SUMMARIZING REGIONAL RESEARCH DATA CONTRIBUTING TO THE U.S. RAPID CARBON ASSESSMENT IN THE NORTHERN GREAT PLAINS

A Paper
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Sciences

By

Edward Alton Kraft

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Natural Resources Management

February 2014

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Summarizing Regional Research Data Contributing To The U.S. Rapid Carbon Assessment In The Northern Great Plains

By

Edward Alton Kraft

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Larry Cihacek
Chair

Dr. David Hopkins

Dr. Tom DeSutter

Dr. Mark Liebig

Approved:

2-19-2016
Date

Dr. Frank Casey
Department Chair

ABSTRACT

Research on soil organic carbon (SOC) within the northern Great Plains has not been clearly documented. Objectives of this study were (i) to inventory literature reporting SOC responses to agroecosystem management, (ii) extract data for the Northern Great Plains Rapid Carbon Assessment, and (iii) summarize data to identify relationships between SOC and land use management. Soil organic carbon at 0 – 15 cm depth was 1.57 – 6.87 kg C m^{-2}, 1.56 – 5.34 kg C m^{-2}, and 1.48 – 5.48 kg C m^{-2} under grasslands, conservation tillage (CST), and conventional tillage (CT), respectively. Soils with a Productivity Index (PI) of 80 – 100 had greater mean SOC (4.14 kg C m^{-2}) across all managements. Correlation between SOC and PI for CT was significant ($r=0.240$) ($P=0.05$) and highly significant ($r=0.418$) ($P=0.01$) for CST. Management practices for cropland soils combined with productivity potential appear to relate to the C accrual potential of northern Great Plains soils.

ACKNOWLEDGMENTS

I would like to express my appreciation to the following people for their guidance, patience, encouragement, and support:

- Dr. Larry Cihacek for serving as my major advisor, giving me the opportunity to work in the lab, and for his guidance, patience, and encouragement over the last several years.
- Dr. Dave Hopkins for all the interesting field trips during my first semester and serving on my committee.
- Dr. Thomas DeSutter for making the classroom an interesting place to be and serving on my committee.
- Dr. Mark Liebig for taking the time to serve on my committee and providing guidance and advice.
- Dr. Susan Samson-Liebig for giving me the guidance, advice, and the opportunity to work on this project. Also, for the advice and guidance in my first couple years with the NRCS.
- Jeanne Heilig for making me feel welcome in western North Dakota and for working with the NRCS to ensure that I finished my paper.
- John Kempenich for making me feel welcome in western North Dakota, and providing me with countless opportunities to pursue the wonderful outdoor activities in SW ND.
- Keith Anderson for your guidance during my first year with the NRCS and having me over for Thanksgiving dinner when the snow kept me away from home.

I would like to thank the Natural Resource Conservation Service for the opportunity to work on this project and to be part of the STEP and SCEP programs.

I would also like to give a special thanks to my beautiful wife, Katie, for the love and support you have shown me the last couple of years. You are truly amazing. I would like to extend a big thanks to my mom, dad, and brothers for constantly badgering me to finish my paper, their support and encouragement the past six years, and the reminder that you should always finish what you start. I would also like to thank Russell Formico for always encouraging me to do my best and Wilfred Kraft for showing me that with hard work and determination I could achieve my goals. Last, but not least I would like to thank my in-laws for their constant support, encouragement, and fishing adventures the last couple of years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Recently there has been an increased interest in the ability to accurately estimate site and condition-specific soil carbon (C). The need to accurately estimate United States C stocks is being addressed by the Soil Survey Division of the United States Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) National Soil Survey Center, which initiated a Rapid Carbon Assessment (RCA) of U.S. soils in 2010. The assessment was designed to increase the reliability of estimating the potential quantity of soil C sequestered by different land uses and management practices. The comprehensive nationwide soil C data set was envisioned to provide information to improve accuracy of process-based models for estimating soil C stocks for use in global C accounting programs and greenhouse gas inventories (USDA-NRCS, 2010).

To enhance the soil C data set for the northern Great Plains region, it was essential to review the literature and summarize relevant data already available within the region. The Northern Great Plains Comprehensive Soil Carbon Inventory was a sub-project plan to the nationwide USDA-NRCS's RCA. There has been limited compilation of data related to studies on soil C in the northern Great Plains. To fully understand and characterize soil C in the region, it is necessary to compile and analyze currently available data. A compilation of literature/data can be used as a public resource with the potential to increase the efficiency of agencies working with soil C sequestration (S. Samson-Liebig, unpublished data, 2010). Furthermore, a summary can be conducted to provide a better understanding of the relationship between SOC, land use management, and agro ecosystem co-benefits associated with accrual of soil C. Data summaries may also provide answers to common questions researchers and land managers/producers share in the northern Great Plains, such as; "How much C should be in a particular soil, given the soil type and land use management?" or "What management practices can increase C in a soil profile?"

Previous efforts to compile and analyze soil C data in the northern Great Plains region have focused on larger geographic domains, including studies at both national and international scales (West and Post, 2002; Liebig et al., 2005). In a review article by West and Post (2002), research on soil C sequestration rates were compiled from sources around the globe in an effort to improve estimates of soil C sequestration rates within agricultural systems. Their objectives were to (i) measure the response in SOC to changes in tillage practices and crop rotation, (ii) measure the duration of soil C sequestrations rates, and (iii) assist with policy and C cycle modeling by providing confidence intervals for soil C sequestration rates.

They compiled published journal articles, which included 67 global, long-term experiment sites where response in SOC to changes in land use management was measured for five years or more. Three locations within the northern Great Plains were represented, and included research from Fargo, North Dakota (Deibert and Utter, 1989), Mandan, North Dakota (Black and Tanaka, 1997), and Culbertson, Montana (Aase and Pikul, 1995). Journal articles were summarized by location in a table that also included data on crop or tillage practices, history, duration, treatment, sample depth, and change in SOC (West and Post, 2002).

The results of their review indicated that converting from conventional tillage (CT) to no-till (NT) sequestered 57 ± 14 g C m^{-2} yr^{-1}**,** excluding a system that lacks periodic biomass input, such as a wheat-fallow rotation. In addition, adding diversity with increased biomass production to a crop rotation sequestered an average of 20 ± 12 g C m^{-2} yr^{-1}. Thus, increasing diversity and changing from a high biomass input system to a low input biomass system, such as continuous corn (*Zea mays*) to a corn-soybean (*Glycine max*) rotation, will not increase soil C sequestration rates. West and Post (2002) also showed that the response time associated soil C sequestration can be delayed 5 to 10 years and reach equilibrium within 15 to 20 years after changing to a NT system. Their research concluded that a decrease in tillage and an increase in crop diversity, if implemented simultaneously, will increase SOC in both the short-term (15 – 20 years) and long-term (40 – 60 years). Short-term increases in SOC would be due to the change in tillage and long-term increases would be mostly due to a greater diversity in the crop rotation, which will increase biomass input. Therefore, when assessing soil C sequestration potential for agricultural soils it is important to consider crop rotation as well as the current tillage practices (West and Post, 2002).

Liebig et al. (2005b) conducted a review of U.S. and Canadian literature as part of an effort called GRACEnet (Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network) using several USDA-ARS entities and Agriculture and Agri-Food Canada. Their review summarized the available data regarding land use management on SOC, CO_2, N_2O, and CH_4 for crop and rangeland throughout northwestern USA and western Canada. They compared their data with estimates made by the Intergovernmental Panel on Climate Change (IPCC) (Liebig et al., 2005b).

The bulk of their paper was organized by management effects on SOC and trace gas flux for crop and rangelands. Journal articles reporting SOC were organized by treatments such as tillage, crop sequence, fertilization, manure and residue management, and irrigation. Furthermore, textural class, sample depth, management practice, duration of study or tillage, and SOC loss or storage rate were provided in two different tables. The first table was a historical record of SOC loss due to the conversion to cropping. The second table described changes in SOC in cropland systems as affected by management (Liebig et al., 2005b).

The range in topics covered in their review did not allow for comprehensive conclusions, therefore a synthesis of the results was provided. They also noted that there may be literature missing from the review, due to diverse research objectives and the range in geographic area. Liebig et al. (2005b) concluded that SOC under no-till continuous cropping increased by 0.27 ± 0.19 Mg C ha^{-1} yr^{-1}, which was comparable to the estimates placed by the IPCC for annual change in C stocks for improved crop management. The historic native grassland region of the USA was estimated to have a C storage of 91.5 Mg C ha^{-1} to 1 m depth, but the potential for C sequestration in rangelands were highly variable and additional long-term research was recommended. There was a gap in research with regard to trace gas flux due to few data points in the targeted geographical area (Liebig et al., 2005b).

The previous northern Great Plains review papers summarized existing long-term experiments and estimated soil C sequestration rates on a broad geographic scale. Despite the effort made by West and Post (2002) to examine soil C sequestrations rates on a global scale, the review does not provide enough data within the northern Great Plains to estimate local soil C sequestration rates. Likewise, the review by Liebig et al. (2005b), although assessing a smaller geographic area, was still too large to use at a local level. Both reviews compiled journal articles with long-term experiments that specifically focused on soil C sequestration rates as influenced by management practices. Their collection methods did not allow the authors to gather as much soil C data as possible, because the number of journal articles with long-term experiments tailored specifically to soil C sequestration rates is limited. Furthermore, their review papers reported soil C sequestration rates, and not the present soil C value in any one particular soil. They also did not provide a correlation between SOC, land use management, and specific soil series in their review. These limitations make it difficult for local researchers, land use managers, and producers to utilize the data provided in a realistic manner.

The objectives of this study, reflecting the goals of the USDA-NRCS RCA, and researchers at North Dakota State University (NDSU), were: (i) to inventory journal articles reporting SOC responses to agroecosystem management, (ii) extract pertinent data for the Northern Great Plains Comprehensive Soil Carbon Inventory, and (iii) summarize collected data to identify relationships between SOC, land use management, and inherent productivity potential for soils within the Northern Great Plains.

MATERIALS AND METHODS

This study was focused on collecting information from literature representing the USDA Land Resource Region F (LRR-F), also known as the Northern Great Plains Spring Wheat Region (USDA-NRCS, 2006). Land Resource Regions (LRR) are large areas grouped by geographically associated major land resource areas (MLRA) and consist of broad similarities between soils, climate, water resources, and land use. The geographic extent of LRR-F encompasses 368,361 km^2; made up of North Dakota (48%), South Dakota (23%), Montana (23%), and Minnesota (6%) (USDA-NRCS, 2006). Literature sources that were not within the LRR-F boundary were collected and data was recorded in the database, because many of the journal articles had data that overlapped the LRR-F boundary. However, only data that was taken within LRR-F was used for the summary of SOC and land use management. Land Resource Region F and surrounding LRRs are depicted in Figure 1.

Northern Great Plains Spring Wheat Region

The Northern Great Plains Spring Wheat Region almost covers the entire state of North Dakota, a third of South Dakota, the northern edge of Montana, and the northwestern edge of Minnesota (Figure 1). The region possesses a dry and continental climate, including short summers and long winters with evaporation typically exceeding precipitation in any given year (Bailey, 1995). Annual precipitation for the region averages 14 – 21 inches (355 – 535 mm), of which 30% occurs as snow during the winter months. The average temperature across the region is 39 – 45 degrees Fahrenheit (4 – 7° C) with a freeze free period ranging from 130 – 170 days. The eastern portion is dominated by till and lacustrine deposits from glacial lakes, while the western edge is composed of residual sediment weathered from sedimentary rock. The landscape is generally flat with fertile soils, dominated by Mollisols (USDA-NRCS, 2006).

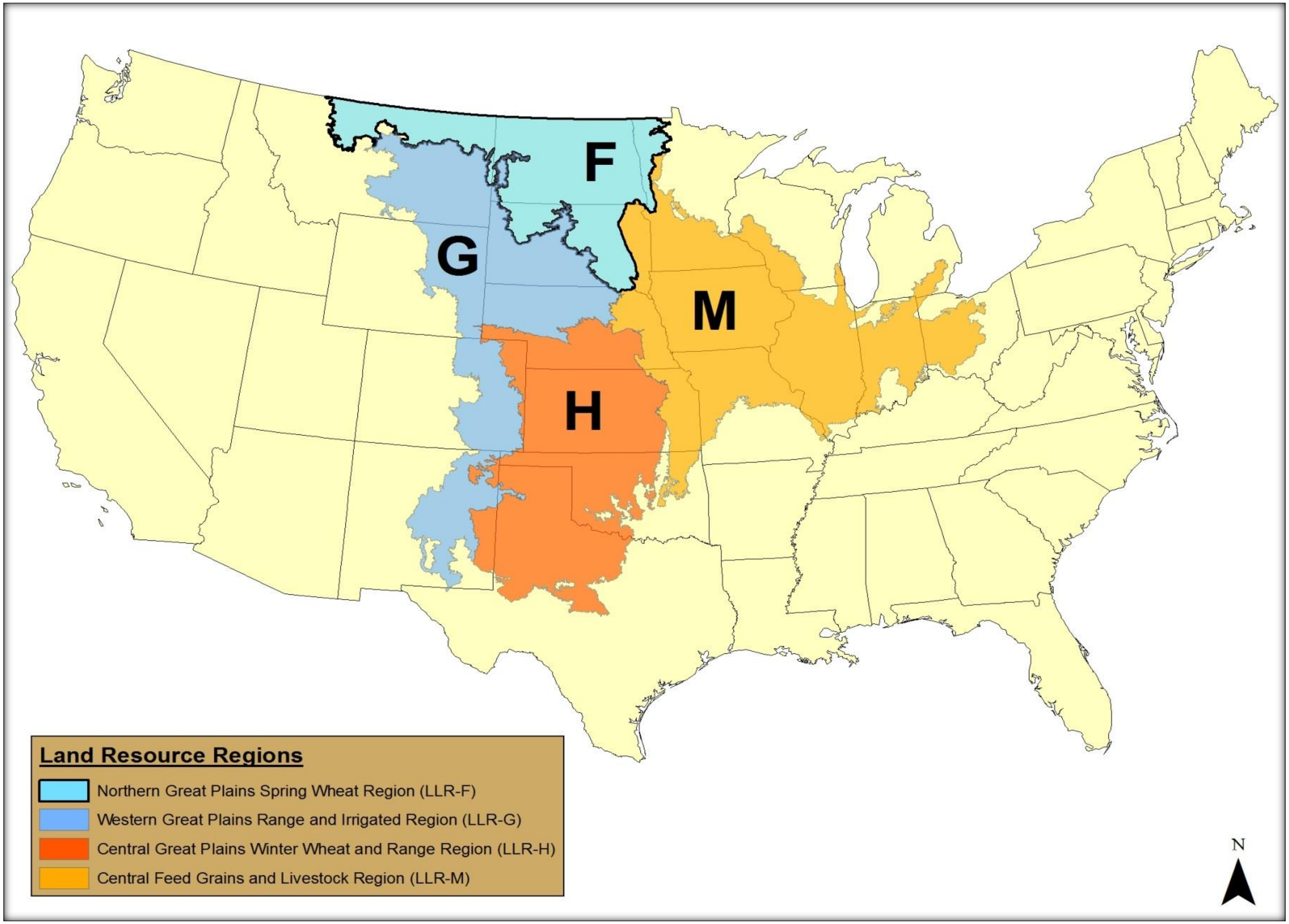

Figure 1. Location of USDA Land Resource Regions (LRR) F, G, H and M (USDA-NRCS, 2006).

Native vegetation consists of drought-tolerant short and medium grasses. The soils are suitable for agriculture, but because of temperature extremes and unpredictable precipitation, drought-resistant crops such as spring wheat (*Triticum aestivum*) have dominated the region. However, by the adoption of moisture conserving practices, such as conservation tillage (CST), land use managers and/or producers have diversified their crop rotations throughout the region to include, but not limited to barley (*Hordeum vulgare*), corn, oats (*Avena sativa*), canola (*Brassica napus*), flax (*Linum usitatissimum*), sugarbeets (*Beta vulgaris*), potatoes (*Solanum tuberosum*), sorghum (*Sorghum bicolor*), mustard (*Brassica hirta*), canary seed (*Phalaris canariensis*), and chickpea (*Cicer arietinum*)(Padbury et al., 2002).

Literature Inventory

Literature related to soil C research within the northern Great Plains LRR-F region was compiled beginning in June of 2010. The majority of literature was gathered using online resources such as ISI Web of Knowledge, NDSU's library e-journals, and Google Scholar. Keywords included, but were not limited to "soil organic carbon" and "carbon sequestration" during the search. Google Scholar was used to locate publications missed by other search engines. Each journal article was printed and saved electronically in a file called - "Lit_Review\Literature\Printed". Literature was organized in a Microsoft Excel spread sheet titled - "Lit Review Inventory.xlsx" in a tab titled - "Journal Articles", which was updated simultaneously as literature was collected. This ensured journal articles would not be duplicated. Entry numbers were given to each literature source in the order they were acquired. During the initial entry of literature in the "Lit Review Inventory.xlsx," the following metadata were documented; entry number, title, topic, authors, date of publication, publication location, soil series, research location, soil properties, and sampling depth (cm). Printed hard copies were filed into three ring binders according to entry number. Theses published at NDSU had been previously inventoried in a file called - "Thesis Inventory_NDSU.xls" by former students (NDSU, unpublished data, 2008). Theses were extracted from this file according to the soil properties collected during research. Each relevant thesis was added to the overall literature review. The reference section of all literature sources was filtered for new literature that could be added to the inventory. The literature search ended in October of 2010, after the search began to result in duplicate journal articles, and the focus was turned to data extraction.

Data was extracted from relevant literature published on research throughout LRR-F and surrounding area. Desired data included all soil C stocks, soil C change, and pertinent data related to soil C dynamics, including percent slope, pH, soil texture, and soil bulk density as partitioned by land use management and sample depth. In addition, management practices such as grazing or crop rotations were also recorded. Data on such items as total N, ^{13}C, and microbial biomass were also collected if the item was relevant to the study. The data was recorded in "Lit Review Inventory.xlsx" in a tab titled "Data." Data was organized in columns by type and units of measure. Many journals found in the "Journal Article" tab of the spreadsheet were not included under the "Data" tab, because no hard data was provided. However, data represented by graphs or charts was interpolated for the data summary. Other desired information included the Methods used for each study and were included in a spreadsheet titled "Methods."

Data Summary

Literature that was collected covered a large region of the U.S. In order to provide a summary of SOC and land use management, it was necessary to have a clear concise boundary (LRR-F) of the area and to convert the data into common reporting units of measure. In addition, the data was sorted by soil series and then again by land use management. Data not associated with a specific soil series or association was grouped into a mixed soils category. The productivity index (PI), which is a measure of a given soils ability to produce a specific dryland commodity crop (spring wheat) was also added to the summary (USDA-NRCS, 2012b) to allow the reader to make general comparisons based on soils, land use, and productivity potential. Although relevant data was extracted from all literature sources, the summary only consisted of peer-reviewed published literature. Therefore, theses and unpublished papers were excluded from the summary.

To select literature relevant to LRR-F, the journal articles were sorted by sample site location (City, State) using Microsoft Excel. Latitude and longitude information for the nearest city were used, not sample location, because not all literature provided the appropriate spatial data to identify the exact location. When counties were used to describe the research location, the largest city within the county was used to identify the location. The spreadsheet also included a column for the quantity of research at each location. The data from the spreadsheet was imported into Arc Map (ESRI 9.2, 2006) and the points were projected on a map. Using a "select by location" tool in Arc Map, the research locations within LRR-F were annotated. Much of the data was reported in different units, such as g C kg^{-1} or mg C ha^{-1}. To facilitate data comparisons, all SOC values were converted to kg C m^{-2}. This standardized the reporting and allowed conversion of data to Mg C ha^{-1} if desired. Although data in the format of graphs or charts was not included in the "Data" tab of the "Lit Review Inventory.xlsx" spreadsheet, it was necessary to estimate the SOC values for the summary, thus allowing the summary to include the majority of the literature collected. Also, because of differences in sampling depth, all data was normalized to a 0-15 cm depth.

Cropped systems were categorized as conventional tillage (CT), minimum tillage (MT), or no-till (NT). Given the many definitions for the tillage treatments in the literature, treatments were separated according to the author's and or producer's definitions that most closely fit the categories as defined (Table 1). Minimum tillage can encompass a wide range of tillage practices which produce less soil disturbance than CT, but more disturbance than NT. Although MT and NT are different, they are sometimes grouped within a more general category called conservation tillage (CST), which allows a comparison between general CST practices and CT. In addition, grasslands were categorized as grazed (G) or ungrazed (U).

Table 1. Recent definitions of tillage practices.

Conventional Tillage (CT)	Systems that involve primary tillage utilizing moldboard plows or heavy disks followed by one or more secondary tillage, planting and row cultivation operations that bury nearly all previous crop residue and all of the soil is disturbed (http://ecat.sc.egov.usda.gov/Help.aspx, verified 10/29/2015).
No-Till (NT)	These systems consist of fertilizer and planting operations in narrow strips or slots that involve disturbance of less than one third of the inter row area (http://ecat.sc.egov.usda.gov/Help.aspx, (verified 10/29/2015).
Minimum Tillage (MT)	The least soil manipulation necessary for crop production or for meeting tillage requirements under existing soil conditions (ASAE EP 291.3, 2005).
Conservation Tillage (CST)	Methods of soil cultivation that leaves the previous year's crop residue on fields before and after planting the next crop. A minimum of 30% of the soil surface must be covered with residue while planting. Some conservation tillage methods include; no-till, minimum-till, strip-till, and mulch-till (http://www.mda.state.mn.us/protecting/conservation/practices/constillage.aspx, verified, 10/29/2015).

Grasslands included native prairie (NP), modified, and restored sites. Native prairie sites have never been tilled, while modified grasslands have been deliberately altered or inter-seeded with non-native plants, such as alfalfa (*Medicago sativa*). Restored grasslands consisted of sites that were created under the Conservation Reserve Program (CRP), and with the exception of being occasionally hayed, they were generally left ungrazed. Grassland sites that were not designated G or U were categorized as G for this summary, because most grasslands not in CRP are either being grazed or have been previously grazed. Ungrazed (U) management consisted native or restored grasslands. The U native prairie sites were typically native prairie controls used during research and were specifically designated U in the journal articles.

Soils were grouped into three categories based on PI ranges to outline potential trends in SOC for different land use management (Table 4). Categories included a low (PI 0 – 39), mid-range (PI 40 – 79), and high (PI 80 – 100). The PI for each soil series was determined by using the NRCS Field Office Technical Guide (FOTG), which is the agency's primary scientific reference and record of soil characteristics, properties, and capabilities. Each county in the state has their own FOTG, specific to their geographic area. Therefore, it was necessary to know the associated county where samples were taken. The PI tables were organized by map units and then by series within the map unit. The literature generally did not report soils by map units, but rather by soil series. In addition, percent slope was usually given as part of the study site description, which was inventoried during the data extraction phase. A map unit was selected that best represented the soil series and slope range. The PI for the series within the map unit was selected (http://efotg.sc.egov.usda.gov/, 10/29/2015). In addition, a simple correlation analysis of the relationship between SOC and PI was completed for each management practice (CT, CST, G, U) using Microsoft Excel.

RESULTS AND DISCUSSION

Summary of Literature Collected Throughout Land Resource Region F

A total of 101 peer-reviewed journal articles were collected for the review, which included research at 79 different research sites (Appendix A). Of the 79 sites identified, 29 were located within LRR-F (Figure 2). The majority of research sites were located in North Dakota (57%), with small concentration in Montana (14%), South Dakota (21%), and Minnesota (7%). Publication dates for the literature ranged from Hass et al. (1957) to multiple journal articles published in 2010. The majority (74%) of the literature was published in or after 2000**.** Research locations within some journal articles were not depicted in Figure 2 because the precise sampling locations could not be identified. Additionally, some research journals may have not been included in the review, because they were missed during the collection phase due to the size of geographic area or a limitation in search terms that failed to encompass all research topics that may have had SOC data.

Several research sites were associated with multiple journal articles, including Mandan, ND with 34. The concentration of research at some sites can be attributed to USDA-ARS research facilities (Mandan, ND; Akron, CO; Sidney, MT). The concentration of research at each site is represented in Figure 2.

Journal articles in the review covered several different research topics. Crop rotation and/or tillage practices accounted for 57% of all journal articles collected. Other notable research topics included CRP (6%), nitrogen management (15%) and grazing (15%), which together accounted for approximately 36% of the research. Three percent of journal articles collected focused on irrigation and 2% on landscape relationships. In addition, there were about 3% of journal articles that did not fit into these categories.

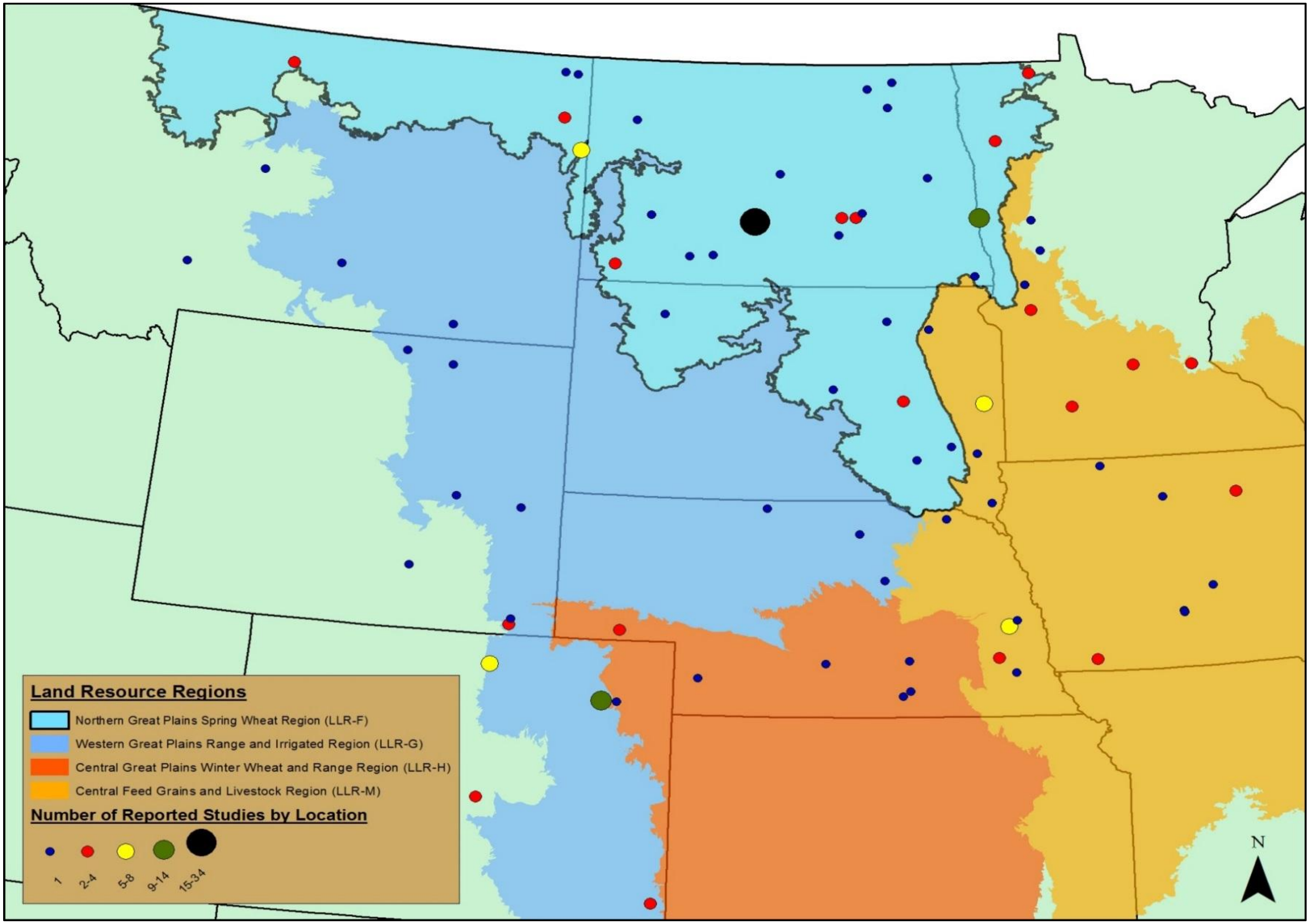

Figure 2. Distribution and concentration of research within Land Resource Region F and surrounding states (USDA-NRCS, 2006).

The evaluated research was conducted by numerous authors over a wide variety of landscapes, treatments, and methods. Several different units were used to report SOC (Table 2). For example, Liebig et al. (2006a) reported SOC by using Mg C ha^{-1} in their study of the influence of long-term grazing, while Black and Tanaka (1997) reported SOC in g kg^{-1} in their study of SOC stocks under dryland cropping treatments.

Table 2. Examples of different units used to report SOC.

Articles	SOC Units	Example Reference
2	Mg C ha^{-1}	Liebig et al. (2006a)
5	kg C m^{-2}	Springsteen et al. (2009)
13	kg C ha^{-1}	Follett et al. (2009)
25	g kg^{-1}	Black and Tanaka (1997)
65	%	Larson et al. (1971)

Summary of SOC Data Collected Throughout Land Resource Region F

Collected data represented 26 different soils series or soil associations. The majority of authors reported soils by series, but some were reported as associations (Table 3). According to the USDA-NRCS Official Soil Series Description (OSD) there are 57 benchmark soils within LRR-F (https://soilseries.sc.egov.usda.gov/osdquery.aspx, verified 10/29/15). Of the 26 different soil series or soil associations represented, 10 of them are classified as benchmark soils, which is 38%. Only 32% of the total samples are from benchmark soils. This is important because the USDA-NRCS National Soil Survey Handbook (NSSH) classifies benchmark soils as soils that cover a large geographic area and hold key positions within soil classification. In addition, these soils typically have a large amount of data available, are important to one or more significant land use, have ecological importance within the geographic area and the soil properties can be extended to similar soils allowing researchers and land use managers/producers to make comparisons (USDA-NRCS, NSSH, Part 630, 2013). Despite the importance of benchmark soils, the largest amount of research collected was done on a Temvik-Wilton, at Mandan, North Dakota, which is not a benchmark soil.

Conventional Tillage

Conventional tillage was the most studied land-use management topic within the LRR-F region (Table 3). Twenty soil series or associations included research data associated with CT. Soil organic C concentrations for CT ranged from 1.48 – 5.48 kg C m^{-2} with a PI range of 59 – 100.

The lowest SOC value (1.48 kg C m^{-2}) for CT was reported by Sainju et al. (2006b). The research was done on a Scobey clay loam and a Kevin clay loam west-northwest of Havre, Montana (Table 3). The Scobey clay loam was the dominate soil and had a PI of 60. The research compared CT and NT management systems for five different crop rotations, which included fallow and CRP rotations for dryland soils. The management for all sample plots before the experiment was initiated was CRP for approximately 11 years. Over the course of the 6 year study the average SOC across all rotations for NT was 23% greater than in the CT from 0 – 5 cm in depth. The results indicated that crop rotation did not influence SOC, but rather tillage had a greater influence on SOC concentrations throughout the duration of the six year study. This would be consistent with West and Post (2002) conclusions that short-term SOC changes are likely due to tillage practices, while long-term SOC changes are influenced by crop rotation. Results also showed that C was lost at a rate of approximate 134 kg ha^{-1} yr^{-1} in CT, but was gained by 100 kg ha^{-1} yr^{-1} in a NT system. Although there was a net gain of soil C in the NT system, the rate of soil C sequestered was less than previous studies (Sainju et al., 2006b). Halvorson et al. (2002) research suggested a C sequestration rate of 233 kg ha^{-1} yr^{-1} for a NT system. Sainju et al. (2006b) thought the differences in C sequestration rates were an influence

Table 3. Summary of data collected throughout Land Resource Region F.

Soil Series	Management	Average SOC (kg C m^{-2})	Range (kg C m^{-2})	PI	Sample # (n)	Location	Reference
Amor*	CT	2.64	NA	76	1	SW ND	Cihacek and Ulmer (1997)
	G	4.24	NA	76	1	SW ND	Cihacek and Ulmer (1997)
	G	4.79	NA	32-76	1	Bison, SD	Mortenson et al. (2004)
	U	5.80	NA	32-76	1	Bison, SD	Mortenson et al. (2004)
	CT	3.19	3.00 - 3.38	46	2	Morton Co, ND	Wienhold and Tanaka (2001)
	MT	3.77	3.70 - 3.83	46	2	Morton Co, ND	Wienhold and Tanaka (2001)
	NT	3.47	3.05 - 3.88	46	2	Morton Co, ND	Wienhold and Tanaka (2001)
Barnes*	CT	4.14	NA	48-85	1	Medina, ND	Follett et al. (2009a)
	G	6.87	NA	48-85	1	Medina, ND	Follett et al. (2009a)
	U	4.61	NA	48-85	1	Medina, ND	Follett et al. (2009a)
Barnes*-Buse	U	4.50	NA	80	1	Munich, ND	Liebig et al. (2008b)
Barnes*-Svea	U	4.50	NA	80-85	1	Streeter, ND	Liebig et al. (2008b)
Buse	CT	3.29	2.79 - 3.78	35	2	Medina, ND	Liebig and Doran (1999)
	G	5.32	NA	35	1	Medina, ND	Liebig and Doran (1999)
Cabba	G	5.60	5.07 - 6.37	20-38	5	Mandan, ND	Springsteen et al. (2009)
Dooley	CT	2.03	NA	81	1	Culbertson, MT	Pikul and Aase (1995)
	CST	2.31	NA	81	1	Culbertson, MT	Pikul and Aase (1995)
	CT	2.05	1.64 - 2.33	81	4	Culbertson, MT	Sainju et at. (2006a)
	NT	2.33	NA	81	1	Culbertson, MT	Sainju et at. (2006a)
	CT	4.63	3.60 - 5.29	81	4	Culbertson, MT	Sainju et at. (2008a)
	NT	5.34	NA	81	1	Culbertson, MT	Sainju et at. (2008a)
	CT	2.00	1.62 - 2.25	81	4	Culbertson, MT	Sainju et at. (2009)
	NT	2.25	NA	81	1	Culbertson, MT	Sainju et at. (2009)
Fargo*	CT	5.48	5.40 - 5.55	90	2	Fargo	Cihacek and Meyer (2002)

Table 3. Summary of data collected throughout Land Resource Region F (continued).

Soil Series	Management	Average SOC (kg C m^{-2})	Range (kg C m^{-2})	PI	Sample # (n)	Location	Reference
Fargo* (cont.)	U	4.20	NA	90	1	Fargo	Cihacek and Meyer (2002)
Farnuf	CT	3.71	NA	68-85	1	Mandan, ND	Follett et al. (2009a)
	G	3.75	NA	68-85	1	Mandan, ND	Follett et al. (2009a)
	U	3.72	NA	68-85	1	Mandan, ND	Follett et al. (2009a)
Glenha-Prosper	U	3.88	NA	NA	1	Highmore, SD	Liebig et al. (2008b)
Houdek*	U	2.88	NA	NA	1	Huron, SD	Liebig et al. (2008b)
-Prosper	U	2.60	NA	NA	1	Ethan, SD	Liebig et al. (2008b)
Lihen	NA	2.59	NA	42-44	1	Nesson Valley, ND	Sainju et al. (2008b)
Mixed Soils	CT	3.08	NA	NA	1	Grant CO, ND	Bauer and Black (1992)
	MT	3.47	NA	NA	1	Grant CO, ND	Bauer and Black (1992)
	G	4.24	NA	NA	1	Grant CO, ND	Bauer and Black (1992)
	U	4.86	NA	NA	1	Grant CO, ND	Bauer and Black (1992)
	CT	3.72	NA	NA	1	SW ND	Cihacek and Ulmer (1995)
	G	5.15	NA	NA	1	SW ND	Cihacek and Ulmer (1995)
	NA	2.00	NA	NA	1	Sidney, MT, Mandan, ND, Medina, ND, Dorothy, MN and Roseau, MN	Follett et al. (2001)
	NA	3.95	NA	NA	1	ND, SD, MN	Liebig et al. (2005a)
	U	4.07	NA	NA	1	ND, SD, MN	Liebig et al. (2005a)

Table 3. Summary of data collected throughout Land Resource Region F (continued).

Soil Series	Management	Average SOC (kg C m^{-2})	Range (kg C m^{-2})	PI	Sample # (n)	Location	Reference
Mixed Soils (cont.)	U	3.979	NA	NA	1	Sidney, MT, Mandan, ND, Medina, ND, Dorothy, MN and Roseau, MN	Follett et al. (2001)
Percy	CT	2.33	NA	82-85	1	Roseau, MN	Follett et al. (2009a)
	G	5.62	NA	82-85	1	Roseau, MN	Follett et al. (2009a)
	U	4.63	NA	82-85	1	Roseau, MN	Follett et al. (2009a)
Radium	CT	3.24	NA	39	1	Dorthy, MN	Follett et al. (2009a)
	G	2.66	NA	39	1	Dorthy, MN	Follett et al. (2009a)
	U	6.45	NA	39	1	Dorthy, MN	Follett et al. (2009a)
Reeder	G	2.45	NA	59-85	1	Bison, SD	Mortenson et al. (2004)
	U	2.99	NA	59-85	1	Bison, SD	Mortenson et al. (2004)
Scobey*	CT	1.48	1.43 - 1.53	59-60	5	Havre, MT	Sainju et al. (2006b)
	NT	1.56	1.46 - 1.65	59-60	5	Havre, MT	Sainju et al. (2006b)
	U	1.58	1.49 - 1.67	59-60	2	Havre, MT	Sainju et al. (2006b)
	CT	3.06	2.85 - 3.39	59-60	5	Havre, MT	Sainju et at. (2006c)
	NT	3.08	2.76 - 3.50	59-60	5	Havre, MT	Sainju et at. (2006c)
Shambo	CT	2.47	NA	80-85	1	SW ND	Cihacek and Ulmer (1997)
	G	4.44	NA	80-85	1	SW ND	Cihacek and Ulmer (1997)
Stady	CT	3.38	NA	56	1	SW ND	Cihacek and Ulmer (1997)
	G	3.91	NA	56	1	SW ND	Cihacek and Ulmer (1997)
Svea*	CT	4.41	4.14 - 4.69	95-100	2	Windsor, ND	Liebig and Doran (1999)
	U	3.34	NA	95-100	1	Windsor, ND	Liebig and Doran (1999)

Table 3. Summary of data collected throughout Land Resource Region F (continued).

Soil Series	Management	Average SOC (kg C m^{-2})	Range (kg C m^{-2})	PI	Sample # (n)	Location	Reference
Tally	CT	1.82	NA	64	1	SW ND	Cihacek and Ulmer (1997)
	G	3.87	NA	64	1	SW ND	Cihacek and Ulmer (1997)
Temvik-Wilton	CT	3.79	3.54 - 3.83	80-85	6	Mandan, ND	Black and Tanaka (1997)
	MT	3.75	3.27 - 3.92	80-85	6	Mandan, ND	Black and Tanaka (1997)
	NT	3.74	3.29 - 4.08	80-85	6	Mandan, ND	Black and Tanaka (1997)
	G	4.72	4.46 - 4.98	80	2	Mandan, ND	Frank et al. (1995)
	U	4.95	NA	80	1	Mandan, ND	Frank et al. (1995)
	CT	3.68	3.62 - 3.77	80-85	2	Mandan, ND	Halvorson et al. (2002)
	MT	3.87	3.76 - 3.97	80-85	2	Mandan, ND	Halvorson et al. (2002)
	NA	3.84	3.59 - 4.05	80-85	6	Mandan, ND	Halvorson et al. (2002)
	NT	3.96	3.56 - 4.22	80-85	2	Mandan, ND	Halvorson et al. (2002)
	G	5.69	5.16 - 5.83	85	3	Mandan, ND	Liebig et al. (2006b)
	G	5.07	5.02 - 5.12	85	3	Mandan, ND	Liebig et al. (2008a)
	U	5.30	NA	85	1	Mandan, ND	Liebig et al. (2008a)
	NT	3.62	3.61 - 3.63	85	2	Mandan, ND	Liebig et al. (2010c)
	G	5.33	4.31 - 6.38	85	4	Mandan, ND	Liebig et al. (2010a)
	G	5.35	4.54 - 6.24	85	2	Mandan, ND	Liebig et al. (2010a)
	G	4.50	NA	85	1	Mandan, ND	Liebig et al. (2010b)
	U	4.58	4.56 - 4.63	85	3	Mandan, ND	Liebig et al. (2010b)
	CT	3.96	3.58 - 4.16	80-85	2	Morton Co, ND	Wienhold and Halvorson (1998)
	MT	4.16	3.65 - 4.68	80-85	2	Morton Co, ND	Wienhold and Halvorson (1998)
	NT	4.27	3.80 - 4.44	80-85	2	Morton Co, ND	Wienhold and Halvorson (1998)
	G	3.65	3.25 - 4.04	80	2	Mandan, ND	Wienhold et al. (2001)
	U	3.40	2.85 - 3.95	80	2	Mandan, ND	Wienhold et al. (2001)
Vebar*	CT	2.61	NA	46-57	1	SW ND	Cihacek and Ulmer (1997)
	G	3.69	NA	46-57	1	SW ND	Cihacek and Ulmer (1997)

Table 3. Summary of data collected throughout Land Resource Region F (continued).

Soil Series	Management	Average SOC (kg C m^{-2})	Range (kg C m^{-2})	PI	Sample # (n)	Location	Reference
Vebar* (cont.)	G	1.89	NA	46-57	1	Bison, SD	Mortenson et al. (2004)
	U	2.09	NA	46-57	1	Bison, SD	Mortenson et al. (2004)
Werner-Sen-Chama	G	3.43	3.25 - 3.60	12-26	2	Mandan, ND	Frank, A.B. (2001)
	U	3.30	NA	12	1	Mandan, ND	Frank and Dugas (2001)
	G	3.53	3.35 - 3.70	12-26	2	Mandan, ND	Frank et al. (2002)
	U	3.40	NA	12-26	1	Mandan, ND	Frank et al. (2002)
	G	4.22	NA	12-26	1	Mandan, ND	Frank et al. (2006)
Williams *	CT	3.05	2.06 - 4.29	90	11	Mandan, ND	Bauer and Black (1994)
	NA	2.71	NA	96	1	Rasmussen, MT	Sainju et al. (2008b)
	CT	3.87	NA	85	1	Mandan, ND	Zheng et al. (2004)
	NT	4.61	NA	85	1	Mandan, ND	Zheng et al. (2004)
	U	4.11	3.19 - 5.04	85	2	Mandan, ND	Zheng et al. (2004)
Wilton	NT	3.39	3.28 - 3.50	90-95	2	Mandan, ND	Frank et al. (2006)
	CT	3.28	NA	90-95	1	Mandan, ND	Liebig et al. (2004)
	G	6.31	NA	90-95	1	Mandan, ND	Liebig et al. (2004)
	CST	3.68	2.17 - 4.46	90-95	6	Mandan, ND	Liebig et al. (2004)
	NT	4.74	NA	90-95	1	Mandan, ND	Liebig et al. (2004)

[†]CT-conventional tillage; MT-minimum tillage; NT-no till; CST-conservation tillage; G-grazed; U-ungrazed; NA-data was not available or was not specific; PI-productivity index; Mixed Soils-includes all un-identified soil series. *-benchmark soils.

of land use history. Lower rates of C sequestered suggested soils were near the saturation point for sequestering C, due primarily to the fact that the previous land use was CRP. The study concluded that NT with continuous cropping and reduced fallow periods were found to increase SOC concentrations at 0 – 5 cm within dryland soils and can be similar to that of CRP (Sainju et al., 2006b).

The highest SOC value (5.48 kg C m^{-2}) reported for CT was by Cihacek and Meyer (2002) on a Fargo silty clay with a PI of 90 (Table 3). The research was conducted in Fargo, ND on several long-term plots. The plots included wheat, flax, and bromegrass *(Bromus inermis*) and had been maintained by researchers at the NDSU Agricultural Experiment Station for 104, 116, and 70 years, respectively. Their research focused on the influence of N fertilization on SOC storage within a 100 cm soil profile. Furthermore, the research focused on the SOC storage at depths below 30 cm, but did report SOC concentrations for 0 – 15 cm. When comparing the bromegrass treatments, the results indicated that high rates of nitrogen (N) fertilizer increases soil C deep in the soil profile (>30 cm). The amount of C sequestered was inconsistent, but was expected, due to the physical attributes of the soils. According to Cihacek and Meyer (2002) the plots were made up of Vertisols, which are subject to deep (>100 cm) cracking during periods of dry weather. At times this would allow C rich material from the surface to potentially enter the cracks, increasing soil C deep within the profile. The soils are also subject to wind erosion during the winter months and dry springs. The erosion was thought to explain why the treatments exhibited similar soil C concentrations in the upper 30 cm of the soil profile. The results from comparing unfertilized bromegrass to wheat and flax plots indicated that bromegrass distributed the highest amount of soil C throughout the soil profile. Their research concluded that SOC stored at soil depths below 30 cm may be important for offsetting global CO_2

emissions. However, additional research was recommended in order to identify conditions and management practices that promote deep storage of SOC (Cihacek and Meyer, 2002).

Conservation Tillage

Conservation tillage (CST) practices consisted of MT and NT management systems. There were a small number of literature sources with SOC data on MT. The majority of CST practices were related to NT. In some cases, MT and NT were combined to compare CST to CT. Pikul and Aase (1995) reported MT and NT together for research conducted on a Dooley sandy loam with a PI of 81 north of Culbertson, MT. They compared CST that consisted of MT and NT annual cropping treatments to CT fallow treatments. Their results for CST and CT were 2.31 kg C m^{-2} and 2.03 kg C m^{-2}, respectively. They concluded that SOC was significantly greater near the surface of the CST annual cropping treatment than with the CT fallow treatment. Thus annual cropping treatments with reduced tillage helped maintain a higher level of soil quality than the fallow treatment (Pikul and Aase, 1995).

The lowest SOC concentration for a NT management system was 1.56 kg C m^{-2} reported by Sainju et al. (2006b) on a Scobey clay loam and Kevin clay loam west-northwest of Havre, MT (Table 3). Their results were previously discussed. The highest SOC concentration for NT was 5.34 kg C m^{-2} (Sainju et al. 2008a) on a Dooley sandy loam with a PI of 81 north of Culbertson, MT (Table 3). Their research was done as part of a study on the influence of long-term tillage and cropping sequences on soil aggregates on an experiment established in 1983. Long-term reduced tillage was found to increase soil aggregation when compared to spring and fall tilled treatments in the continuous spring-wheat system for the 2.00 – 4.75 mm aggregate size class at the 0 – 5 cm depth and 0.25 – 2.00 mm aggregate size class at the 5 – 20 cm depth. No-till had a higher SOC concentration (5.34 kg C m^{-2}) than CT treatments (4.63 kg C m^{-2}) for both aggregate size classes at a 0 – 15cm depth (Table 3). The decrease in tillage intensity reduced disturbance, which enhanced soil aggregation by increasing soil organic matter and fungal growth, which helped bind soil particles. The results indicated that reduced tillage with annual cropping can increase soil aggregation and soil C sequestration in the northern Great Plains (Sainju et al., 2008a).

Bauer and Black (1992) conducted research on Regent, Amor, and Vebar soils in Grant County, ND. They compared CT, MT, G, and U treatments for sandy, medium, and fine textured soil groups. Their objectives were to measure management-induced changes in SOC in relation to the available water capacity of the three textural groups. Minimum till SOC averaged 3.47 kg C m^{-2} for all three textural groups, which was greater than CT, but less than G and U. Their results found an increase in SOC caused a greater increase in the water content by weight at field capacity than at the permanent wilting point in sandy soils. The research also indicated that in the fine and medium textural groups, an increase in SOC caused a similar increase in water content by weight at field capacity and the permanent wilting point. They concluded that the greatest cause of productivity loss due to erosion was most likely due to the loss of nutrients and biological activity and not by a loss in available water holding capacity of the soils (Bauer and Black, 1992).

Research by Weinhold and Halvorson (1998) reported the highest SOC concentration for MT at 4.16 kg C m^{-2} (Table 3). The research was conducted on a Temvik-Wilton soil with a PI of 80-85 southwest of Mandan, ND. Their objectives were to compare commonly used soil quality indicators such as bulk density, number of fungi, total N, and organic C for a spring wheat-fallow system and an annual cropping system of spring wheat-winter wheat-sunflower rotation. They compared the two rotations using CT, MT, and NT. The NT management system for annual cropping SOC was 2.13 kg C m^{-2} for 0 – 5 cm. This was greater than the CT and MT in the annual cropping system and all tillage practices in the crop-fallow system. The results indicated that tillage intensity did not significantly influence soil C for the crop-fallow system at either depth of 0 – 5 or 5 – 15 cm. Conventional tillage (2.51 kg C m^{-2}) and MT (2.74 kg C m^{-2}) annual cropping systems had greater SOC than the NT annual cropping system (2.31 kg C m^{-2}) for 5 – 15 cm depth. However, when comparing tillage intensity to annual cropping, NT was greater in the 5 – 15 cm depth (2.59 kg C m^{-2}) than in the 0 – 5 cm depth (2.05 kg C m^{-2}). Minimum till (2.11 kg C m^{-2}) was the greatest in the 0 – 5 cm depth and CT had the least amount of SOC in both the 0 – 5 and 5 – 15 cm depth (1.81 kg C m^{-2}, 2.20 kg C m^{-2}, respectively). They concluded that a more intense cropping system (annual) increased the number of soil quality indicators, likely due to the increase in crop residue. In addition, the CST for both cropping systems increased soil quality indicators greater than CT (Weinhold and Halvorson, 1998).

Grasslands

Native Prairie (NP) sites were reported on several different soil series throughout LRR-F. Usually, no more than one NP sample was reported, because the data was used as a reference for comparing NP to tillage or grazing practices. This comparison was used by researchers to determine the loss of SOC over a period of time, assuming that the NP represented the natural condition of the soils when not disturbed. The bulk of the NP sites were categorized into the G category unless the management was specifically labeled as U.

Grazing (G) research was conducted on native prairie, modified, or restored grasslands. Most of the grazing specific research that was collected for this review was done at Mandan, North Dakota, but many of the journal articles that focused on tillage and or crop rotation also reported SOC concentrations for native prairie or rangeland sites for control purposes. Soil organic C ranged from 1.89 – 6.87 kg C m^{-2} and PI ranged from 12 – 85 for grassland sites included in the study. Mortenson et al. (2004) reported an SOC concentration of 1.89 kg C m^{-2} for a Vebar soil with a PI range of 46 – 57 near Bison, SD (Table 3). They evaluated the influence of interseeding alfalfa into native rangelands on C sequestration. Both the seeded rangeland and control were grazed throughout the year. They found that interseeding alfalfa into native rangelands can increase C sequestration. They proposed that interseeding alfalfa into rangeland enhances the nitrogen status of the rangeland ecosystem, which would increase the nutrient cycling capacity (Mortenson et al., 2004).

The highest SOC value for G management was reported by Follett et al. (2009a) near Medina, ND. The SOC concentration was 6.87 kg C m^{-2} and the research was conducted on a Barnes soil with a PI of 48 – 85 (Table 3). The objective of their study was to compare SOC values for native, cultivated, and restored grasslands so that the potential loss of SOC from converting native vegetation into cultivated land could be better understood across a broad area. Samples were collected in 13 states including several locations within LRR-F. Their research found that SOC remaining in cultivated soils within 0 – 10 cm and 10 – 30 cm was approximately 59 and 68%, respectively, whereas re-vegetated soils within 0 – 10 cm and 10 – 30 cm were 83 and 86%, respectively, of native SOC. Their research concluded that the amount of SOC within the top 30 cm and its vulnerability to loss should not be overlooked (Follett et al., 2009a). Liebig et al. (2004) reported a high SOC value of 6.31 kg C m^{-2} for a grazed pasture on a Wilton silt loam with a PI of 90 – 95 near Mandan, ND (Table 3). Their research was tailored to determine the influence of tillage and crop sequences on soil quality. The grazed pasture was used in the study as a native check for comparison to cropped treatments (Liebig et al., 2004).

There were many journal articles that published data related to U treatments. Many of the treatments consisted of alfalfa, CRP, or U-NP. Soil organic C concentrations for U treatments ranged from 1.59 – 6.45 kg C m^{-2} and PI ranged from 12 – 100. Within this land use, Sainju et al. (2006a) reported the least amount of SOC (1.59 kg C m^{-2}) from a Scobey clay loam and Kevin clay loam west-northwest of Havre, MT (Table 3). Follett et al. (2009a) reported an SOC value of 6.45 kg C m^{-2} for a Radium soil with a PI of 39 near Dorothy, MN (Table 3). Other aspects of their studies have been discussed previously in this manuscript.

Trends in SOC for Different Land Use Management

Management systems that involved annual cover and zero disturbances (G or U) for all three PI groups had consistently greater SOC values than tilled treatments (Table 4). Many authors, including Sainju et al. (2008a), have concluded that this trend is also apparent when comparing annual crop rotations to crop-fallow rotations. The lowest SOC value for all land use management was within the PI range of 40 – 79 (2.89 kg C m^{-2}) and the highest SOC value for U was in the 0 – 39 PI range (4.38 kg C m^{-2}). Although the reason for these trends is not apparent, land use history as described by Halvorson et al. (2002) may have influenced soil C levels prior to treatment implementation. Conservation tillage practices on soils in the 40 – 79 and 80 – 100 PI range exhibited greater SOC values than the CT management systems for the same PI ranges. This is constant with Pikul and Aase (1995) where they found annual cropping CST practices had a greater SOC value than CT with crop-fallow rotations.

A correlation analysis of the relationships between PI and SOC showed that under CT management, PI and SOC were significantly correlated ($r=0.240$) ($P=0.05$) and under CST management were highly significantly correlated ($r=0.418$) ($P=0.01$). However the PI and SOC were not significantly correlated for G and U management. Since PI is an index developed to measure a given soils ability to produce a specific dryland crop, it does not represent the productivity of grasslands very well. Most soils with permanent cover generally have a low PI due to soil texture, soil depth, water holding capacity, slope steepness and other factors that make them less suitable for crop production. However SOC may be higher in sites with permanent cover due to the absence of tillage practices (Table 4). According to the USDA-NRCS, the PI model does not account for land use mismanagement or changes in weather, which may temporarily influence productivity (USDA-NRCS, 2012b). A soil within any of the PI ranges may be subject to management practices or weather abnormalities creating greater than average or lower than average production. Therefore, U managements in the PI range of 80 – 100 may have been tilled in the past, resulting in a lower SOC value than a similar management system that has never been tilled with a lower PI. Likewise, SOC can be increased in soils with a low PI by management practices that promote annual cover.

Soils with a PI of 80 – 100 had a greater mean SOC value across all management systems (4.14 kg C m^{-2}) than soils with a PI of 0 – 39 (3.93 kg C m^{-2}) and 40 – 79 (2.58 kg C m^{-2}). In addition, the higher correlation between PI and SOC for the CST management as compared to the CT management may also illustrate the resilience of soils that have high productivity potential. This suggests that more productive soils can sequester greater amounts of C.

Table 4. A summary of SOC and land use management by productivity index (PI) grouping.

Management	Average SOC (kg C m^{-2})	Range (kg C m^{-2})	PI	PI Range	n
		PI Range 0 – 39			
CT	3.26	3.24 - 3.29	37	35-39	3
CST	NA	NA	NA	NA	NA
G	4.13	2.66 - 5.73	27	19-39	12
U	4.38	3.30 - 6.45	23	12-39	3
		PI Range 40 – 79			
CT	2.89	1.48 - 4.14	62	46-77	18
CST	2.97	1.56 - 4.74	53	46-60	14
G	3.95	1.89 - 6.87	63	52-76	9
U	3.46	1.59 - 5.80	63	52-77	7
		PI Range 80 – 100			
CT	3.36	2.00 - 5.48	85	81-98	42
CST	3.73	2.25 - 5.34	84	81-93	36
G	5.14	3.65 - 6.31	84	80-93	20
U	4.35	3.34 - 5.30	85	80-98	14

†CT-conventional tillage; CST-conservation tillage practices; G-grazed; U-ungrazed; NA-data not available; PI-productivity index; n-number of samples.

SUMMARY AND CONCLUSION

When conducting soil C research it is essential to review literature and compile data already available in order to make efficient use of all possible resources. Although this literature collection was comprehensive, not all of the research publications may have been included. However, knowing the general distribution and concentration of journal articles within LRR-F will allow future studies to build on previous research and assist researchers with addressing the lack of research in many areas throughout LRR-F. In any case, many journal articles collected did not focus on SOC in their research. Instead, SOC was merely a byproduct of the intended research, such as crop production, irrigation, or fertilizer use. This highlights the importance and need for further research focused specifically on soil C sequestration, which will assist policy makers with decisions pertaining to C accounting programs.

The body of research suggests that in order to sequester soil C, producers, land managers, and conservationists must maximize soil cover and minimize soil disturbance. Crop-fallow systems can have a negative impact on the soils ability to sequester C, due to the lack of crop residue available throughout the crop-fallow cycle. In addition, practices such as conventional tillage can lead to the loss of nutrients and biological activity through soil erosion (Bauer and Black 1992).

Findings from the correlation analysis and PI groupings suggest that soils with a high PI (80 – 100) have the potential to sequester greater amounts of C than soils with a lower PI (0 – 39, 40 – 79). Soils in lower precipitation areas will have lower production capabilities; therefore, they will be limited to the amount of C that the soil can sequester. This infers that, naturally, there are soils that can sequester greater amounts of C dependent upon the geographic setting. However, tillage treatments and crop management systems, both past and present, put in place for food production can compound the already stringent constraints of the geographic and environmental setting, even for soils with a high PI. Likewise, soils with low production capabilities can increase C sequestration with management practices that promote annual cover.

Summarizing the data already published and making it available will play an important role in helping producers, land managers, and conservationists understand the importance of SOC and how management and mitigation practices can influence the soils ability to sequester C. Carbon sequestration varies for different types of soils and is highly dependent on land use management. Thus, it is important to continue research on SOC in order to better understand the influence of modern agricultural practices on the land.

REFERENCES

Aguilar, R., E.F. Kelly, and R.D. Heil. 1988. Effects of cultivation on soils in northern Great Plains rangeland. Soil Sci. Soc. Am. J. 52:1081-1085.

Allmaras, R.R., D.R. Linden and C.E. Clapp. 2004. Corn-residue transformations into root and soil carbon as related to nitrogen, tillage, and stover management. Soil Sci. Soc. Am J. 68:1366-1375.

ASAE 2005. ASAE Standard EP291.3: Terminology and definitions for soil tillage and soil-tool relationships. ASAE, St. Joseph, MI.

Bailey, R. G. 1995. Description of the ecoregions of the United States. Misc. Publ. 1391, 2nd ed. USDA, Forest Service, Washington, DC. p. 108.

Bauer, A., and A.L., Black. 1981. Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. Soil Sci. Soc. Am. J. 45:1166-1170.

Bauer, A., and A.L., Black. 1992. Organic carbon effects on available water capacity of three soil textural groups. Soil Sci. Soc. Am. J. 56:248-254.

Bauer, A., and A.L., Black. 1994. Quantification of the effect of soil organic matter content on soil productivity. Soil Sci. Soc. Am. J. 58:185-193.

Bauer, A., C.V. Cole, and A.L. Black. 1987. Soil property in virgin grasslands between grazed and nongrazed sites. Soil Sci. Soc. Am. J. 51:176-182.

Benjamin, J.G., A.D. Halvorson, D.C. Nielsen, and M.M. Mikha. 2010. Crop management effect on crop residue production and changes in soil organic carbon in the central Great Plains. Agron. J. 102:990-997.

Benjamin, J.G., M.M. Mikha, and M.F. Vigil. 2008. Organic carbon effects on soil physical and hydraulic properties in a semiarid climate. Soil Sci. Soc. Am. J. 72:1357-1362.

Black, A.L., and D.L. Tanaka. 1997. A conservation tillage-cropping systems study in the Northern Great Plains of the United States. In: E.A. Paul et al., editors, Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Inc. Boca Raton, Florida. P. 335-342.

Blake, G.R., and K.H. Hartge. 1986. Bulk density. In: A. Klute. editor, Methods of Soil Analysis. Part I: Physical and Mineralogical Methods. 2nd ed. ASA, Madison, WI. p. 363-376.

Bowman, R.A., and R.L. Anderson. 2002. Conservation Reserve Program: effects on soil organic carbon and preservation when converting back to cropland in northeastern Colorado. J. Soil Water Conserv. 57:121-126.

Bowman, R.A., M.F. Vigil, D.C. Nielsen, and R.L. Anderson. 1999. Soil organic matter changes in intensively cropped dryland systems. Soil. Sci. Soc. Am. J. 63:186-191.

Campbell, C.A., H.H. Janzen, K. Paustian, E.G. Gregorich, L. Sherrod, B.C. Liang, and R.P. Zentner. 2005. Carbon storage in soils of the North American Great Plains: effect of cropping frequency. Agron. J. 97:349-363.

Cihacek, L.J., and M.G. Ulmer. 1995. Estimated soil organic carbon losses from long-term crop-fallow in the northern Great Plains of the USA. In: R. Lal et al., editors, Soil management and greenhouse effect. CRC Press, Inc. Boca Raton, Florida. p. 85-92.

Cihacek, L.J., and M.G. Ulmer. 1997. Effects of tillage on profile soil carbon distribution in the northern Great Plains of the U.S. In: J. Kimble, and R. Follett, editors, Management of carbon sequestration in soil. CRC Press, Inc. Boca Raton, Florida. p. 83-91.

Cihacek, L.J., and D.W. Meyer. 2002. Influence of nitrogen fertility management on profile soil carbon storage under long-term bromegrass production. In: J. Kimble, and R. Follett, editors, Agricultural practices and policies for carbon sequestration in soil. CRC Press, Inc. Boca Raton, Florida. p. 281-286.

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. In: L. Kimble and S. Follett, editors, Agricultural practices and policies for carbon sequestration in soil. CRC Press, Inc. Boca Raton, Florida. p. 63-69.

Clapp, C.E., R.R. Allmaras, M.F. Layese, and D.R. Linden. 2000. Soil organic carbon and 13-C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 55:127-142.

Clay, D., G Carlson, T. Schumacher, C. Owens, and F. Mamani-Pati. 2010. Biomass estimation approach impacts on calculated soil organic carbon maintenance requirements and associated mineralization rate constants. J. Environ. Qual. 39:784-790.

Collins, H.P., E.T. Elliott, K. Paustian, L.G. Bundy, W.A. Dick, D.R. Huggins, A.J.M. Smucker, and E.A. Paul. 2000. Soil carbon pools and fluxes in long-term corn belt agroecosystems. Soil Biol. Biochem. 32:157-168.

Conant, R.T., K. Paustain, S.J. Del Grosso, and W.J. Parton. 2005. Nitrogen pools and fluxes in grassland soils sequestering carbon. Nutr. Cycl. Agroecosy. 71:239-248.

Cymbaluk, W.P. 2002. Soil, stratigraphy, and hydrology on shale landscape. M.S. diss., North Dakota State Univ. 108 p.

Deibert, E.J., and R.A. Utter. 1989. Growth and NPK uptake by soybean cultivars in northern USA under reduced tillage systems. Can. J. Plant Sci. 69:1101-1111.

Denef, K., C.E. Stewart, J. Brenner, and K. Paustain. 2008. Does long-term center-pivot irrigation increase soil carbon stocks in semi-arid agro-ecosystems? Geoderma. 145:121-129.

Derner, J.D., T.W. Boutton, and D.D. Briske. 2006. Grazing and ecosystem carbon storage in the North American Great Plains. Plant Soil. 280:77-90.

Derner, J.D., D.D. Briske, and T.W. Boutton. 1997. Does grazing mediate soil carbon and nitrogen accumulation beneath C4, perennial grasses along an environmental gradient. Plant Soil. 191:147-156.

Derner, J.D., and G.E. Schuman. 2007. Carbon sequestration and rangelands: A synthesis of land management and precipitation effects. Soil Water Conserv. Society. 62:77-85.

Doran, J.W., E.T. Elliott, and K. Paustian. 1998. Soil microbial activity, nitrogen cycling, and long term changes in organic carbon pools as related to fallow tillage management. Soil Tillage Res. 49:3-18.

ESRI. 2006. ArcMap 9.2. ESRI, Redlands, California.

Frank, A.B. 2001. Carbon dioxide fluxes over a grazed prairie and seeded pasture in the northern Great Plains. Environ. Pollut. 116:397-403.

Frank, A.B. 2004. Six years of CO_2 flux measurements for a moderately grazed mixed-grass prairie. Environ. Manage. 33:S426-S431.

Frank, A.B., J.D. Berdhl, J.D. Hanson, M.A. Liebig, and H.A. Johnson. 2004. Biomass and carbon partitioning in switchgrass. Crop Sci. 44:1391-1396.

Frank, A.B., and W.A. Dugas. 2001. Carbon dioxide fluxes over a northern, semiarid, mixed-grass prairie. Agric. For. Meteorol. 108:317-326.

Frank, A.B., M.A. Liebig, and J.D. Hanson. 2002. Soil carbon dioxide fluxes in the northern semiarid grasslands. Soil Biol Biochem. 34:1235-1241.

Frank, A.B., M.A. Liebig, D.L. Tanaka. 2006. Management effects on soil CO_2 efflux in northern semiarid grassland and cropland. Soil Tillage Res. 89:78-85.

Frank, A.B., D.L Tanaka, L. Hoffmann, 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.

Follett, R., J.M. Kimble, E.G. Pruessner, S. Samson-Liebig, and S. Waltman. 2009a. Soil organic carbon stocks with depth and land use at various U.S. sites. In: R. Lal and R.F. Follett, editors, Soil carbon sequestration and the greenhouse gas effect. SSSA special publication 57. Madison, WI. p. 29-46.

Follett, R.F., E.A. Paul, and E.G. Pruessner. 2007. Soil carbon dynamics during a long-term incubation study involving ^{13}C and ^{14}C measurements. Soil Sci. 127:189-208.

Follett, R., S.E. Samson-Liebig, J.M. Kimble, E.G. Pruessner, S. Waltman. 2001. Carbon sequestration under the Conservation Reserve Program in the historic grassland soils of the United States of America. In: R. Lal, editor, Soil carbon sequestration and the greenhouse effect. SSSA special publication 57. Madison, WI p. 27-40.

Follett, R.F., G.E. Varvel J.M. Kimble, and K.P. Vogel. 2009b. No-till corn after bromegrass: effect on soil carbon and soil aggregates. Agron. J. 101:261-268.

Franzluebbers, A.J. 2005. Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA. Soil Tillage Res. 83:120-147.

Freeland, J.A. 1996. Soils and sediments as indicators of agricultural impact on northern prairie wetlands. M.S. diss., North Dakota State Univ. 133 p.

Gebhart, J.L., H.B. Johnson, H.S. Johnson, H.S. Mayeux, and H.W. Polley. 1994. The CRP increases soil organic carbon. J. Soil Water Conserv. 49:448-492.

Guzman, J.G., and M. Al-Kaisi. 2010. Landscape position and age of reconstructed prairies effect on soil l organic carbon sequestration rate and aggregate associated carbon. J. Soil Water Conserv. 65:9-21.

Halvorson, A.D., C.A. Reule, and R.F. Follett. 1999. Nitrogen fertilization effects on soil carbon and nitrogen in a dryland cropping system. Soil Sci. Soc. Am. J. 63:912-917.

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

Hass, H.J., C.E. Evans, E.F. Miles. 1957. Nitrogen and carbon changes in Great Plains soils as influenced by cropping and soil treatments. Technical Bulletin No. 1164, USDA, U.S. Government Printing Office, Washington, D.C.

Huggins, D.R., C.E. Clapp, R.R. Allmaras, J.A. Lamb, and M.F. Layese. 1998. Carbon dynamics in corn-soybean sequences as estimated from natural carbon-13 abundance. Soil Sci. Soc. Am. J. 62:195-203.

Ingram, L.J., P.D. Stahl, G.E. Schuman, J.S. Buyer, F.F. Vance, G.K. Ganjegunte, J.M. Welker, and J.D. Derner. 2007. Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem. Soil Sci. Soc. Am. J. 72:939-948.

Johnson, J.M.F., D.C. Reicosky, R.R. Allmaras, T.J. Sauer, R.T. Venterea, and C.J. Dell. 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. Soil Tillage Res. 83:73-94.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. 1971. Effects of increasing amounts of organic residues on continuous corn: II. Organic carbon, nitrogen, phosphorus, and sulfur. Agron. J. 64:204-209.

Liebig, M.A., L. Carpenter-Boggs, J.M.F. Johnson, S. Wright, and N. Barbour. 2006a. Cropping system effects on soil biological characteristics in the Great Plains. Renew. Agric. Food Syst. 21:36-48.

Liebig, M.A., and J. Doran. 1999. Impact of organic production practices on soil quality indicators. J. Environ. Qual. 28:1601-1609.

Liebig, M.A., J. Doran, and J. Gardner. 1996. Evaluation of a field test kit for measuring selected soil quality indicators. Agron. J. 88:683-686.

Liebig, M.A., J.R. Gross, S.L. Kronberg, J.D. Hanson, A.B. Frank, and R.L. Phillips. 2006b. Soil response to long-term grazing in the northern Great Plains of North America. Agric. Ecosyst. Environ. 115:270-276.

Liebig, M.A., J.R. Gross, S.L. Kronberg, R.L. Philips, and J.D. Hanson. 2010a. Grazing management contributions to net global warming potential: a long-term evaluation in the northern Great Plains. J. Environ. Qual. 39:799-809.

Liebig, M.A., J.R. Hendrickson, and J.D. Berdahl. 2010b. Response of soil carbon and nitrogen to transplanted alfalfa in North Dakota rangeland. Can. J. Soil Sci. 90:523-526.

Liebig, M.A., J.R. Hendrickson, J.D. Berdahl, and J.F. Karn. 2008a. Soil resistance under grazed intermediate wheatgrass. Can. J. Soil Sci. 88:833-836.

Liebig, M.A., H.A. Johnson, J.D. Hanson, and A.B. Frank. 2005a. Soil carbon under switchgrass stands and cultivated cropland. Biomas. Bioenerg. 28:347-354.

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

Liebig, M.A., K.N. Potter, and M.M. Mikha. 2009. Management of dryland cropping systems in the U.S. Great Plains: effects on soil organic carbon. In: R. Lal and R.F. Follett, editors, Soil carbon sequestration and the greenhouse effect, 2nd edition. SSSA special publication 57. Madison, WI. p. 97-113.

Liebig, M.A., M.R. Schmer, K.P. Vogel, and R.B. Mitchell. 2008b. Soil carbon storage by switchgrass grown for bioenergy. Bioenerg. Res. 1:215-222.

Liebig, M.A., D.L. Tanaka, and J.R. Gross. 2010c. Fallow effects on soil carbon and greenhouse gas flux in central North Dakota. Soil Sci. Soc. Am. J. 75:358-365.

Liebig, M.A., D.L. Tanaka, and B.J. Wienhold. 2004. Tillage and cropping effects on soil quality indicators in the northern Great Plains. Soil Tillage Res. 78:131-141.

Liebig, M.A. D.J. Wikenheiser, and K.A. Nichols. 2007. Opportunities to utilize the USDA-ARS Northern Great Plains Research Laboratory Soil Sample Archive. Soil Sci. Soc. Am. J. 72:975-977.

Lueking, M.A., and J.S. Schepers. 1985. Changes in soil carbon and nitrogen due to irrigation development in Nebraska's sandhill soils. Soil Sci. Soc. Am. J. 49:626-630.

Malhi, S.S., R.L. Lemke, M.A. Liebig, B. McConkey, J.J. Schoenau, L.J. Cihacek, and C. Campbell. 2010. Management strategies and practices for increasing storage of organic C and N in soil in cropping systems in the northern Great Plains of North America. In: Malhi, S.S. et al., editors, Recent trends in soil science and agronomy research in the northern Great Plains of North America. Research Signpost, Kerala, India. p. 325-384.

Malo, D.D., T.E. Schumacher, J.J. Doolittle. 2005. Long-term cultivation impacts on selected soil properties in the northern Great Plains. Soil Tillage Res. 81:277-291.

Martens, D.A., W. Emmerich, J.E.T McLain, and T.N. Johnsen. 2005. Atmospheric carbon mitigation potential of agricultural management in the southwestern USA. Soil Tillage Res. 83:95-119.

McCallister, D.L., and W.L. Chien. 2000. Organic carbon quantity and forms as influenced by tillage and cropping sequence. Commun. Soil Sci. Plant Anal. 31:465-479.

McLauchlan, K.K. 2006. Effects of soil texture on soil carbon and nitrogen dynamics after cessation of agriculture. Geoderma. 136:289-299.

Mikha, M.M., J.G. Benjamin, L.R. Stone, A.J. Schlegel, D.J. Lyon, M.F. Vigil, P.W. Stahlman. 2009. Regional study of no-till impacts on near-surface aggregate properties that influence soil erodibility. Soil Sci. Soc. Am. J. 73:1361-1668.

Mikha, M.M., M.F. Vigil, M.A. Liebig, R.A. Bowman, B. McConkey, E.J. Deibert, and J.L. Pikul. 2006. Cropping system effects on soil chemical properties and soil quality in the Great Plains. Renew. Agric. Food Syst. 21:26-35.

Miller, P.R., D.E. Buschena, C.A. Jones, and J.A. Holmes. 2008. Transition from intensive tillage to no-tillage and organic diversified annual cropping systems. Agron. J. 100:591-599.

Minnesota Department of Agriculture. Conservation Practices: Minnesota Conservation Funding Guide. www.mda.state.mn.us/protecting/conservation/practices/ constillage.aspx. (accessed 29 Oct. 2015).

Miyomoto, D.I., G.E. Schuman, and R.A. Olson. 2004. Long-term effects of mechanical renovation of a mixed-grass prairie: II. Carbon and nitrogen balance. Arid Land Res. Manage. 18:141-151.

Mortenson, M.C., G.E. Schuman, and L.J. Ingram. 2004. Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (Medicago sativa ssp. Falcata). Environ. Manage. 33:475-481.

Mostafa, S.M. 1995. Effects of calcium on growth, development, and nitrogen uptake by wheat. M.S. diss., North Dakota State Univ., Fargo, ND. 130 p.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: D.L. Sparks et al., editors, Methods of soil analysis. Part 3 SSSA Book Ser. 5. SSSA, Madison, WI. p. 961-1010.

Ortega, R.A., G.A. Peterson, and D.G. Westfall. 2002. Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till dryland agroecosystems. Agron. J. 94:944-954.

Padbury G., S. Waltman, J. Caprio, G. Coen, S. McGinn, D. Mortensen, G. Nielsen, and R. Sinclair. 2002. Agroecosystems and land resources of the northern Great Plains. Agron. J. 94:251-261.

Pendall, E., S.D. Grosso, J.Y. King, D.R. LeCain, D.G. Milchunas, J.A. Morgan, A.R. Mosier, D.S. Ojima, W.A. Paron, P.P. Tans, and J.W.C White. 2003. Elevated atmospheric CO_2 effects and soil water feedbacks on soil respiration components in a Colorado grassland. Global Biogeochem. Cycles. 17:1-15.

Peterson, G.A., A.D. Halvorson, J.L. Havlin, O.R. Jones, D.J. Lyon, and D.L. Tanaka. 1998. Reduced tillage and increasing cropping intensity in the Great Plains conserves soil C. Soil Tillage Res. 47:207-218.

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.

Pikul, J.L., J. Johnson, T.E. Schumacher, M. Vigil, and W.E. Riedell. 2008. Change in surface soil carbon under rotated corn in eastern South Dakota. Soil Sci. Soc. Am. J. 72:1738-1744.

Pikul, J.L., R.C. Schwartz, J.G. Benjamin, R.L. Baumhardt, and S. Merrill. 2006. Cropping system influences on soil physical properties in the Great Plains. Renew. Agric. Food Syst. 21:15-25.

Prechtel, A., M.V. Lützow, B.U Schneider, O. Bens, C.G. Bannick. I. Kögel-Knabner, and R.F. Hüttl. 2009. Organic carbon in soils of Germany: status quo and the need for new data to evaluate potentials and trends of soil carbon sequestration. J. Plant Nutr. Soil Sci. 172:601-614.

Reeder, J.D., and G.E. Schuman. 2002. Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. Environ. Pollut. 116:457-463.

Reeder, J.D., G.E. Schuman, and R.A. Bowman. 1998. Soil C and N changes on Conservation Reserve Program lands in the central Great Plains. Soil Tillage Res. 47:339-349.

Reeder, J.D., G.E. Schuman, J.A. Morgan, and D.R. LeCain. 2004. Response of organic and inorganic carbon and nitrogen to long-term grazing of the shortgrass steppe. Environ. Manage. 33:485-495.

Reicosky, D.C., S.D. Evans, C.A. Cambardella, R.R. Allmaras, A.R. Wilts, and D.R. Huggins. 2002. Continuous corn with moldboard tillage: residue and fertility effects on soil carbon. J. Soil Water Conserv. 57:277-284.

Riopel, J.A. 2009. Evaluating carbon sequestration in CRP and restored grasslands in the north central US. M.S. thesis, North Dakota State Univ., Fargo, ND. 310 p.

Russell, A.E., D.A. Laird, T.B. Parkin and A.P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in midwestern Mollisols. Soil Sci. Soc. Am. J. 69:431-422.

Sainju, U.M., T. Caesar-Tonthat, and J.D. Jabro. 2008a. Carbon and nitrogen fractions in dryland soil aggregates affected by long-term tillage and cropping sequences. Soil Sci. Soc. Am. J. 73:1488-1495.

Sainju, U.M., T. Caesar-Tonthat, A.W. Lenssen, R.G. Evans, and R. Kolberg. 2006a. Long-term tillage and cropping sequence effects on dryland residue and soil carbon fractions. Soil Sci. Soc. Am. J. 71:1730-1739.

Sainju, U.M., J.D. Jabro, and T. Caesar-Tonthat. 2010. Tillage, cropping sequence, and nitrogen fertilization effects on dryland soil carbon dioxide emission and carbon content. J. Environ. Qual. 39:935-945.

Sainju, U.M., J.D. Jabro, and W.B. Stevens. 2008b. Soil carbon dioxide emissions and carbon content as affected by irrigation, tillage, cropping system, and nitrogen fertilization. J. Environ. Qual. 37:98-106.

Sainju, U.M., A. Lenssen, T. Caesar-Tonthat, and J. Waddell. 2006b. Carbon sequestration in dryland soils and plant residue as influenced by tillage and crop rotation. J. Environ. Qual. 35:1341-1347.

Sainju, U.M., A. Lenssen, T. Caesar-Tonthat, and J. Waddell. 2006c. Tillage and crop rotation effects on dryland soil and residue carbon nitrogen. Soil Sci. Soc. Am. J. 70:668-678.

Sainju, U.M., A. Lenssen, T. Caesar-Tonthat, J. Waddell, and R.G. Evans. 2009. Dryland crop yields and soil organic matter as influenced by long-term tillage and cropping sequence. Agron. J. 101:243-251.

SAS Institute. 2009. The SAS system for Windows. Release 9.2. SAS Inst., Cary, NC.

Schuman, G.E., J.D. Reeder, J.T. Manley, R.H. Hart, and W.A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecol. Applic. 9:65-71.

Sherrod, L.A., G.A. Peterson, D.G. Westfall, and L.R. Ahuja. 2003. Cropping intensity enhances soil organic carbon and nitrogen in a no-till agroecosystem. Soil Sci. Soc. Am. J. 67:1533-1543.

Springsteen, A., W. Loyal, M. Liebig, and J. Hendrickson. 2009. Soil carbon and nitrogen across a chronosequence of woody plant expansion in North Dakota. Plant Soil. doi: 10.1007/s11104-009-0117-8

Stahl, P.D., J.D. Anderson, LJ. Ingram, G.E. Schuman, and D.L. Mummey. 2003. Accumulation of organic carbon in reclaimed coal mine soils of Wyoming. Paper presented at: National meeting of the American Society of Mining and Reclamation. Billings land reclamation symposium. Billings, MT. 2003. ASMR, Lexington, KY. p. 1206-1215.

Stone, L.R., Schlegel, D.J. Lyon, M.F. Vigil, M.M. Mikha, P.W. Stahlman, and C.W. Rice. 2009. No-till induced increase in organic carbon reduces maximum bulk density of soils. Soil Sci. Soc. Am. J. 73:1871-1879.

USDA-NRCS. 2006. Land resource regions and major land resource areas of the United States, Caribbean, and the Pacific Basin. USDA Handbook 296. Washington, D.C. 2006.

USDA-NRCS. 2010. Rapid assessment of U.S. soil carbon status for climate change and conservation planning, Attachment B. USDA-NRCS National Bulletin 403-10-6.

USDA-NRCS. 2012a. Energy Estimator. http://ecat.sc.egov.usda.gov/Help.aspx, (accessed, 10/29/2015).

USDA-NRCS. 2012b. User guide for the national commodity crop productivity index. Version 2.0.

USDA-NRCS. 2015. National soil survey handbook. Title 430-VI, Part 630. 2013.

USDA-NRCS. Field Office Technical Guide. http://efotg.sc.egov.usda.gov/ (accessed 29 Oct. 2015).

USDA-NRCS. Official soil series description: Query facility .https://soilseries.sc.egov. usda.gov/osd.query.aspx. (accessed 29 Oct. 2015).

VandenBygaart, A.J., E.G. Gregorich and D.A. Angers. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can. J. Soil Sci. 83:363–80.

Varvel, G.E. 2006. Soil organic carbon changes in diversified rotation of the western corn belt. Soil Sci. Soc. Am. J. 70:426-433.

Varvel, G., W. Riedell, E. Deibert, B. McConkey, D. Tanaka, M. Vigil, and R. Schwartz. 2006. Great Plains cropping system studies for soil quality assessment. Renew. Agric. Food Syst: 21: 3-14.

West, T.O. and G. Marland. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agric. Ecosyst. Environ. 91:217–32.

West, T.O., and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66:1930-1946.

Wienhold, B.J., and A.D. Halvorson. 1998. Cropping systems influences on several soil quality attributes in the northern Great Plains. J. Soil Water Conserv. 53:254-258.

Wienhold, B.J., J.R. Hendrickson, and J.F. Karn. 2001. Pasture management influences on Soil properties in the northern Great Plains. J Soil Water Conserv. 56:27-31.

Wienhold, B.J., J.L. Pikul, M.A. Liebig, M.M. Mikha, G.E. Varvel, and J.W. Doran. 2006. Cropping system effects on soil quality in the Great Plains: synthesis from a regional project. Renew. Agric. Food Syst. 21:49-59.

Wienhold, B.J., and D. Tanaka. 2001. Soil property changes during conversion from perennial vegetation to annual cropping. Soil Sci. Soc. Am. J. 65:1795-1803.

Wilts, A.R., D.C. Reicosky, R.R. Allmaras, and C.E. Clapp. 2004. Long-Term corn residue effects: harvest alternatives, soil carbon turnover, and root-derived carbon. Soil Sci. Soc. Am. J. 68:1342-1351.

Yassin, M. 1991. Effects of cultivation and erosion on soil properties along two toposequences. M.S. thesis, North Dakota State Univ., Fargo, ND. 184 p.

Zheng, F., S. Merrill, C. Huang, D. Tanaka, F. Darboux, M.A. Liebig, and A. Halvorson. Runoff, soil erosion, and erodibility of Conservation Reserve Program land under crop and hay production. Soil Sci. Soc. Am. J. 68:1332-13

APPENDIX. PUBLICATIONS COLLECTED FOR THIS STUDY

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
1	Soil carbon under switchgrass stands and cultivated cropland	Liebig et al. (2005a)	2005a	Embden, Emerick	ND, SD, MN	120
2	Soil response to long-term grazing in the northern Great Plains of North America	Liebig et al. (2006b)	2006b	Temvik-Wilton silt loam	Mandan, ND	100
3	Soil Carbon Storage by Switchgrass Grown for Bioenergy	Liebig et al. (2008b)	2008b	Barnes-Buse and Barnes-Svea loam	NE, SD, ND	120
4	Fallow Effects on Soil Carbon and Greenhouse Gas Flux in Central North Dakota	Liebig et al. (2010c)	2010c	Temvik-Wilton silt loam	Mandan, ND	10
5	Soil Carbon and Nitrogen across a chronosequence of woody plant expansion in North Dakota	Springsteen et al. (2009)	2009	Cabba loam	Mandan, ND	15
6	Great Plains cropping system studies for soil quality assessment	Varvel et al. (2006)	2006	Fargo silty clay and Wilton silt loam	Akron, CO., Brookings, SD., Mandan and Fargo, ND., Bushland, TX., Mead, NE., Sidney, MT., Swift Current, SK.	30
7	Cropping system effects on soil quality in the Great Plains: Synthesis from a regional project	Wienhold et al. (2006)	2006	Fargo silty clay and Wilton silt loam	Akron, CO., Brookings, SD., Mandan and Fargo, ND., Bushland, TX., Mead, NE., Sidney, MT., Swift Current, SK.	15
8	Cropping system effects on soil chemical properties and soil quality in the Great Plains	Mikha et al. (2006)	2006	Fargo silty clay and Wilton silt loam	Akron, CO., Brookings, SD., Mandan and Fargo, ND., Bushland, TX., Mead, NE., Sidney, MT., Swift Current, SK.	30
9	Cropping system influences on soil physical properties in the Great Plains	Pikul et al. (2006)	2006	Fargo silty clay and Wilton silt loam	Akron, CO., Brookings, SD., Mandan and Fargo, ND., Bushland, TX., Mead, NE., Sidney, MT., Swift Current, SK.	30

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
10	Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada	Liebig et al. (2005b)	2005b	N/A	KS, NE, ND, SD, CO, WY, MT, ID, OR, WA, AK, Canada	15
11	Management of Dryland Cropping Systems in the U.S. Great Plains: Effects on Soil Organic Carbon	Liebig et al. (2009)	2009	N/A	Mandan, ND	15
12	Opportunities to utilize the USDA-ARS Northern Great Plains Research Laboratory Soil Sample Archive	Liebig et al. (2007)	2007	N/A	Mandan, ND	NA
13	Soil organic carbon stocks with depth and land use at various U.S. sites	Follett et al. (2009a)	2009a	Farnuf, Barnes	ND, OH, IN, NE, ID, KS, CO, IA, TX, MT, MO, MN, OK	100
14	Carbon sequestration under the Conservation Reserve program in the historic grassland soils of the United States of America	Follett et al. (2001)	2001	Farnuf, Barnes	ND, OH, IN, NE, ID, KS, CO, IA, TX, MT, MO, MN, OK	100
15	Estimated soil organic carbon losses from long-term crop-fallow in the northern Great Plains of the USA.	Cihacek and Ulmer (1995)	1995	Amor, Shambo, Bowdle, Stady	MLRA 54	15
16	Nitrogen and carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments.	Hass et al. (1957)	1957	Barnes, Morton, Williams	Mandan and Dickinson, ND	45
17	Tillage, Nitrogen, and Cropping System Effects on Soil Carbon Sequestration	Halvorson et al. (2002)	2002	Temvik-Wilton silt loam	Mandan, ND	30

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
18	Evaluating Carbon Sequestration in CRP and restored Grasslands in the North Central US	Riopel, J.A. (2009)	2009	N/A	MT, ND, SD, MN, IA	NA
19	Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland.	Bauer and Black (1981)	1981	Vebar, Arnegard, Morton, Amor, Grail, Regent	Carson, ND	45
20	Quantification of the effect of soil organic matter content on soil productivity.	Bauer and Black (1994)	1994	Williams	Mandan, ND	30
21	Reduced tillage and increasing cropping intensity in the Great Plains conserves soil C	Peterson et al. (1998)	1998	N/A	ND, NE, KS, CO, TX	30
22	Organic carbon Effects on Available Water capacity of Three Soil Textural Groups	Bauer and Black (1992)	1992	N/A	Mandan, ND	NA
23	See Entry # 48					
24	Soil property Changes during Conversion from Perennial Vegetation to Annual Cropping	Wienhold and Tanaka (2001)	2001	Amor loam	Mandan, ND	NA
25	A conservation tillage-cropping systems study in the Northern Great Plains of the United States.	Black and Tanaka (1997)	1997	Temvik-wilton silt-loam	NE	183
26	Growth and NPK uptake by soybean cultivars in northern USA under reduced tillage systems.	Deibert and Utter (1989)	1989	Fargo clay	ND	60
27	Cropping systems influences on several soil quality attributes in the Northern Great Plains.	Wienhold and Halvorson (1998)	1998	Temvik-Wilton silt loam	Mandan, ND	15

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
28	Soil Organic carbon Sequestration rates by Tillage and Crop Rotation: A global data analysis	West and Post (2002)	2002	N/A	Mandan and Fargo, ND	30
29	Tillage and Cropping effects on soil quality indicators in the northern Great Plains	Liebig et al. (2004)	2004	Wilton silt loam	Mandan, ND	NA
30	Effects of Tillage on Profile Soil Carbon Distribution in the Northern Great Plains of the U.S.	Cihacek and Ulmer (1997)	1997	Amor, Shambo, Bowdle, Stady, Vebar	MLRA 54	100
31	Influence of Nitrogen Fertility Management on Profile Soil carbon Storage under Long-Term Bromegrass Production	Cihacek and Meyer (2002)	2002	Fargo silty clay	Fargo, ND	100
32	Effects of Tillage on Inorganic Carbon Storage in Soils of the Northern Great Plains of the U.S.	Cihacek and Ulmer (2002)	2002	Amor, Shambo, Bowdle, Stady, Vebar	MLRA 54	100
33	Soil carbon and nitrogen of northern great plains grasslands as influenced by lon-term grazing	Frank et al. (1995)	1995	Temvik silt loam	Mandan, ND	107
34	Biomass and carbon partitioning in Switchgrass	Frank et al. (2004)	2004	N/A	Mandan, ND	100
35	Pasture Management influences on Soil Properties in the Northern Great Plains	Wienhold et al. (2001)	2001	Temvik-Wilton silt loam	Mandan, ND	15
36	Impact of Organic Production Practices on Soil Quality Indicators	Liebig and Doran (1999)	1999	Buse, Svea	Medina and Windsor, ND	30
37	Evaluation of a field test kit for measuring selected soil quality indicators	Liebig et al. (1996)	1996	Buse, Svea	Medina and Windsor, ND	30
38	See Entry # 7					

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
39	Management effects on soil CO2 efflux in northern semiarid grassland and cropland	Frank et al. (2006)	2006	Werner-Sen-Chama, Wilton silt loam	Mandan, ND	30
40	Cropping system effects on soil biological characteristics in the Great Plains	Liebig et al (2006a)	2006a	Fargo Silty Clay, Wilton Silt Loam	Fargo and Mandan, ND	30
41	Runoff, Soil Erosion, and Erodibility of Conservation Reserve Program Land under Crop and Hay production	Zheng et al. (2004)	2004	Williams loam	Mandan, ND	10
42	Effects of Cultivation on Soils in Northern Great Plains Rangeland	Aguilar et al. (1988)	1988	See literature	ND	NA
43	Effects of Cultivation and Erosion on Soil Properties along Two Toposequences	Yassin, M. (1991)	1991	N/A	Hankinson, ND	NA
44	Soil Property in Virgin Grasslands Between Grazed and Non-grazed Sites	Bauer et al. (1987)	1987	Vebar, Arnegard, Morton, Amor, Grail, Regent	Grant Co., ND	45
45	Biomass Estimation Approach Impacts on Calculated Soil Organic Carbon Maintenance Requirements and Associated Mineralization Rate Constants	Clay et al. (2010)	2010	See literature	Clarnida and Nashua, IA., Rosemont, Morris, and Lamberton, MN., Brookings, SD., Mead, NE..	NA
46	Carbon Dynamics in Corn-Soybean Sequences as Estimated from Natural Carbon-13 Abundance	Huggins et al. (1998)	1998	Webster Clay loam	Lamberton, MN	30
47	Carbon and nitrogen fractions in dryland soil aggregates affected by long-term tillage and cropping sequences	Sainju et al. (2008a)	2008a	Dooley sandy loam	Culbertson, MT	8

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
48	Carbon sequestration in dryland soils and plant residue as influenced by tillage and crop rotation	Sainju et al. (2006b)	2006b	Scobey clay loam, Kevin clay loam	Havre, MT	20
49	Carbon Sequestration and Rangelands: A Synthesis of Land Management and Precipitation Effects	Derner and Schuman (2007)	2007	N/A	CO, WY, SD, and ND	NA
50	Accumulation of Organic Carbon in Reclaimed Coal Mine Soils of Wyoming	Stahl et al. (2003)	2003	Aridisols	Rosebud, Cyprus-Shoshone, and Dave Johnson Coal mines in Wyoming	30
51	Carbon Sequestration in Rangelands Interseeded with Yellow-Flowering Alfalfa (Medicago sativa ssp. Falcata)	Mortenson et al. (2004)	2004	Amor Loam, Reeder Loam , Vebar fine sandy loam	Perkins CO, SD	100
52	Carbon Storage in Soils of the North American Great Plains: Effect of Cropping Frequency	Campbell et al. (2005)	2005	See… Sherrod et al., 2003 Bowmen et al,. 1999 Halvorson et al., 2002	See… Sherrod et al., 2003 Bowmen et al,. 1999 Halvorson et al., 2002	20
53	Cropping Intensity Enhances Soil Organic carbon and Nitrogen in a No-Till Agroecosystem	Sherrod et al. (2003)	2003	Weld, Satanta, Albinas, Norka, Richfield, Kuma, Nunn	Sterling, Stratton, and Walsh, CO.	20
54	Soil organic matter changes in intensively cropped dryland systems.	Bowman et al. (1999)	1999	Weld	Akron, CO	15
55	Tillage and crop rotation effects on dryland soil and residue carbon nitrogen	Sainju et al. (2006c)	2006c	Scobey clay loam, Kevin clay loam	Havre, MT	20
56	Change in surface soil carbon under rotated corn in eastern South Dakota	Pikul et al. (2008)	2008	Barnes	Brookings, SD	15

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
57	Conservation Reserve Program: effects on soil organic carbon and preservation when converting back to cropland in northeastern Colorado.	Bowman and Anderson (2002)	2002	N/A	NE CO	40
58	Corn-residue transformations into root and soil carbon as related to nitrogen, tillage, and stover management	Allmaras et al. (2004)	2004	Waukegan Silt Loam	Rosemount, MN	30
59	Crop management effect on crop residue production and changes in soil organic carbon in the central Great Plains.	Benjamin et al. (2010)	2010	Weld silt loam	Akron, CO	30
60	See Entry # 8					
61	See Entry # 27					
62	Does grazing mediate soil carbon and nitrogen accumulation beneath C4, perennial grasses along an environmental gradient?	Derner et al. (1997)	1997	N/A	Flint Hills andFort Hays, KS, and North-central CO	30
63	Does long-term center-pivot irrigation increase soil carbon stocks in semi-arid agro-ecosystems?	Denef et al. (2008)	2008	Alliance, Goshen, Rosebud, Weld, Platner	Imperial, NE., and Otis, CO.	75
64	Dryland crop yields and soil organic matter as influenced by long-term tillage and cropping sequence	Sainju et al. (2009)	2009	Dooley sandy loam	Culbertson, MT	20
65	Effects of increasing amounts of organic residues on continuous corn: II. Organic carbon, nitrogen, phosphorus, and sulfur	Larson et al. (1971)	1971	Marshall silty caly loam	Clarinda, Iowa	NA

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
66	Effects of soil texture on soil carbon and nitrogen dynamics after cessation of agriculture	McLauchlan, K.K. (2006)	2006	Formdale, Sisseton, Barnes, Arvilla, Dorset	Grant and Otter Tail Counties, MN	10
67	Grazing and ecosystem carbon storage in the North American Great Plains	Derner et al. (2006)	2006	Sandy loams	Flint Hills andFort Hays, KS, and North-central CO	30
68	Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem	Ingram et al. (2007)	2007	Ascalon, Altvan	Cheyenne, WY	60
69	Grazing management contributions to net global warming potential: a long-term evaluation in the Northern Great Plains.	Liebig et al. (2010a)	2010a	Temvik-Wilton silt loam	Mandan, ND	60
70	Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland	Schuman et al. (1999)	1999	Ascalon and Altvan sandy loams	Cheyenne, Wy	60
71	Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern Mollisols	Russell et al. (2005)	2005	Kenyon, Readlyn, and Webster	Iowa State University Research Farms	100
72	Infiltration and soil properties as affected by annual cropping in the Northern Great Plains	Pikul and Aase (1995)	1995	Dooley sandy loam	Culbertson, MT	NA
73	Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands	Reeder and Schuman (2002)	2002	Ascalon and Altvan sandy loams, Olney, Remmit	Cheyenne, WY and Fort Collins, CO	90
74	Landscape position and age of reconstructed prairies effect on soil organic carbon sequestration rate and aggregate associated carbon	Guzman and Al-Kaisi (2010)	2010	N/A	Jasper County and Warren County, IA.	60

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
75	Long-Term corn residue effects: harvest alternatives, soil carbon turnover, and root-derived carbon	Wilts et al. (2004)	2004	Hamerly clay loam, McIntosh silt loam, Winger silty clay loam	Morris, MN	NA
76	Long-term cultivation impacts on selected soil properties in the northern great plains	Malo et al. (2005)	2005	Argiustolls, Natrustolls, Argialbolls, Calciustolls, Haplustolls, Argiaquolls, Endoaquolls, and Fluvaquents	Beadle, Minnehaha, McCook, and Union Counties, ND	100
77	Long-term effects of mechanical renovation of a mixed-grass prairie: II. Carbon and nitrogen balance	Miyomoto et al. (2004)	2004	Ascalon	Cheyenne, WY	60
78	Long-term tillage and cropping sequence effects on dryland residue and soil carbon fractions	Sainju et al. (2006a)	2006a	Dooley sandy loam	Culberston, MT	20
79	Nitrogen fertilization effects on soil carbon and nitrogen in a dryland cropping system	Halvorson et al. (1999)	1999	Weld silt loam	Akron, CO	15
80	Nitrogen pools and fluxes in grassland soils sequestering carbon	Conant et al. (2005)	2005	See; Reeder et al. (1998), Schuman et al. (1999), and Frank et al. (1995)	See; Reeder et al. (1998), Schuman et al. (1999), and Frank et al. (1995)	NA
81	No-till corn after bromegrass: effect on soil carbon and soil aggregates	Follett et al. (2009b)	2009b	Filbert silt loam	Mead, NE	30
82	No-till induced increase in organic carbon reduces maximum bulk density of soils	Stone et al. (2009)	2009	Weld and Duroc loam	Akron, CO., Sidney, NE., Tribune and Hays, KS.	5
83	Organic carbon effects on soil physical and hydraulic properties in a semiarid climate	Benjamin et al. (2008)	2008	Weld silt loam	Akron, CO	NA

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
84	Organic carbon quantity and forms as influenced by tillage and cropping sequence	McCallister and Chien (2000)	2000	Sharpsburg silty caly loam	Lincoln, NE	10
85	Regional study of no-till impacts on near-surface aggregate properties that influence soil erodibility	Mikha et al. (2009)	2009	Weld and Duroc loam	Akron, CO., Sidney, NE.	10
86	Response of organic and inorganic carbon and nitrogen to long-term grazing of the shortgrass steppe	Reeder et al. (2004)	2004	Olney fine sandy loam	Fort Collins, CO.	90
88	Six years of CO2 flux measurements for a moderatley grazed mixed-grass prairie	Frank, A.B. (2004)	2004	Werner-Sen-Chama complex	Mandan, ND	110
89	Soil carbon dioxide emissions and carbon content as affected by irrigation, tillage, cropping system, and nitrogen fertilization	Sainju et al. (2008b)	2008b	Lihen sandy loam, Williams loam	Nesson Valley, ND., and Rasmussen, MT.	20
90	Soil carbon dynamics during a long-term incubation study involving 13C and 14C measurements	Follett et al. (2007)	2007	Weld, and Duroc loam	Akron, CO., and Sidney, NE.	10
91	Soil C and N changes on conservation reserve program lands in the central great plains	Reeder et al. (1998)	1998	Ulm clay loam, Phiferson sandy loam	Arvada, WY., and Keeline, WY.	28
92	Soil organic carbon changes in diversified rotation of the western corn belt	Varvel, G.E. (2006)	2006	Sharpsburg (fine, smectitic, mesic Typic Argiudoll)	Mead, NE.	30
93	Tillage, cropping sequence, and nitrogen fertilization effects on dryland soil carbon dioxide emission and carbon content	Sainju et al. (2010)	2010	Williams loam	Eastern MT	120

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
94	Transition from intensive tillage to no-tillage and organic diversified annual cropping systems	Miller et al. (2008)	2008	Amsterdam silt loam	Bozeman, MT	60
95	Changes in soil carbon and nitrogen due to irrigation development in Nebraska's sandhill soils	Lueking and Schepers (1985)	1985	Valentine fine sand loam, Dunday loamy sand	Nebraska's sandhill region	30
96	Soil organic carbon and 13-C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota	Clapp et al. (2000)	2000	Waukegan silt loam	Rosemount, MN.	30
97	The CRP increases soil organic Carbon	Gebhart et al. (1994)	1994	Valentine fine sand	Valentine, NE.	300
98	Continuous corn with moldboard tillage: residue and fertility effects on soil carbon	Reicosky et al. (2002)	2002	Hamerly caly loam, McIntosh silt loam, Winger slity clay loam	Morris, MN.	100
99	Soil carbon pools and fluxes in long-term corn belt agroecosystems	Collins et al. (2000)	2000	Normania loam	Lamberton, MN	100
100	Management strategies and practices for increasing storage of organic C and N in soil in cropping systems in the Northern Great Plains of North America	Malhi et al. (2010)	2010	See literature	See Literature	NA
101	Carbon dioxide fluxes over a northern, semiarid, mixed-grass prairie	Frank and Dugas (2001)	2001	Werner-Sen-Chama	Mandan, ND	NA

Entry No.	Title	Authors	Date	Soil Series	Location	Depth (cm)
102	Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till dryland agroecosystems	Ortega et al. (2002)	2002	Weld, Norka	Sterling, Stratton, and Walsh, CO.	10
103	Soil microbial activity, nitrogen cycling, and long term changes in organic carbon pools as related to fallow tillage management	Doran et al. (1998)	1998	Alliance, Duroc	Sidney, NE	122
104	Carbon Dioxide fluxes over a grazed prairie and seeded pasture in the Northern Great Plains	Frank, A.B. (2001)	2001	Werner-Sen-Chama complex	Mandan, ND	100
105	Soil carbon dioxide fluxes in the northern semiarid grasslands	Frank et al. (2002)	2002	Werner-Sen-Chama complex	Mandan, ND	NA
106	Elevated atmospheric CO2 effects and soil water feedbacks on soil respiration components in a Colorado grassland	Pendall et al. (2003)	2003	Ustollic Camborthid	Fort Collins, CO.	NA
107	Soil resistance under grazed intermediate wheatgrass	Liebig et al. (2008a)	2008a	Temvik-Wilton siltt loam	Mandan, ND	30
108	Response of soil carbon and nitrogen to transplanted alfalfa in North Dakota rangeland	Liebig et al. (2010b)	2010b	Temvik silt loam	Mandan, ND	40
109	Soil, stratigraphy, and hydrology on shale landscape	Cymbaluk, W.P. (2002)	2002	See literature	Langdon, ND	165
110	Soils and Sediments as indicators of agricultural impact on northern prairie wetlands	Freeland, J.A. (1996)	1996	See literature	Stutsman County, ND	45
111	Effects of Calcium on growth, development, and nitrogen uptake by wheat	Mostafa, S.M. (1995)	1995	See literature	Kindred, Buffalo, Prosper, Mapleton, Davenport, Embden, and Galesburg, ND.	120