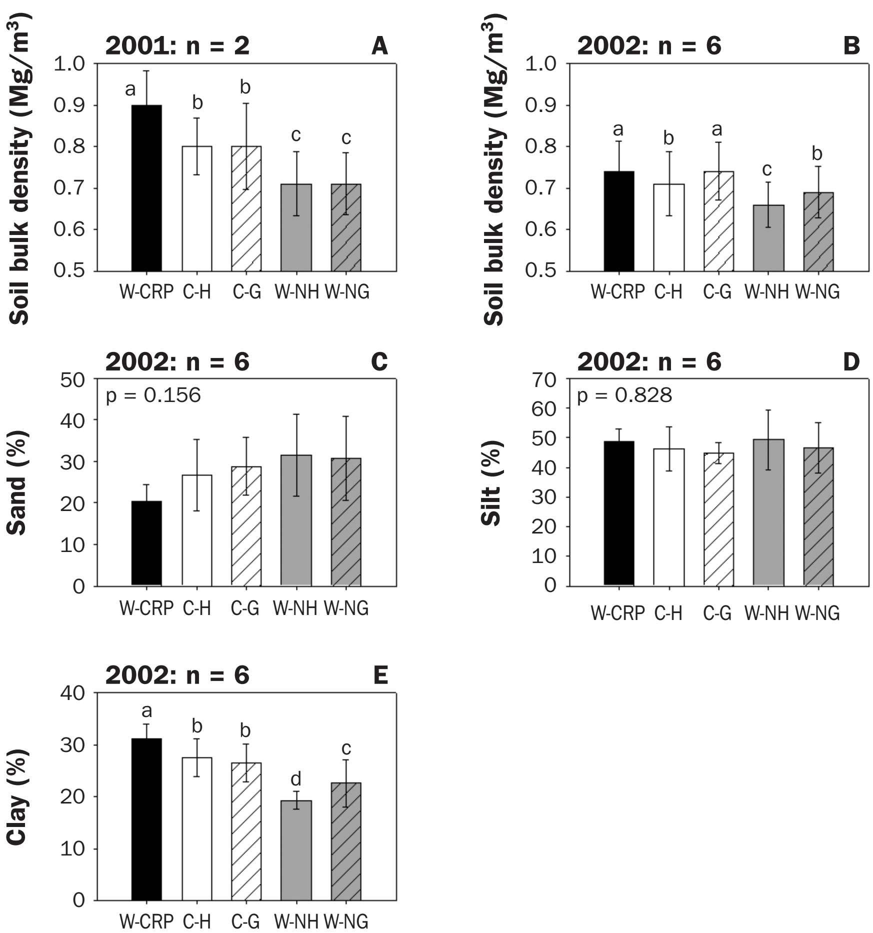



## Results and Discussion

***Chemical indicators.*** Although 2001 soil N and C showed no significant differences (Figure 1a and 1c), trends were identical as in 2002, when significant differences existed (Figure 1b and 1d) ($F_{4,25} = 16.63$, $p < 0.001$; $F_{4,25} = 12.33$, $p < 0.001$; soil N and C, respectively ($F_{x,y}$; x = degrees of freedom for management term, y = degrees of freedom for error term)). Total soil N and C were lowest in warm season-CRP and cool-season hay fields, intermediate in warm-season native hay and cool-season grazed, and highest in warm-season native grazed fields. With respect to organic matter, warm season-CRP and cool-season hay fields were not significantly different from each other and had the lowest soil organic matter contents (Figure 1e) ($F_{4,25} = 11.24$, $p < 0.001$). Cool-season grazed, warm-season native hay, and warm-season native grazed fields were similar to each other and had the highest soil organic matter contents. Soil pH was lowest in warm-season native hay and warm-season native grazed fields, while warm season-CRP, cool-season hay and cool-season grazed fields had the highest soil pH values (Figure 1f) ($F_{4,25} = 4.11$, $p = 0.011$). Plant available P did not show any significant differences among management regimes (Figure 1g) due to large variations within the sites.

**Figure 2**

Physical soil quality indicator averages with standard deviations for each management regime. W-CRP = Conservation Reserve Program; C-H = cool-season hay; C-G = cool-season grazed; W-NH = warm-season native hay; and W-NG = warm-season native grazed. Differing letters signify significant differences at $\alpha = 0.05$ level using least significant difference tests. The n is the number of samples represented in the calculated mean presented in each graph.




***Physical indicators.*** In 2001, bulk density differed significantly among the regimes (Figure 2a) ($\chi^2_{0.05,4} = 85.22$; $p < 0.001$). Of the five management regimes, warm season-CRP fields had the highest bulk density. Cool-season fields were significantly lower than warm season-CRP and warm-season native fields had the lowest bulk density of all management regimes. Within both cool-season and warm-season native grasslands, hay and grazed fields were similar.

As in 2001, bulk density varied significantly among the regimes in 2002 (Figure 2b) ($\chi^2_{0.05,4} = 49.97$, $p < 0.001$). Warm season-CRP and cool-season grazed fields were not significantly different and had the highest bulk density. Cool-season hay and warm-season native grazed fields were not significantly different and significantly higher than warm-season native hay bulk density. Further, within both cool-season and warm-season native grasslands, hay fields had significantly lower bulk density than grazed fields.

Particle size analyses showed significant differences only in clay content among management regimes (Figure 2c, 2d, and 2e) ($F_{4, 25} = 11.08$, $p < 0.001$). Warm season-CRP contained the highest clay content, cool-season hay, and cool-season grazed were similar and contained intermediate clay contents. Warm-season native grazed fields were significantly lower still, while warm-season native hay fields contained the lowest clay content.

***Overall soil quality.*** Principal components analysis showed that the first four axes explained 92.1 percent of the variation in soil quality indicators (Table 2). The first axis (PC1) contrasted soil N, C, and organic matter against percent clay, soil bulk density and pH (P was not included in this axis) (Figure 3). These contrasts in soil quality indicators from principal components analysis indicated that native warm-season grasslands had higher values of C, N, and organic matter, cool-season grasslands had intermediate values, and warm season-CRP had the highest values of percent clay, bulk density, and pH. Soil C and N were the variables that loaded the most on the first axis. Axis 2 (PC2) was a general soil quality axis because all principal component loadings were of similar magnitude and positive in sign (Table 2). This indicated that grazed fields had higher loadings of soil quality, hay fields had lower values and warm season-CRP had intermediate values of soil quality indicators (Figure 3). Here, plant available P and organic matter loaded the most onto the axis.

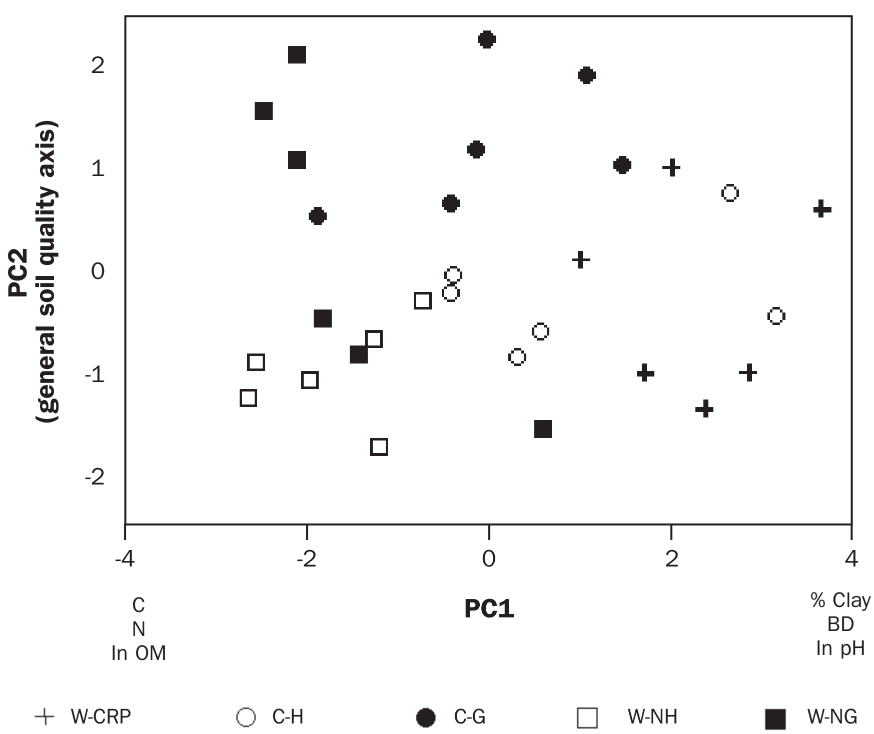
***Cultivation history and current management.*** To determine if PC1 loadings were significantly different among cultivation histories, a one-way analysis of variance was used to assess differences between fields that were non-cultivated (warm-season native hay and warm-season native grazed) and those that were cultivated (warm season-CRP, cool-season hay, and cool-season grazed). Non-cultivated fields had significantly lower loadings than those that were cultivated historically (Figure 4a) ($F_{1, 28} = 31.69$, $p < 0.001$). Within fields that were cultivated, PC1 scores decreased significantly as the time since last cultivation increased (Figure 4b) ($F_{1, 16} = 12.22$, $p = 0.003$, $r^2 = 0.433$).

Among non-cultivated fields, there were no differences in PC2 scores between warm-season native hay and warm-season native grazed fields (Figure 4c). However, among cultivated fields, warm season-CRP and cool-season hay fields were similar but lower in PC2 scores than cool-season grazed fields (Figure 4d) ($F_{2, 15} = 7.88$, $p = 0.005$).

Variation among fields in soil quality indicators and overall soil quality reflected the impacts of current management and cultivation history. Both current agricultural land-use and historical land-use were reflected in differences in N, C, organic matter, pH, bulk density, and clay content and also through overall soil quality (PC2 scores) among historically cultivated fields. Differences in overall soil quality were also detected between cultivated and non-cultivated fields (PC1).

Cool-season grazed fields contained higher amounts of N, C, and organic matter than

**Figure 3**
Scatter plot for the Principal Component Analysis scores using the first two axes and with management regimes designated. Scores of the second Principal Component axis (PC2) (general soil quality axis) against the first Principal Component axis (PC1) (C, N and organic matter vs. percent clay, soil bulk density and pH) (68.7 percent of the variance is explained by these two axes). W-CRP = Conservation Reserve Program; C-H = cool-season hay; C-G = cool-season grazed; W-NH = warm-season native hay; and W-NG = warm-season native grazed.




both warm season-CRP and cool-season hay fields. Although both cool-season hay and grazed fields remove vegetation, nutrient replacement occurs via very different mechanisms. Grazing replaces nutrients via dung and urine (Petersen et al., 1956; Lotero et al., 1966; Weeda, 1967; McNaughton, 1979; Day and Detling, 1990; Holland et al., 1992; Frank et al., 1998), whereas haying relies on mineral fertilization. The higher N and C contents in warm-season native grazed fields compared to warm-season native hay may also reflect these different means of recycling nutrients.

Effects of grazing on soil quality can be variable. Grazing can decrease soil quality (Dormaar et al., 1989; Naeth et al., 1990; Villamil et al., 2001; Donkor et al., 2002), induce no observable effect (Ford and Grace, 1998), or promote an increase in soil nutrients (Bauer et al., 1987). Grazing intensity and frequency (Naeth et al., 1990), differences in soil quality indicators measured (Bauer et al., 1987), time of measurement (season variability) (Naeth et al., 1990) and soil texture (Dormaar et al., 1989) may drive this variability in response. In a previous study examining these fields, grazing increased soil bulk density (Murphy et al., 2004), indicating a decrease in soil quality. However, the results presented here show that grazed fields are associated with higher overall soil quality than warm season-CRP or hay fields, emphasizing the importance of using more than one soil quality indicator to assess soil quality.

We found that overall soil quality is mainly determined by the land-use history of the field (PC1). Fields that have never been cultivated have higher levels of soil N, C, and organic matter and lower soil bulk density, clay content and pH than those fields that have been cultivated in the past. Many studies have also documented that non-cultivated fields have higher soil quality when compared to cultivated fields (Burke et al., 1995; Gardi et al., 2002; Brye and Kucharik, 2003; Sparling et al., 2003). Cultivation can deplete the soil of N, C, and organic matter through homogenization and erosion of the topsoil (Compton et al., 1998; Knops and Tilman, 2000; Richter et al., 2000; Foster et al., 2003) and through reductions in the abundance of plant material remaining for decomposition. Erosion subsequently can increase bulk density and expose the lower soil horizons, which are higher in clay content. From soil survey maps and personal observations (Table 1), soil erosion was detected in almost every historically cultivated field in this study, consistent with the differences seen in the soil quality indicators and lower soil quality.

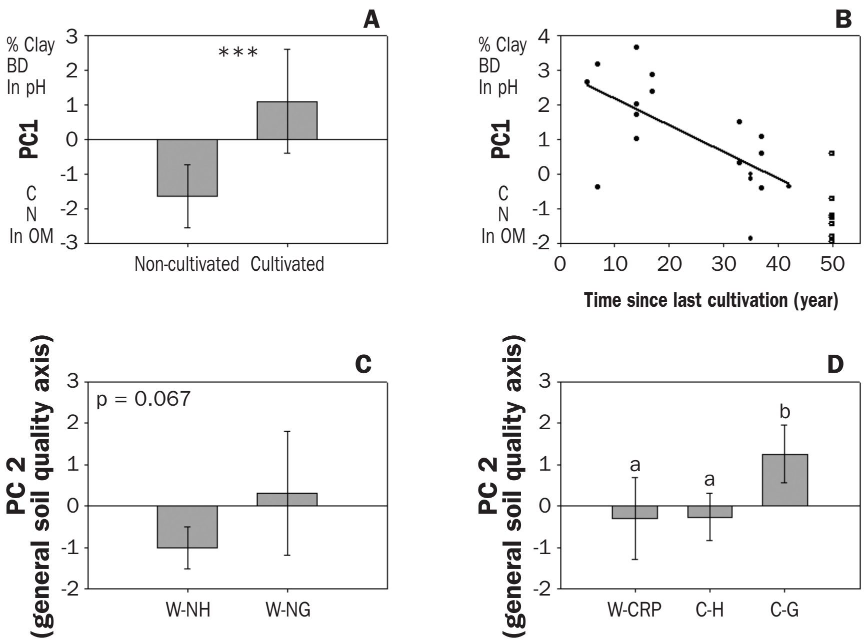
Time since last cultivation impacts soil quality in cultivated fields. Fields that have been out of cultivation the longest have higher N, C, and organic matter contents (lower soil bulk density, clay contents and pH) than those most recently cultivated. This finding is in agreement with several others who have found that N, C and organic matter content is dependent on the amount of time the soil has been out of cultivation (Burke et al., 1995; Knops and Tilman, 2000; Pulleman et al., 2000; Brye and Kucharik, 2003; Sparling et

**Table 2. Elements of the unit eigenvector and eigenvalues for Principal Components 1 to 4 and all variables (n = 30).**

| | Component | | | |
|---|---|---|---|---|
| Variable | PC1 | PC2 | PC3 | PC4 |
| % Clay | 0.372 | 0.311 | 0.058 | 0.674 |
| Bulk density | 0.378 | 0.259 | 0.109 | -0.711 |
| ln pH | 0.385 | 0.406 | 0.335 | -0.088 |
| % C | -0.492 | 0.270 | -0.086 | -0.088 |
| % N | -0.471 | 0.353 | -0.055 | -0.093 |
| ln organic matter | -0.308 | 0.425 | 0.588 | 0.125 |
| ln P | 0.110 | 0.541 | -0.719 | 0.025 |
| Eigenvalue | 3.499 | 1.313 | 1.017 | 0.616 |
| Cumulative % of variance | 50.0 | 68.7 | 83.3 | 92.1 |

**Figure 4**

Principal Component scores from the first two axes and their relationship with cultivation history and current management regime. Error bars are standard deviations. A) Average PC1 scores for non-cultivated fields and fields that had been cultivated in the past (***: $p < 0.001$); B) regression of PC1 against time since last cultivation (year) using only fields that had been cultivated in the past (darkened circles), open circles represent scores from non-cultivated fields for reference. ($PC1 = -0.077(year) + 2.948$; $F_{1, 16} = 12.22$, $p = 0.003$, $r^2 = 0.433$); C) average PC2 scores for hay and grazed fields using only non-cultivated fields (warm-season native); and D) average PC2 scores for W-CRP, hay and grazed fields using only fields that had been cultivated historically (W-CRP and cool-season). Differing letters signify significant differences at $\alpha = 0.05$ level using least significant difference tests. W-CRP = Conservation Reserve Program; C-H = cool-season hay; C-G = cool-season grazed; W-NH = warm-season native hay; and W-NG = warm-season native grazed.




al., 2003) and may be a reflection of two things: 1) the amount of topsoil loss due to cultivation, and 2) the time allotted for recovery. Typically however, even after several decades to centuries, soil quality under re-established permanent cover is detectably different than those of non-cultivated fields (Foster et al., 2003; this study), highlighting the slow processes of soil formation and recovery.

Among non-cultivated fields, N, soil bulk density, and clay content were significantly different, however, overall soil quality did not differ between hayed and grazed fields. These results may reflect the large variation among the grazed fields' soil quality due to differences in grazing intensity and frequency. Also, the absence of past cultivation may have reduced the impact of different current land management in these fields.

Warm season-CRP and cool-season hay fields had similar PC2 loadings, consistent with work suggesting that soil quality under CRP management may improve even within 10 years of enrollment (Robles and Burke, 1997; Brejda et al., 2000; Amelung et al., 2001; Huang et al., 2002). The similar soil quality of these two management regimes could be due to the lack of haying in warm season-CRP, while cool-season hay fields have had substantial amounts of nutrients removed annually. In addition, two out of the six cool-season hay fields were taken out of cultivation less than 10 years ago (Table 1), increasing the similarities in cultivation histories between these management regimes.

Using several soil quality indicators to assess overall soil quality is ideal. However, many investigators are restricted in the time and resources available to them for sampling. Thus, identifying one or two soil quality indicators that represent overall soil quality would be beneficial (Langley-Turnbaugh and Evans, 2001). Because soil databases, such as the U.S. Department of Agriculture Cooperative Soil Survey, do not take into account soil differences due to land-use, "the property-related estimates for a particular soil series are based on the major land-use at the time of mapping" (Seybold et al., 2003). Identifying a few soil quality indicators that are representative of overall soil quality and reflective of land management could be important for better interpretations of these soil databases.

Soil quality indicators representative of overall soil quality have included chemical, physical and biological indicators, with the most useful indicators being region dependent (Langley-Turnbaugh and Evans, 2001; Gardi et al., 2002; Seybold et al., 2003; Murphy et al., 2004). The most consistent indicators of soil quality as related to land management have included soil C, N, and/or organic matter (Brejda et al., 2000; Pulleman et al., 2000; Sparling et al., 2003). For example, Pulleman et al. (2000) found that soil organic matter could be predicted if land management for a particular soil series was known.

The results from this study show that soil quality can be assessed and be reflective of cultivation history with only a few soil quality indicators (N, C, and organic matter), which is consistent with the studies described above. However, these selected indicators, when considering current management, could not assess soil quality as well. Whether or not a few indicators could be used to address current management warrants further investigation. In addition, sampling biological indicators could be useful in determining representatives of soil quality for both historical and current land-use.

## Summary and Conclusion

In summary, our results suggest that variation in soil quality in this agricultural landscape reflects impacts of both current management (hay vs. grazing) and cultivation history. Soil quality indicators such as C, N, and organic matter reflect historical land-use, but are not as useful when current land-use (such as haying and grazing) is being considered. Agricultural practices such as the ones used in this study can have long-lasting implications and the impacted soils may take decades to recover.

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## Reference Cited

Agagpoff, J., A. Barbarika, J. Conelly, I. Gray, P. Harte, M. Linsenbigler, B. Preston, S. Rafter, R. Stephenson, J. Williams, and L. Winemiller. 2003. The Conservation Reserve Program 26th Sign-up. Farm Service Agency, U.S. Department of Agriculture. http://www.fsa.usda.gov/dafp/cepd/default.htm.

Amelung, W., J.M. Kimble, S. Samson-Liebig, and R.F. Follett. 2001. Restoration of microbial residues in soils of the Conservation Reserve Program. Soil Science Society of America Journal 65:1704-1709.

Bauer, A., C.V. Cole, and A.L. Black. 1987. Soil property comparisons in virgin grasslands between grazed and nongrazed management systems. Soil Science Society of America Journal 51:176-182.

Brady, N.C. and R.R. Weil. 2002. The nature and properties of soils. Thirteenth Edition. Prentice Hall, Upper Saddle River, New Jersey.

Bray, R.H. and L.T. Kurtz. 1945. Determination of total, organic, and available form of phosphorus in soil. Soil Science 59:39-45.

Brejda, J.J., T.B. Moorman, D.L. Karlen, and T.H. Dao. 2000. Identification of regional soil quality factors and indicators: I. Central and Southern High Plains. Soil Science Society of America Journal 64:2115-2124.

Brye, K.R. and C.J. Kucharik. 2003. Carbon and nitrogen sequestration in two prairie topochronosequences on contrasting soils in Southern Wisconsin. The American Midland Naturalist 149:90-103.

Burke, I.C., W.K. Lauenroth, and D.P. Coffin. 1995. Soil organic matter recovery in semiarid grasslands: Implications for the Conservation Reserve Program. Ecology Applications 5:793-801.

Compton, J.E., R.D. Boone, G. Motzkin, and D.R. Foster. 1998. Soil carbon and nitrogen in a pine-oak sand plain in central Massachusetts: Role of vegetation and land-use history. Oecologia 116:536-542.

Day, T.A. and J.K. Detling. 1990. Grassland patch dynamics and herbivore grazing preference following urine deposition. Ecology 71:180-188.

Dickey, H.P. 1977. Soil Survey of Douglas County, Kansas. U.S. Department of Agriculture. Soil Conservation Service in cooperation with Kansas Agricultural Experiment Station, Manhattan, Kansas. 73 pp.

Dickey, H.P., J.L. Zimmerman, and H.T. Rowland. 1977. Soil Survey of Jefferson County, Kansas. U.S. Department of Agriculture. Soil Conservation Service in cooperation with Kansas Agricultural Experiment Station, Manhattan, Kansas. 67 pp.

Diebel, P.L., T.T. Cable, and P.S. Cook. 1993. The future of Conservation Reserve Program land in Kansas: The landowner's view. Report of Progress No. 690, Agricultural Experiment Station, Kansas State University, Manhattan, Kansas.

Donkor, N.T., J.V. Gedir, R.J. Hudson, E.W. Bork, D.S. Chanasyk, and M.A. Naeth. 2002. Impacts of grazing systems on soil compaction and pasture production in Alberta. Canadian Journal of Soil Science 82:1-8.

Doran, J.W. and A.J. Jones (eds.). 1996. Methods for assessing soil quality. Soil Science Society of America Special Publication No. 49. Soil Science Society of America, Madison, Wisconsin.

Doran, J.W., A. Sarrantonio and M.A. Liebig. 1996. Soil health and sustainability. Advances in Agronomy 56:1-54.

Dormaar, J.F., S. Smoliak, and W.D. Williams. 1989. Vegetation and soil response to short-duration grazing on fescue grasslands. Journal of Range Management 42:252-256.

Douglas, J.T., A.J. Koppi, and C.J. Moran. 1992. Changes in soil structure induced by wheel traffic and growth of perennial grass. Soil Tillage Research 23: 61-72.

Elliott, E.T., J.W. Heil, E.F. Kelly, and H.C. Monger. 1999. Soil structural and other physical properties. Pp. 74-85. *In:* Standard soil methods for long-term ecological research. G.P. Robertson, D.C. Coleman, C.S. Bledsoe, and P. Sollins (eds.) Oxford University Press Inc., New York, New York.

Ford, M.A. and J.B. Grace. 1998. Effects of vertebrate herbivores on soil processes, plant biomass, litter accumulation and soil elevation changes in a coastal marsh. Journal of Ecology 86:974-982.

Foster, D., F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman, and A. Knapp. 2003. The importance of land-use legacies to ecology and conservation. BioScience 53:77-88.

Frank, D.A., S.J. McNaughton, and B.F. Tracy. 1998. The ecology of the Earth's grazing ecosystems: Profound functional similarities exist between the Serengeti and Yellowstone. BioScience 48:513-521.

Gardi, C., M. Tomaselli, V. Parisi, A. Petraglia, and C. Santini. 2002. Soil quality indicators and biodiversity in northern Italian permanent grasslands. European Journal of Soil Biology 38:103-110.

Gebhart, D.L., H.B. Johnson, H.S. Mayeux and H.W. Polley. 1994. CRP increases soil organic carbon. Journal of Soil and Water Conservation 49:488-492.

Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. Pp. 383-412. *In:* Methods of soil analysis. Part I: Physical and mineralogical methods (2nd edition) A. Klute (ed.) American Society of Agronomy, Madison, Wisconsin.

Holland, E.A., W.J. Parton, J.K. Detling, and D.L. Coppock. 1992. Physiological responses of plant populations to herbivory and other consequences of ecosystem nutrient flow. American Naturalist 140:685-706.

Huang, X., E.L. Skidmore, and G.L. Tibke. 2002. Soil quality of two Kansas soils as influenced by the Conservation Reserve Program. Journal of Soil and Water Conservation 57(6):344-350.

Islam, K.R. and R.R. Weil. 2000. Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. Journal of Soil and Water Conservation 55(1):69-78.

Karlen, D.L., M.J. Mausbach, J.W. Dorn, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Science Society of America Journal 61:4-10.

Kindscher, K. and L.L. Tieszen. 1998. Floristic and soil organic matter changes after five and thirty-five years of native tallgrass prairie restoration. Restoration Ecology 6:181-196.

Kirsten, W. 1983. Organic elemental analysis: Ultramicro, micro, and trace methods. Academic Press/Harcourt Brace Jovanovich, New York, New York. 146 pp.

Knops, J.M.H. and D. Tilman. 2000. Dynamics of soil nitrogen and carbon for 61 years after agricultural abandonment. Ecology 81:88-98.

Langley-Turnbaugh, S.J. and C.V. Evans. 2001. A hierarchical evaluation of soil quality indicators in disturbed systems. Journal of Soil and Water Conservation 56(3):176-181.

Larson, W.E. and F.J. Pierce. 1991. Conservation and enhancement of soil quality. Pp. 175-203. *In:* Evaluation for sustainable land management in the developing world. Volume 2. IBSRAM Proceedings 12(2). Bangkok, Thailand. International Board of Soil Resource Management, Bankok, Thailand.

LEAD Technologies, Inc. 2002. SPSS for Windows. Version 11.5.0. Chicago, Illinois.

Lotero, J., W.W. Woodhouse, and R.G. Petersen. 1966. Local effect on fertility of urine voided by grazing wheatgrass. Journal of Range Management 13:318-321.

Lyon, T.L., H.O. Buckman, and N.C. Brady. 1952. The nature and properties of soils, 5th edition. Macmillan Press, New York, New York.

McGarigal, K., S. Cushman, and S. Stafford (eds.). 2000. Multivariate statistics for wildlife and ecology research. Springer-Verlag, New York, New York. 283 pp.

McLean, E.O. 1982. Soil pH and lime requirement. Pp. 199-224. *In:* A.L. Page, R.H. Miller, and D.R. Keeney (eds.). Methods of soil analysis Part 2. 2nd edition. Agronomy Monogram No. 9. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.

McNaughton, S.J. 1979. Grazing as an optimization process: Grass-ungulate relationships in the Serengeti. American Naturalist 113:691-703.

Minitab, Inc. 1996. Minitab for Windows, Version 11.21. State College, Pennsylvannia.

Murphy, C.A., B.L. Foster, M.E. Ramspott, and K.P. Price. 2004. Grassland management effects on soil bulk density. The Kansas Academy of Science 107:45-54.

Naeth, M.A., D.J. Pluth, D.S. Chanasyk, A.W. Bailey, and A.W. Fedkenheuer. 1990. Soil compacting impacts of grazing in mixed prairie and fescue grassland ecosystems of Alberta. Canadian Journal of Soil Science 70:157-167.

Petersen, R.G., W.W. Woodhouse, and H.L. Lucas. 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility. 2. Effect of returned excreta on the residual concentrations of some fertility elements. Agronomy Journal 48:444-449.

Post, W.M. and K.C. Kwon. 2000. Soil carbon sequestration and land-use change: Processes and potential. Global Change Biology 6:317-327.

Proffitt, A.P., S. Bendotti, M.R. Howell, and J. Eastham. 1993. The effect of sheep trampling on soil physical properties and pasture growth for a red-brown earth. Australian Journal of Agronomy Research 44:317-331.

Pulleman, M.M., J. Bouma, E.A. van Essen, and E.W. Meijles. 2000. Soil organic matter content as a function of different land use history. Soil Science Society of America Journal 64:689-693.

Richter, D.D., D. Markowitz, P.R. Heine, V. Jin, J. Raikes, K. Tian, and C.G. Wells. 2000. Legacies of agriculture and forest regrowth in the nitrogen of old-field soils. Forest Ecology Management 138:233-248.

Robles, M.D. and I.C. Burke. 1997. Legume, grass, and Conservation Reserve Program effects on soil organic matter recovery. Ecology Applications 7:345-357.

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers. 1997. Quantification of soil quality. Pp. 387-404. *In:* Soil processes and the carbon cycle. R. Lal et al. (ed.) CRC Press, Boca Raton, Florida.

Seybold, C.A., R.B. Grossman, and F.J. Pierce. 2003. On-site assessment of use-dependent soil properties in Michigan. Communication in Soil Science and Plant Analysis 34(5-6):765-780.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research, 3rd edition. W.H. Freeman and Company, New York, New York. 850 pp.

Sparling, G., D. Ross, N. Trustrum, G. Arnold, A. West, T. Speir, and L. Schipper. 2003. Recovery of topsoil characteristics after landslip erosion in dry hill country of New Zealand, and a test of the space-for-time hypothesis. Soil Biology Biochemistry 35:1575-1586.

Tiessen, H., J.W.B. Stewart, and J.R. Bettany. 1982. Cultivation effects on the amounts and concentration of carbon, nitrogen, and phosphorus in grassland soils. Agronomy Journal 74:831-835.

Turner, C.L., T.R. Seastedt, and M.I. Dyer. 1993. Maximization of aboveground grassland production: The role of defoliation frequency, intensity, and history. Ecology Applications 3:175-186.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 1998. Soil survey geographic (SSURGO) database for Jefferson County, Kansas. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/SSURGO/

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 1999a. Soil survey geographic (SSURGO) database for Douglas County, Kansas. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/SSURGO/

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 1999b. Soil survey geographic (SSURGO) database fore Leavenworth and Wyandotte Counties, Kansas. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/SSURGO/

University of Missouri Agricultural Experiment Station. 1998. Recommended chemical soil test procedures for the North Central Region. North Central Regional Publication No. 221 (Revised). Columbia, Missouri. 75 pp.

Villamil, M.B., V.M. Amiotti, and N. Peinemann. 2001. Soil degradation related to overgrazing in the semi-arid southern caldenal area of Argentina. Soil Science 166:441-452.

Walkley, A. and I.A. Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chronic acid titration method. Soil Science 37:29-37.

Weeda, W.C. 1967. The effect of cattle dung patches on pasture growth, botanical Composition, and pasture utilization. New Zealand Journal of Agricultural Research 10:150-159.

Yeomans, J.C. and J.M. Bremner. 1991. Carbon and nitrogen analysis of soil by automated combustion techniques. Communications in Soil Science and Plant Analysis 22:843-850.

Zavesky, L.D. and W.C. Boatright. 1977. Soil survey of Leavenworth and Wyandotte Counties, Kansas. U.S. Department of Agriculture. Soil Conservation Service with cooperation with Kansas Agricultural Experiment Station, Manhattan, Kansas. 80 pp.