A Soil Carbon Survey of the Transitional Cropping Systems at the NDSU Hettinger Research and Extension Center, Adams County, North Dakota

Larry J. Cihacek and Gayatri Yellajosula
Soil Science Department
North Dakota State University
Fargo, ND 58105

Timothy Faller and Christopher Schauer
Hettinger Research and Extension Center
North Dakota State University
Hettinger, ND 58639

EXECUTIVE SUMMARY

Due to recent increased interest in carbon (C) sequestration and storage by soils to mitigate increasing atmospheric CO_2 levels, soil carbon surveys were conducted in the Plains CO_2 Reduction Partnership (PCOR) region to obtain information on soil C storage under cropland and native rangeland. This survey was done in an area where limited information on C sequestration potential presently exists.

Plots established in 1999 to evaluate conversion of grassland to cropland and changes in management of both grassland and cropland were sampled in detail for this study. A total of eleven treatments were sampled to evaluate the changes in C sequestration that have occurred since the establishment of the study plots.

Carbon sequestration potential was estimated for grazed and ungrazed re-established grassland and for continuous spring wheat, barley and oats grown under conventionally tilled or no-till culture. Where native grassland was tilled and converted to either restored grass or cropland, soil organic C was an average of 0.691 kg/m^2 lower than undisturbed grassland. Where long-term cropland was continued in cropping or restored to grass, the soil organic C was an average of 1.521 kg/m^2 lower than undisturbed grass. Because of exceptionally dry growing seasons or early frost in two of the four years that the study has been established, it is unlikely that an equilibrium between soil C sequestration and management system has been attained.

Introduction

Soils have long been known to have the capacity to store carbon as organic matter. With recent concerns of the effects of CO_2 emissions on climate change, interest in the potential of agricultural soils to sequester and store C from atmospheric CO_2 to mitigate effects of anthropogenic CO_2 emissions on climate change. Recently, de Silva et al. (2004) reviewed the role soils have in relation to carbon sequestration. Information about the capacity of soils in the northern Great Plains to sequester carbon (C) is limited. Cihacek and Ulmer (1995, 1997, 2002) have reported on C distribution in long-term crop-fallow and rangeland management for several soils in Major Land Resource Area (MLRA) 54 of North Dakota. However, they did not attempt to estimate the capacity of soils to sequester C. A recent review by Liebig et al. (2005) reported that historical records in the literature showed that based on 8 reports, the average relative loss of soil organic C (SOC) was 34 ± 14 % (12.1 ± 7.9 g C kg^{-1}) for soil depths ≤ 30 cm due to conversion of native vegetation to cropping. Estimates of mean C storage rate (C sequestration) were reported only for only two studies in the PCOR region. Pikul and Aase (1995) reported that under continuous cropping and no-till 0.22 Mg C ha^{-1} yr^{-1} was sequestered. Halvorson et al. (2002) reported that in a spring wheat-winter wheat-fallow cropping system, 0.23 Mg C ha^{-1} yr^{-1} was sequestered under no-till, 0.03 Mg C ha^{-1} yr^{-1} was sequestered under moderate tillage, and 0.14 Mg C ha^{-1} yr^{-1} was lost under conventional tillage. In general, Liebig et al. (2005) report that in the northwestern USA and western Canada, no-till increased soil organic carbon by 0.27 ± 0.19 Mg C ha-1 yr^{-1}. This value is similar to estimates made by the Intergovernmental Panel on Climate Change (IPCC).

Agriculture is southwestern North Dakota can be tenuous for those involved in farming. The southwestern portion of the state is considered to be semi-arid and little irrigation water is available. Most of the crop production is under rain-fed conditions and rainfall is highly variable from one growing season to another and has been generally adapted to small grain production.

In 1999, a series of cropping system management plots was established at the NDSU Hettinger Research and Extension Center near Hettinger in Adams County, North Dakota in collaboration with NDSU Animal and Range Science, Agricultural Economics and Agri-Business, and Soil Science Departments. A native grassland site and a long-term cropped site were identified to examine the feasibility for farmers and ranchers to either (i) convert rangeland to cropland, (ii) convert cropland to rangeland and within each of these options to (iii) graze, or (iv) not graze the rangeland, or to use (v) conventional tillage, or (vi) no-till for production of small grains including spring wheat, barley or oats. An underlying objective of this study was to examine the effects of changes in land management on soil quality especially on soil organic matter (C sequestration).

The objective the work reported here is to evaluate the changes in soil C four years after the establishment of the study with the data obtained to be used in comparing soil C levels with baseline data collected at the initiation of the study and to develop future models for predicting soil C sequestration.

Procedures

In 1999, 24 plots were laid out in an area that was previously under crop production using a completely randomized design with three replications . Twenty-seven plots were established in an adjacent area where native rangeland was tilled and converted to crop production using a completely randomized design with three replications. Three plots within the native rangeland were not disturbed to allow for comparison of the cropped plots with rangeland that was undisturbed. Two treatments of restored grass were included with the cropping systems to compare changes in soil C when land is taken out of production and converted back to grassland. One of the restored treatments included grazing as a management variable and the other was left ungrazed. All of the plots with the exception of the grazed grass plots were 10 feet wide and 100 feet long (3.1 m by 31 m). The grazed plots were 80 feet wide by 100 feet long (24.6 m by 31 m) and enclosed by a fence to allow for managing animal grazing.

Triplicate soil cores were collected at the selected sites using a truck mounted hydraulic soil-coring device in early August of 2004. The cores were collected with 2-foot-long (60-cm) 2 3/8-inch (59-mm) diameter steel sampling tube lined with a 2 ¼ (57-mm) acetate contamination liner to a minimum depth of 24-inches (0.6-meter). The soils at the study site are underlain by gravel which limits the sampling depth. Four cores were collected from the plots at a spacing of approximately 25 feet (7.5 meters) apart. Since the conventionally tilled plots had both cropped and fallow areas collecting four cores allowed for two cores to be taken in the cropped area and two cores to be taken from the fallow area of each plot. All cores were coded or numbered from east to west so that information obtained from this sampling could be related to past and future samplings that may be conducted. Each core was also identified by latitude and longitude using a Garmin GPS 76 hand-held GPS unit.

Once a soil core was taken, the core and acetate liner were removed from the steel sampling tube. The acetate liner was trimmed to the length of the soil core, if necessary, capped with plastic caps and sealed with duct-tape. The sealed cores were then transported back to NDSU and placed in cold storage until they could be processed for analysis.

In preparing the cores for analysis, the acetate liners were cut open with a carpet knife and the cores were cut into 6-inch (15-cm) increments beginning at the end of the core representing the soil surface. The core segments were weighed, hand-crushed and subsampled for moisture content. The remaining portion of each core segment was then air-dried, crushed to pass a 2-mm screen and bagged as individual soil samples. From the core segment weight and moisture content, core bulk density for each core segment was determined for use in C mass calculations.

A 10-15 gram subsample was taken from each well-mixed sample for C analysis. Each subsample was milled in a ball mill to pass a 100-mesh screen. Approximately 150 milligrams of each subsample were used for total C and inorganic C analysis. The C analysis was done by high temperature (~1000º C) combustion and inorganic C was done by CO_2 release from sample acidification using a Skalar Primacs™ carbon analyzer, which has the capability of performing both analyses. Organic C values were obtained by difference from the total C and inorganic C data.

Carbon mass was calculated for each depth increment for total C, organic C and inorganic C by multiplying the % C value obtained from the C analysis by the core bulk density. The C mass for all depths were summed up and adjusted by the appropriate factors to give C mass per unit area per depth of the soil. The data for the four cores in each plot was averaged to give a whole plot value. Consequently, all data for the conventionally tilled plots includes data for both the cropped and fallow areas of each plot. Since cropping and fallow occur in alternating years handling the data in this manner is representative of soil C changes in a crop-fallow management system. Only data for the 2004 sampling is reported here.

The Soils

Two soil series with very similar properties were identified at the study site. The first soil series was the Bowdle series which was mapped on the northern 20 % of the long-term cropped site. The second soil series was the Ruso series which was mapped on the remainder of the long-term cropped site and the native grass site. Since both soils at the study site are similar in texture and depth to gravel, no distinction is made with respect to differences between soils in this report.

Bowdle Series:

The Bowdle series soils are classified as fine-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Pachic Haplustolls This series consists of well-drained soils formed in alluvium underlain by sand and gravel. They are moderately deep over sand and gravel and are found on outwash plains and stream terraces. Depth to gravel ranges from 20 to 40 inches. Slopes range from 0 to 15 percent but are generally less than 6 percent. Mean annual precipitation is 12 to 18 inches (305 to 457 mm) and mean annual temperature is about 34 to 44º F. The surface mollic horizon is 16 to 32 inches thick. The surface textures are generally sandy loams , loams or silt loams. These soils are well-drained with moderate permeability in the upper profile and rapid to very rapid in the underlying material.

The soils of the Bowdle series are generally extensively found in glaciated areas of north-central South Dakota and central North Dakota mostly east and north of the Missouri River in MLRA's 53 A and 53B. Where these soils have been mapped on residual landforms such as found in MLRA 54, they have been more recently classified as the Stady series. The potential native plant community is primarily western wheatgrass, blue grama, green needlegrass, needle-and-thread grass, forbs and sedges. These soils are primarily cropped to small grains, alfalfa and some flax and corn.

This series was established in Edmunds County, South Dakota in 1973. The diagnostic horizons and features recognized in a typical pedon of these soils are:

- An A horizon that is loam or silt loam textured and is slightly acid or neutral in reaction.

- A Bw horizon that is loam or clay loam in texture. It is slightly acid t neutral in the upper part and neutral to slightly alkaline in the lower part.
- A Bk horizon that is gravelly loam, gravelly sandy loam, sandy loam or loam and is slightly to moderately alkaline in reaction.
- A 2C horizon that is gravelly sand, gravelly loamy sand, very gravelly loamy sand very gravelly sand or gravelly loamy sand. It may contain fragments of shale and carbonates may be present.

This description is based on

Information on the Bowdle soil series can be found at
http://ortho.ftw.nrcs.usda.gov/osd/dat/B/BOWDLE.html

Ruso Series:

Soils of the Ruso series are classified as coarse-loamy, mixed, superactive, frigid Pachic Haplustolls. This series consists of very deep, well-drained soils that are formed in loamy alluvium over sand and gravel on outwash plains and stream terraces. Depth to sand and gravel ranges from 24 to 40 inches. Slopes range from 0 to 9 percent but are typically less than 3 percent. Mean annual precipitation is 12 to 17 inches most of which falls in the spring and summer and mean annual temperature is 34 to 45° F. The thickness of the mollic horizon ranges from 16 to 30 inches. Surface textures are fine sandy loam, sandy loam or coarse sandy loam. The soils are well drained with slow runoff, moderately rapid permeability in the upper part and very rapid permeability in the lower part of the profile.

The Ruso soils are moderately extensive in the glaciated areas of central North Dakota and north-central South Dakota mostly east and north of the Missouri River in MLRA's 53 A and 53 B. The potential native vegetation consists of needle-and-thread grass, prairie sandreed, western wheatgrass, blue grama, little bluestem, forbes and snowberry. These soils are primarily cropped to small grains and alfalfa and some areas may be irrigated. In residual land forms it may be classified as the Manning series.

This series was established in McLean County, North Dakota in 1974. The diagnostic horizons and features recognized in a typical pedon of these soils are:

- An A horizon that has a fine sandy loam, sandy loam or coarse sandy loam texture and has more than 50 percent fine or coarser sand. It is neutral in reaction.
    - A Bw horizon that has a coarse sandy loam, fine sandy loam or sandy loam texture and has more than 50 percent fine or coarser sand. It is neutral or slightly alkaline in reaction. Some profiles may have a 2Bw horizon.
    - A Bk horizon that is coarse sandy loam, sandy loam or fine sandy loam in texture containing up to 35 percent coarse fragments. It is slightly alkaline to moderately alkaline in reaction. Some profiles may have a 2Bk or 2 BCk horizon which have

textures of loamy coarse sand, loamy sand, or coarse sand and contain up to 80 percent coarse fragments.

- A 2C horizon that has a coarse sand loamy sand or sand containing up to 80 percent coarse fragments. This horizon is slightly alkaline or moderately alkaline in reaction.

This description is based on North Dakota Agricultural Experiment Station laboratory data SU72ND-28-4.

Information on the Ruso soil series can be found at http://ortho.ftw.nrcs.usda.gov/osd/dat/R/RUSO.html

Results and Discussion

The soil C data is shown in Tables 1a through 1i and is arranged by treatment with the treatments for the area with the previously converted native grassland on the left side of the table and the treatments for the previously cropped area on the right side of the table. Because most of the short term C dynamics occur within the surface 1 foot of the soil (30 cm), comparisons will be made only on the 0 to 12-inch depth values reported in the tables.

Table 1a shows the distribution of organic, inorganic, and total C for the undisturbed native grassland treatment. This treatment was considered as the baseline treatment for comparing all of the other treatments superimposed on the cropped and previous rangeland. It is assumed that the C levels in this treatment represent the "natural" or "original" levels of C before this region of the northern Great Plains was settled and cultivated. For the purposed of this report, the discussion will primarily focus on soil organic C.

Table 1a: Organic (OC), inorganic (IC) and total C (TC) profile distribution in undisturbed native grassland.

Undisturbed Native Grass (Grassland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	3.037	0.000	3.037
4-8	1.839	0.000	1.839
8-12	1.425	0.000	1.425
12-18	2.259	0.246	2.505
18-24	2.471	0.753	3.224
Total (0-12)	6.301	0.000	6.301
Total (0-24)	11.031	0.999	12.030

Table 1b shows the organic, inorganic and total C levels in land that has been restored to grass or pasture with managed livestock grazing (no overgrazing). Restoring grass on recently tilled native rangeland showed a decrease of 0.553 kg/m^2 while the same treatment on the soils with a long-term history of cropping showed soil organic C levels that were 1.424 kg/m^2 lower than the native grass.

Table 1b: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution in restored grass cover at the native grassland and cropped history sites with managed livestock grazing.

Restored Grass – Grazed (Grassland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.827	0.000	2.827
4-8	1.758	0.000	1.758
8-12	1.163	0.000	1.163
12-18	1.803	0.076	1.879
18-24	1.370	0.000	1.370
Total (0-12)	5.748	0.000	5.748
Total (0-24)	8.921	0.076	8.997

Restored Grass – Grazed (Cropland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	1.905	0.000	1.905
4-8	1.767	0.000	1.767
8-12	1.205	0.000	1.205
12-18	1.963	0.000	1.963
18-24	2.332	0.545	2.877
Total (0-12)	4.877	0.000	4.877
Total (0-24)	9.172	0.545	9.717

Where the restored grass was left ungrazed (Table 1c), the soil organic C levels were 0.540 kg/m^2 lower for the area with a native grass history and 1.383 kg/m^2 for the area that was previously in long-term cropping.

Table 1c: Organic C, inorganic C, and total C profile distribution in restored grass cover at the native grassland and cropped history sites without managed livestock grazing.

Restored Grass – Ungrazed (Grassland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.826	0.000	2.826
4-8	1.717	0.000	1.717
8-12	1.218	0.000	1.218
12-18	1.842	0.338	2.065
18-24	1.216	0.419	1.635
Total (0-12)	5.761	0.000	5.761
Total (0-24)	8.819	0.757	9.462

Restored Grass – Ungrazed (Cropland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	1.858	0.000	1.858
4-8	1.729	0.000	1.729
8-12	1.331	0.049	1.380
12-18	1.821	0.055	1.876
18-24	2.223	0.000	2.223
Total (0-12)	4.918	0.049	4.967
Total (0-24)	8.962	0.104	9.066

Under conventionally tilled spring wheat management (Table 1d), the soil previously in native rangeland had 0.879 kg/m^2 less soil organic C than the undisturbed native rangeland and the previously cropped land had 1.408 kg/m^2 less soil organic C when compared to the undisturbed grassland.

Table 1d: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution at the native grassland and cropped history sites when managed under conventionally tilled wheat.

Wheat - Conventionally Tilled (Grassland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.214	0.000	2.214
4-8	1.879	0.000	1.879
8-12	1.329	0.000	1.329
12-18	1.948	0.132	2.080
18-24	2.192	0.245	2.438
Total (0-12)	5.422	0.000	5.422
Total (0-24)	9.562	0.377	9.939

Wheat - Conventionally Tilled (Cropland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	1.727	0.000	1.727
4-8	1.759	0.000	1.759
8-12	1.407	0.000	1.407
12-18	1.857	0.000	1.857
18-24	2.019	0.754	3.132
Total (0-12)	4.893	0.000	4.893
Total (0-24)	8.769	0.754	9.883

When the wheat was no-tilled (Table 1e), the soil previously in native grassland has an 0.28 kg/m^2 decrease in organic C and a decrease of 1.980 kg/m^2 on soil that was historically cropped.

Table 1e: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution at the native grassland and cropped history sites when managed under no-till wheat.

Wheat - No-tilled (Grassland History)

Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.770	0.000	2.770
4-8	1.871	0.000	1.871
8-12	1.379	0.056	1.435
12-18	2.035	0.058	2.093
18-24	2.064	0.861	2.924
Total (0-12)	6.021	0.056	6.076
Total (0-24)	10.119	0.974	11.093

Wheat - No-tilled (Cropland History)

Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	1.623	0.000	1.960
4-8	1.460	0.000	1.826
8-12	1.238	0.000	1.522
12-18	1.438	0.000	1.929
18-24	1.667	0.170	2.489
Total (0-12)	4.321	0.000	5.309
Total (0-24)	7.426	0.170	9.726

When the soils were managed with conventionally tilled barley (Table 1f), a decrease in soil organic C of 0.685 kg/m^2 was noted for the previously native grassland and the previously cropped soil had a decrease of 1.224 kg/m^2 from the levels in the native grass treatment.

Table 1f: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution at the native grassland and cropped history sites when managed under conventionally tilled barley.

Barley - Conventionally Tilled (Grassland History)

Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.626	0.000	2.496
4-8	1.627	0.000	1.461
8-12	1.363	0.000	1.211
12-18	2.107	0.176	1.907
18-24	2.009	0.927	2.527
Total (0-12)	5.616	0.000	5.168
Total (0-24)	9.732	1.103	9.602

Barley - Conventionally Tilled (Cropland History)

Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	1.832	0.000	1.830
4-8	1.801	0.000	1.746
8-12	1.444	0.000	1.340
12-18	1.975	0.000	1.878
18-24	2.269	0.456	2.675
Total (0-12)	5.077	0.000	4.915
Total (0-24)	9.322	0.456	9.469

Under no-till management (Table 1g), the barley treatment showed an 0.771 kg/m^2 decrease in organic C from the native grass levels and the previously cropped soil showed a decrease organic C of 1.576 kg/m^2.

Table 1g.: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution at the native grassland and cropped history sites when managed under no till barley.

Barley - No-tilled (Grassland History)				Barley - No-tilled (Cropland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)	Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.537	0.000	2.537	0-4	1.779	0.000	1.779
4-8	1.685	0.000	1.685	4-8	1.664	0.000	1.664
8-12	1.308	0.022	1.330	8-12	1.282	0.130	1.412
12-18	1.831	0.329	2.160	12-18	1.805	0.000	1.805
18-24	1.976	0.181	2.157	18-24	2.017	0.170	2.187
Total (0-12)	5.530	0.022	5.553	Total (0-12)	4.725	0.130	4.855
Total (0-24)	9.337	0.533	9.869	Total (0-24)	8.547	0.300	8.847

Conventionally tilled oats (Table 1h) showed soil organic C to be 0.959 kg/m^2 lower than the native grass on the previous grassland soil and 1.567 kg/m^2 lower on the previously cropped soil.

Table 1h: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution at the native grassland and cropped history sites when managed under conventionally tilled oats.

Oats - Conventionally Tilled (Grassland History)				Oats - Conventionally Tilled (Cropland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)	Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.276	0.000	2.276	0-4	1.755	0.000	1.755
4-8	1.741	0.000	1.741	4-8	1.698	0.000	1.698
8-12	1.324	0.000	1.324	8-12	1.281	0.000	1.281
12-18	2.040	0.139	2.178	12-18	2.006	0.000	2.006
18-24	2.055	1.359	3.414	18-24	2.275	1.166	2.830
Total (0-12)	5.342	0.000	5.342	Total (0-12)	4.734	0.000	4.734
Total (0-24)	9.437	1.498	10.934	Total (0-24)	9.015	1.166	9.570

Under no-till (Table 1i), the oats treatment on the previous grassland soil was 0.865 kg/m^2 lower than the native grass treatment and the soil under long-term cropping was 1.612 kg/m^2 lower in soil organic C than the native grass treatment.

Table 1i: Organic C (OC), inorganic C (IC), and total C (TC) profile distribution at the native grassland and cropped history sites when managed under no-till oats.

Oats - No-till (Grassland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	2.401	0.000	2.401
4-8	1.779	0.000	1.779
8-12	1.258	0.000	1.258
12-18	2.044	0.120	2.164
18-24	1.888	1.541	3.226
Total (0-12)	5.438	0.000	5.438
Total (0-24)	9.371	1.661	10.828

Oats - No-till (Cropland History)			
Depth (in)	O.C. (kg/m^2)	I.C. (kg/m^2)	T.C. (kg/m^2)
0-4	1.752	0.000	1.752
4-8	1.634	0.000	1.634
8-12	1.302	0.000	1.302
12-18	1.819	0.000	1.819
18-24	1.927	0.000	1.927
Total (0-12)	4.689	0.000	4.689
Total (0-24)	8.435	0.000	8.435

From the data shown above, all of the cropping treatments that are on the area that was previously grassland show much lower declines in soil organic C than do the cropping treatments on the long-term cropped land. This can be expected because the native grassland was tilled relatively recently (4 years ago) and much of the C that is normally lost due to tillage may still be unoxidized. On the other hand, the soil in long-term cropping shows about a 25 % decrease in soil organic C from the levels found in the undisturbed grass treatment. This would appear to be within the range of losses as reported by Cihacek and Ulmer (1995) and Liebig et al (2005) based on historical literature.

Potential of Soils to Sequester Carbon

The potential of soils to sequester C was calculated using an average value of 0.27±19 Mg C ha-1 yr-1 reported by Liebig et al (2005) in the absence of established values for the cropping systems. Since the Hettinger study site represents soil, climate and production conditions found in the southwestern four counties of North Dakota, the estimates in Table 2 are presented for each crop under each tillage management system for Adams, Bowman, Hettinger and Slope counties.

Table 2. Estimated annual C sequestration potential for no-till or conventionally tilled spring wheat, barley or oats in Adams, Bowman, Hettinger, and Slope counties of North Dakota.

State	**County**	**Crop/Tillage**	**Ecosystem**[1]	**Carbon Sequestration Potential (tons per year)**[2, 3]	**Land Use Statistics (Acreage by County)**[4, 5]
ND	Adams	Barley/ Conventional Tillage	Cropland	155 (347 Mg)	3,177 (1,287 ha)
ND	Adams	Barley/ No-till	Cropland	197 (442 Mg)	4,043 (1,637 ha)
ND	Adams	Oats/ Conventional Tillage	Cropland	95 (214 Mg)	1,954 (791 ha)
ND	Adams	Oats/ No-till	Cropland	121 (272 Mg)	2,486 (1,007 ha)
ND	Adams	Wheat/ Conventional Tillage	Cropland	2,738 (6,139 Mg)	56,144 (22,738 ha)
ND	Adams	Wheat/ No-till	Cropland	3,485 (7,814 Mg)	71,456 (28,940 ha)
ND	Bowman	Barley/ Conventional Tillage	Cropland	224 (501 Mg)	4,585 (1,857 ha)
ND	Bowman	Barley/ No-till	Cropland	285 (638 Mg)	5,835 (2,363 ha)
ND	Bowman	Oats/ Conventional Tillage	Cropland	96 (215 Mg)	1,971 (798 ha)
ND	Bowman	Oats/ No-till	Cropland	122 (274 Mg)	2,509 (1,016 ha)
ND	Bowman	Wheat/ Conventional Tillage	Cropland	3,893 (8,728 Mg)	79,825 (32,329 ha)
ND	Bowman	Wheat/ No-till	Cropland	4,950 (11,099 Mg)	101,505 (41,109 ha)
ND	Hettinger	Barley/ Conventional Tillage	Cropland	219 (492 Mg)	4,497 (1,821 ha)
ND	Hettinger	Barley/ No-till	Cropland	279 (626 Mg)	5,723 (2,318 ha)
ND	Hettinger	Oats/ Conventional	Cropland	75 (167 Mg)	1,531 (620 ha)

		Tillage			
ND	Hettinger	Oats/ No-till	Cropland	68 (152 Mg)	1,389 (563 ha)
ND	Hettinger	Wheat/ Conventional Tillage	Cropland	5,967 (13,378 Mg)	120,956 (49,550 ha)
ND	Hettinger	Wheat/ No-till	Cropland	7,508 (16,834 Mg)	153,944 (62,347 ha)
ND	Slope	Barley/ Conventional Tillage	Cropland	178 (398 Mg)	3,643 (1,475 ha)
ND	Slope	Barley/ No-till	Cropland	226 (507 Mg)	4,636 (1,878 ha)
ND	Slope	Oats/ Conventional Tillage	Cropland	60 (134 Mg)	1,223 (495 ha)
ND	Slope	Oats/ No-till	Cropland	76 (170 Mg)	1,557 (631 ha)
ND	Slope	Wheat/ Conventional Tillage	Cropland	2,573 (5,768 Mg)	52,756 (21,366 ha)
ND	Slope	Wheat/ No-till	Cropland	3275 (7,342 Mg)	67,144 (27,193 ha)

[1]Estimates are for land that has been in long-term cultivation (>80 years).

[2]Carbon sequestration value estimates are based on estimated sequestration values of 0.27 ± 0.19 Mg C ha reported by *Leibig, M. A., J. A. Morgan, J. D. Reeder, B. H. Ellert, H. T. Gollany, and G. E. Schuman. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. Soil & Tillage Res. 83:25-52.* Since most soils that have been cultivated this long have had significant organic matter degradation, estimated effective sequestration periods are up to 52 years for wheat, 46 years for barley, and 58 years for oats depending on management changes implemented within these cropping systems. Actual sequestration rates and quantities may vary with variations in annual temperature and rainfall.

[3]Actual CO_2 sequestration (removal) rates can be obtained by multiplying soil C sequestered by 3.66.

[4]Acreage values are based on averages of 1999 to 2003 acreages reported in *North Dakota Agricultural Statistics Service, 2004 North Dakota Agricultural Statistics, North Dakota State University, Fargo, ND 58105, August 2004.*

[5]Acreage values for conventionally tilled and no-till cropland for each crop are weighted values based on conventional, conservation and no-till acreage distribution data provided by D. Bangsund and L. Leistritz, Agricultural Economics Department, North Dakota

State University, Fargo, ND 58105. Conservation tillage acres have been proportionately distributed between conventional till and no-till due to this type of tillage encompassing a wide range of practices that range from somewhat less tillage than conventional tillage to somewhat more tillage than no-till. These values are based on local soil and water conservation district data.

Summary and Conclusions

Soils having a past history of native grassland showed a much lower loss of organic C than those which were under long-term crop production due to tillage. However, noteable changes in soil C have already occurred in the four years that the native grassland has been under cultivation. Since 2 of the 4 years that the plots have been managed within this study were either very dry or were subject to early frost, crop production and consequently crop biomass production were below normal. As a result, the differences in soil organic C between each of the crop/tillage management system cannot be properly interpreted to clarify the treatments effects on C sequestration. Under the growing season conditions that have existed since the establishment of the plots, it is unlikely that the soil C has yet equilibrated with the existing management conditions.

Limitations of the Data

The data in this data set is subject to the following limitations:

- The soils sampled represent two of the soil series mapped in MLRA 54. However, due to a range of soil properties within a soil series, the sites sampled do not necessarily represent the central properties of that series. In addition, other soils suitable for C sequestration exist in cropland of this MLRA. These other soils have not been evaluated under similar conditions and their abilities to sequester C may be lesser or greater than these two soils.

- Soils were sampled to a minimum depth of 0.60 meter (24 inches) where possible. However, very dry soil conditions, coarse or stony materials or hard substrata prevented sampling to that depth in some cases. In most instances, plant roots have difficulty growing in or through these soil zones and carbon sequestration by plants is negligible.

- Some of the soils exhibited cracking in the profile due to the presence of clay minerals that shrink and swell due to wetting and drying. The estimation of soil bulk density may be affected by the moisture content of the soil profiles, the presence of cracks, and the size of the cracks in the soil profile. Collecting multiple cores at each sampling site reduces the effect of these soil properties but does not eliminate them.

- Although sites were selected based on the management treatments applied to the cropland site soils as well as to the grassland site soils, soil characteristic may vary within each plot over short distances. Land management (i.e., tillage, cropping, crops) impacts changes in soil characteristics. However, this sampling scheme is designed to best incorporate the impacts of land management.

- Although the grassland data represents a picture of C sequestered in grassland believed to have never been tilled, grazing practices (i.e., overgrazing, rotational grazing, no grazing) may have changed the C relationships in the soils since the land was settled in the late 1880's. Thus, the soil C relationships today may differ from the relationships that existed at the time that intensive human settlement occurred throughout the MLRA.

- The C relationships presented in this data could change significantly over a short period (<5-10 years) if significant changes in land management or human or natural disturbance occur.

Acknowledgements

The assistance of the NDSU Hettinger Research and Extension Center staff in providing the hydraulic probe truck, Brian Cihacek and Melisa Toepke-Peterson for processing the soil samples and Keith Jacobson for soil analysis is greatly appreciated.

References

Cihacek, L.J. and M.G. Ulmer. 1995. Estimated soil organic carbon loss from long-term crop fallow in the northern Great Plains of the USA. pp. 85-92. In R. Lal, J.M. Kimble, E. Levine and B.A. Stewart (eds.) Soil Management and Greenhouse Effects - Advances in Soil Science. Lewis Publishers. Boca Raton, FL.

Cihacek, L.J. and M.G. Ulmer. 1997. Effects of tillage on profile soil carbon distribution in the Northern Great Plains of the USA. pp. 83-91. In R. Lal, J.M. Kimble, E. Levine, and B.A. Stewart (eds.) Management of Carbon Sequestration in Soil-Advances in Soil Science. CRC Press, Boca Raton, FL.

Cihacek, L.J., and M.G. Ulmer. 2002. Effects of tillage on inorganic carbon storage in soils of the Northern Great Plains of the U.S. pp.63-69. In J.M. Kimble, R. Lal, and R.F. Follett (eds.) Agricultural Practices and Policies for Carbon Sequestration in Soil. Lewis Publishers, Boca Raton, FL.

de Silva, L. L., L. J. Cihacek, F. L. Leistritz, T. C. Faller, D. A. Bangsund, E. N. Stedman, and J. A. Harju. 2004. The contribution of soils to carbon sequestration. Plains CO2 Reduction (PCOR) Partnership Tech. Rep. Energy and Environment Research Center, University of North Dakota, Grand Forks, ND., 15p. November 2004.

Frank, A. B. 2004. Six years of CO2 flux measurements for moderately grazed mixed-grass prairie. Environ. Manage. 33:S426-S431.

Frank, A. B., D. L. Tanaka, L. Hoffman, and R. F. Follett. 1995. Soil Carbon and nitrogen of Northern Great Plains grasslands as influenced by long term grazing. J. Range Manage. 48:470-474.

Halvorson, A. D., B. J. Wienhold, and A. L. Black. 2002. Tillage, nitrogen and cropping system effects on soil carbon sequestration. Soil Sci. Soc. Am. J. 66:906-912.

Liebig, M. A., J. A Morgan, J. D. Reeder, B. H. Ellert, H. T. Gollany, and G. E. Schuman. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. Soil & Tillage Res. 83:25-52.

Mortenson, M. C., G. E. Schuman, and L. J. Ingram. 2004. Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp, f*alcata*). Environ. Manage. 33:S475-S481.

Pikul, J. L., and J. K. Aase. 1995. Infiltration and soil properties as affected by annual cropping in the northern Great Plains. Agron. J. 87:656-662.

Stahl, P. D., J. D. Anderson, L. J. Ingram, G. E. Schuman, and D. L. Mummey. 2003. Accumulation of organic carbon in reclaimed coal mine soils of Wyoming. In R. I. Barnhisel (ed) Working Together for Innovative Reclamation, 20th Annual Meeting, American Society of Mining and Reclamation, Billings, MT, June 3-6. Amer. Soc. Mining and Reclam., Lexington, KY. PP. 1206-1215.