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Assessing Degradation of Soils Cultivated to Irrigated Corn[(1)]

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ABSTRACT - Understanding spatial variability of soil properties is important in identifying the effects of management on soil degradation and productivity and to suggest management options for enhanced sustainability. Research was conducted on two farm fields in the Platte River Valley of south central Nebraska to determine the utility of spatial variability of soil physical, chemical and biological properties to assess field soil degradation and crop productivity potential. The research sites have been cultivated for over twenty-five years, under intensive soil and crop management. The presence of uncultivated areas in close proximity to the experimental fields were used as reference points. The reference area for the site with a silty clay loam soil (Gibbon) has been under alfalfa (***Medicago sativa*** **L**.), and at the second site (Shelton) with a sandy soil the reference area has been under perennial reed canarygrass (***Pharlaris arundinacea*** **L.**). Because of the great difference in soil management, the relative difference between soil properties measured in these two reference areas and those in adjacent cropped land could be used as an indicator of soil and environmental degradation. The soil properties selected for this propose were: pH, electrical conductivity, bulk density; soil organic matter and particulate organic matter. Loss of organic matter due to soil tillage, acidification associated with application of ammoniacal fertilizer, and subsoil compaction were indicators of soil and environmental degradation. Also, differences in corn grain yield of 4 to 5 Mg ha^{-1} observed under uniform management across the field landscape areas indicated soil degradation and apparent inefficiency of agricultural production as indicated by loss of plant available N and associated soil acidification. Soil properties measured in the field indicate that the systems of soil and crop management used by farmers resulted in reduced soil quality and increased soil degradation in parts of the field where erosion was most intense. In some lower lying areas of the fields soil aggradation occurred due to erosional deposition of soil and associated organic matter.

Introduction - Today, new revolutions in philosophy and technology are reshaping agriculture and crop management and there is greater emphasis on soil and environmental quality and precision agriculture. In the past, most emphasis had been placed on production of agricultural crops. In 1960, more than 80% of private research funding was to improve farm machinery. By 1992, 60% of private research was devoted to increasing crop yields through improvement in crop varieties and increased use of agricultural chemicals [9]. Increasingly, however, attention is being paid to the environmental side effects of agricultural production and to product quality [2].

Interest in the concept of soil quality has recently been renewed. Soil quality was defined by an ad hoc committee of the Soil Science of Society of America [12] as: the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water quality, and support human health and habitation. Soil quality was conceptualized as: a three-legged stool, the function and balance of which require an integration of three major components – sustained biological productivity, environmental quality, and plant and animal health [8]. Evaluation of soil condition using tools available to farmers is needed for assessment of the sustainability of agricultural management practices and the translation of science into practice [5].

Several attributes have been suggested as being useful for assessing changes in soil quality, reflecting changes over space and time. Evaluation of pH, electrical conductivity, organic carbon and nitrogen content in soils are essential for assessing chemical aspects of soil quality [7]. Assessment of chemical and biological aspects of soil quality is important, because they provide an indication of the ability of soil to supply plant nutrients and the capacity for buffering against chemical additives or amendments. Soil organic matter content is often used to assess the impact of management practices on soil degradation, because it is negatively related to soil erosion and directly related to soil structural stability and the nutrient supplying power of soil.

The objective of this research was to use the information of spatial variability of soil physical, chemical, and biological properties to assess within-field soil degradation and to suggest management options to enhance the sustainability of the system.

Keywords: soil degradation, spatial variability, soil quality.

Material and Methods - Two farm fields in the Platte River Valley of south central Nebraska, at an elevation of 600 m above sea level, were selected for study. One site hereinafter referred to, as the Gibbon site is a 53-ha farm

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field in north central Buffalo County. The site has been cultivated at least twenty-five years under conventional tillage, and recently with a transition to a ridge till system. It has been cropped principally to corn (***Zea mays*** L.), with an occasional rotation with soybean (***Glycine max*** **Merr.** (L)], and irrigated with a center-pivot sprinkler irrigation system. Soils within the experimental field consist of deep, gently sloping to steep, well-drained silty soils located on upland with 5 to 11% slopes. They were characterized by A horizon (40 cm depth) with 58% silt, 28% clay, a pH of approximately 6.5, which increases with soil depth to values of 8.0 or more, 1.3% organic carbon, and a CEC of 18 $cmol_c$ kg^{-1} of soil .

The other site hereinafter referred to, as the 'Shelton' site is a 53-ha field located in northwest Adams County. Approximately one-quarter of the area at this site is planted to perennial reed canarygrass (*Pharlaris arundinacea* L.) which is used for hay and three-quarters of the area has been cropped to continuous corn under conventional tillage and center-pivot sprinkler irrigation for the past twenty-five years. Chemical and physical soil profile analysis indicated that the soils were characterized by pH ranging from 6.0 to 7.0, organic carbon 0.4 to 1.0%, sand 30 to 90% and a CEC of 5 to 15 $cmol_c$ kg^{-1} of soil .

At both sites, transect sampling design was the scheme used for soil sampling and crop evaluation. Replicated transects spaced at 40 m from north to south ('Gibbon site') and east to west ('Shelton site'), were established to represent a wide range in landscape position, soil organic matter content, nutrient content, texture and crop productivity. Forty-one plots (9.6 m wide x 12 m long), were placed continuously along transects, from west to east. Also, transects were established in the areas cultivated to alfalfa ('Gibbon' site) and perennial grass ('Shelton' site) to represent a benchmark for the effects of soil management on soil properties for the fields cropped with corn. GPS technology was used to permit the precise and repeatable locating plots within the fields. The fields were sampled in June 1998 when the corn was in the V3 to V4 vegetative stages. Eighteen composite soil cores (17.6-mm diameter) per plot were collected at 0 to 15 and 15 to 30 cm depths. All soil samples were air-dried, and ground to pass a 2 mm screen.

The soil properties selected for this study were: pH as an indicator of acidification; electrical conductivity (EC) indicating soil osmotic condition for biological activity and salinization; bulk density (BD) indicating compaction; soil organic matter (SOM) and particulate organic matter (POM) indicating the effects of tillage and water erosion on reduction of soil organic matter. Soil electrical conductivity (EC) and pH was measured with a conductivity meter and a glass electrode, respectively, in a 1:1 soil: water suspension [11]. Soil organic matter fractions were isolated from 2-mm sieved air-dried samples according to methods described by Cambardella et al. [3], to facilitate organic matter analysis by loss on ignition (LOI) methodology. Bulk density was measured according to Doran and Mielke [6], based on the soil volume sampled in each plot, using the following expression: volume of probe ($V = \pi r^2 h$) times number of soil samples in each plot, divided by the dry soil weight at 105ºC.

Summary statistics for the data set were obtained from the univariate procedure in SAS. Analysis of variance was computed using mixed model procedure to detect differences among treatment means (soil properties of areas cultivated to corn, alfalfa, and grass).

Results and Discussion - The results of the analyses of these soil properties for the Gibbon site are summarized in Table 1. Mean values of pH and EC are higher in the area cultivated in corn mainly in the second transect, which is located in a part of the field characterized by convex landform and which is highly eroded. The strong negative correlation observed between pH (r = - 0.74), EC (r = - 0.57), and grain yield [4], is related to the effect of pH and carbonates on nutrient availability, particularly P, rather than a direct effect of EC on yield. Because the content of sodium in soil is low (21 – 48 kg ha^{-1}), it has a low contribution to electrical conductivity. According to Smith and Doran [11], soils are considered slightly saline if the EC for a 1:1 soil-to-water mixture ($EC_{1:1}$) exceeds 1.0 and 1.4 dS m^{-1} for coarse and fine textured soils, respectively. However, the salt tolerance of agricultural crops varies considerably and for corn, values of $EC_{1:1soil:water}$ of 1.0 to 1.2 dS m^{-1} is a threshold, above which yield will begin to decline. Since that electrical conductivity of a soil is determined by a combination of water content, dissolved salt, clay and mineralogy, it has been used successfully to characterize and map soil attributes.

The main difference observed between cropped and reference areas were in organic matter content. The area in alfalfa has an average of 26 % more organic matter (20-Mg ha^{-1}) than the area cultivated to corn (Table 1). This is of interest for two reasons. First, assuming an average grain yield of 10 Mg ha^{-1} [4], the area in corn has an annual addition of organic matter of 8.0 to 10 Mg ha^{-1}. Secondly, unlike the cornfield, the area in alfalfa is used for hay. It receives no addition of organic matter, except that contributed by root growth.

Intensive uses of tillage and high inputs of N-fertilizers are the main factors affecting the rate of crop residue decomposition in the cornfield. The primary effect of tillage is putting the residue into intimate contact with soil microorganisms, which decompose it. The uniform applications of N-fertilizer through irrigation water to the low nitrogen corn residue also increases decomposition. The relatively higher content of POM, the active pool of the organic matter in soils, in the cornfield could be an indicator of this effect (Table 1).

One other important parameter, bulk density, shows similar values for both areas and at both depths (Table 1). The estimated value of soil bulk density in this field, under natural conditions, based on the percentages of clay, silt, sand, and organic matter, was 1.2 g cm^{-3} [4]. The values measured in the field (1.3 to 1.6 g dm^{-3}) suggest a compaction effect of cropping practices and wheel traffic by agricultural equipment. No generally accepted rule of thumbs exists which states that a certain bulk density value limits plant productivity. However, some studies have been conducted which address this parameter in predicting detrimental effects to plant growth. Arshad et al. [1] suggested that a bulk density of 1.50 to 1.55 g cm^{-3} can impedes root growth in a silty clay loam and, thus, will reduce yield. Based on this information and on the values of bulk density, mainly those measured at 15 to 30 cm depth (Table 1), it is probable that compaction is a problem on only a part of the Gibbon field. However, as observed by Coelho [4], the grain yield was not negatively correlated with bulk density. It appears that compaction doesn't constitute a limiting factor for corn, or that the use of irrigation minimizes its effect. As demonstrated by Phene and Beale [10], with use of high-frequency irrigation, corn roots developed normally in a sandy loam soil, where the A2 horizon was compacted (bulk density = 1.7 – 1.9 g cm^{-3}).

For the Shelton field, predominated by sandy soils, the results of analysis of soil properties are summarized in Table 2. The main differences observed for soil properties between the two areas refer mainly to the pH, organic matter and particulate organic matter at both depths, and bulk density measured at the 15 to 30 cm depth.

The average pH of the area under natural grass for both depths was 6.0, one unit higher than the field planted to corn (pH = 5.0) (Table 2), indicating soil acidification with conventional management. Presumably, the main factor causing acidification is associated with application of ammoniacal fertilizers and the apparent loss of nitrified-N from the plant root zone due to leaching or denitrification [11]. The significant negative correlation between pH and inorganic-N (r = - 0.40) [4], supports this interpretation and is related in part to the lower buffering capacity of sandy soils.

Bulk density of surface soils (0-15 cm), were similar for both grass and corn areas (Table 2), but at the 15 to 30 cm depth, bulk densities were higher with corn, suggesting subsoil compaction. The negative correlation (r = - 0.76) observed between bulk density and grain yield [4], suggest a detrimental association of this property with corn growth and development. The average bulk density of 1.74 g cm^{-3} measured for the 15 to 30 cm depth in the area in corn (Table 2), is close to the threshold values of 1.75 to 1.80 g cm^{-3} given by Arshad et al. [1] as restricting for root growth on sandy soils.

Soil organic matter contents also differed greatly between grass and corn areas. The area with grass has an average of 34% (15 Mg ha^{-1}) more organic matter than area cultivated in corn (Table 2). Although residue additions to the soil occur every year in areas annually cropped to corn, multiple cultivation reduces soil aggregate size, destroys residue, and hastens carbon oxidation and mineralization. Also, nitrogen application through irrigation water contributes to increased residue decomposition.

Conclusion - Soil degradation as associated with corn production was assessed by comparing field properties across the landscape under corn management to those under alfalfa and perennial grass. Loss of organic matter, due mainly too intensive tillage and input of N-fertilizers, acidification associated with application of ammoniacal fertilizer and subsoil compaction were indicators of degradation. Also, differences in grain yield of 4.0 to 5.0 Mg ha^{-1} observed at different landscape positions under uniform management indicate soil degradation and inefficiency of agriculture production. As indicated by soil properties measured in the field, the actual systems of soil and crop management used by farmers resulted in reduced soil quality and increased potential environmental degradation. Additional inputs of fossil fuel derived energy in irrigation and fertilizers will be necessary to sustain high levels of corn production, which will likely lead to further soil and environmental degradation.

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Table 1. Descriptive statistics of soil properties measured in alfalfa and corn fields. Gibbon, NE.

Variable and depth [1]	Transect	Crop	Statistical parameters				Std. dev.	CV (%)
			Min	Max	Median	Mean [2]		
$PH_{1:1}$-water (0 – 15 cm)	01	Alfalfa	5.87	6.47	6.18	6.19a	0.22	3.6
	02	Corn	6.04	7.55	7.08	6.88b	0.59	8.7
	03	Corn	6.13	6.71	6.43	6.43a	0.23	3.5
	04	Corn	6.06	7.06	6.44	6.52a	0.29	4.5
	05	Corn	5.89	7.07	6.30	6.43a	0.37	5.8
$PH_{1:1}$-water (15 – 30 cm)	01	Alfalfa	6.20	7.22	6.53	6.55a	0.31	4.7
	02	Corn	5.96	7.76	7.13	6.98a	0.74	10.7
	03	Corn	5.82	7.49	6.33	6.49a	0.51	7.8
	04	Corn	5.82	7.43	6.35	6.61a	0.58	8.8
	05	Corn	5.92	7.51	6.27	6.54a	0.62	9.5
$EC_{1:1}$-water dS m^{-1} (0 – 15 cm)	01	Alfalfa	0.22	0.48	0.26	0.28a	0.08	30.2
	02	Corn	0.30	0.51	0.33	0.39b	0.09	23.6
	03	Corn	0.20	0.36	0.28	0.28a	0.04	13.5
	04	Corn	0.26	0.41	0.28	0.31a	0.05	17.1
	05	Corn	0.22	0.59	0.28	0.32a	0.11	34.3
$EC_{1:1}$-water dS m^{-1} (15 – 30 cm)	01	Alfalfa	0.18	0.56	0.18	0.23a	0.13	57.0
	02	Corn	0.22	0.52	0.43	0.37b	0.11	31.0
	03	Corn	0.22	0.46	0.26	0.29a	0.08	26.2
	04	Corn	0.23	0.50	0.29	0.35b	0.11	32.6
	05	Corn	0.23	0.57	0.31	0.36b	0.13	34.0
BD g cm^{-3} (0 – 15 cm)	01	Alfalfa	1.30	1.45	1.40	1.40a	0.05	3.3
	02	Corn	1.38	1.46	1.43	1.42a	0.03	2.0
	03	Corn	1.32	1.46	1.42	1.40a	0.05	3.7
	04	Corn	1.34	1.49	1.43	1.43a	0.04	2.9
	05	Corn	1.40	1.58	1.46	1.46b	0.06	4.0
BD g cm^{-3} (15 – 30 cm)	01	Alfalfa	1.40	1.63	1.50	1.50a	0.08	5.2
	02	Corn	1.42	1.64	1.51	1.53a	0.07	4.8
	03	Corn	1.44	1.63	1.56	1.54a	0.06	4.2
	04	Corn	1.47	1.61	1.54	1.54a	0.05	3.2
	05	Corn	1.49	1.66	1.60	1.58b	0.05	3.5
SOM Mg ha^{-1} (0 – 15 cm)	01	Alfalfa	76	83	78	78a	2.1	2.6
	02	Corn	40	59	47	48b	7.1	14.7
	03	Corn	49	62	57	57b	4.3	7.5
	04	Corn	52	63	56	57b	3.4	6.0
	05	Corn	53	94	69	70b	16.3	23.2
POM Mg ha^{-1} (0 – 15 cm)	01	Alfalfa	5.5	11.3	7.3	7.5a	1.8	23.8
	02	Corn	4.3	9.8	7.3	7.5a	1.6	21.3
	03	Corn	7.9	11.1	8.9	9.1b	1.0	10.5
	04	Corn	7.7	10.4	9.6	9.2b	0.9	9.5
	05	Corn	7.1	12.2	8.8	9.4b	1.6	16.8

(1) EC = electrical conductivity, SOM = soil organic matter, POM = particulate organic matter.
(2) Means followed by the same letter, for each soil property, are not significantly different at $\alpha = 0.05$ by the t-test.

Table 2. Descriptive statistics of soil properties measured in perennial grass and corn fields. Shelton, NE.

Variable and depth [1]	Transect	Crop	Statistical parameters: Min	Max	Median	Mean [2]	Std. dev.	CV (%)
$PH_{1:1}$-water (0 – 15 cm)	01	Grass	5.48	6.41	6.11	6.00a	0.35	5.8
	02	Corn	4.74	5.34	4.89	4.64b	0.19	3.8
	03	Corn	4.67	5.16	4.94	4.92b	0.15	3.0
	04	Corn	4.82	5.35	4.94	4.99b	0.16	3.3
	05	Corn	4.56	5.53	4.83	4.95b	0.34	7.0
$PH_{1:1}$-water (15 – 30 cm)	01	Grass	5.72	6.81	6.41	6.31a	0.43	6.8
	02	Corn	4.70	6.42	5.25	5.40b	0.50	10.4
	03	Corn	4.89	6.76	5.28	5.41b	0.55	10.2
	04	Corn	4.83	5.79	5.24	5.30b	0.31	5.9
	05	Corn	4.93	7.17	5.15	5.63b	0.80	14.2
$EC_{1:1}$-water $dS\ m^{-1}$ (0 – 15 cm)	01	Grass	0.09	0.20	0.16	0.15a	0.05	29.7
	02	Corn	0.14	0.23	0.17	0.17a	0.03	18.0
	03	Corn	0.14	0.22	0.17	0.17a	0.03	15.2
	04	Corn	0.14	0.28	0.16	0.18a	0.04	22.2
	05	Corn	0.13	0.22	0.15	0.17a	0.04	22.6
$EC_{1:1}$-water $dS\ m^{-1}$ (15 – 30 cm)	01	Grass	0.10	0.21	0.13	0.14a	0.04	27.2
	02	Corn	0.11	0.28	0.15	0.17a	0.06	35.1
	03	Corn	0.12	0.37	0.18	0.19a	0.07	37.2
	04	Corn	0.12	0.25	0.15	0.16a	0.04	25.4
	05	Corn	0.12	0.35	0.16	0.20a	0.08	39.0
BD $g\ cm^{-3}$ (0 – 15 cm)	01	Grass	1.32	1.49	1.44	1.43a	0.06	4.3
	02	Corn	1.37	1.58	1.50	1.49a	0.07	4.5
	03	Corn	1.45	1.55	1.49	1.49a	0.04	2.7
	04	Corn	1.36	1.63	1.44	1.47a	0.09	6.1
	05	Corn	1.32	1.61	1.48	1.46a	0.10	7.1
BD $g\ cm^{-3}$ (15 – 30 cm)	01	Grass	1.37	1.71	1.50	1.54a	0.11	7.4
	02	Corn	1.60	1.85	1.76	1.74b	0.08	4.6
	03	Corn	1.40	1.86	1.74	1.71b	0.12	7.0
	04	Corn	1.55	1.94	1.73	1.74b	0.13	7.3
	05	Corn	1.43	1.91	1.72	1.70b	0.16	9.6
SOM $Mg\ ha^{-1}$ (0 – 15 cm)	01	Grass	30	63	41	43a	12	27.0
	02	Corn	20	37	21	25b	7	26.0
	03	Corn	21	39	29	29b	6	19.0
	04	Corn	21	41	31	31b	6	19.0
	05	Corn	18	44	25	29b	11	38.0
POM $Mg\ ha^{-1}$ (0 – 15 cm)	01	Grass	13	27	19	19a	5	24.2
	02	Corn	9	13	11	11b	1	12.4
	03	Corn	10	14	12	12b	1	11.7
	04	Corn	7	15	12	11b	3	22.0
	05	Corn	7	14	11	11b	2	19.0

(1)EC = electrical conductivity, SOM = soil organic matter, POM = particulate organic matter.

(2) Means followed by the same letter , for each soil property, are not significantly different at $\alpha = 0.05$ by the t-test.