A carbon assessment of Iowa State University's land

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Iowa State University

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A carbon assessment of Iowa State University’s land

by

Catherine Rosson DeLong

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Co-majors: Soil Science (Soil Morphology and Genesis); Environmental Science

Program of Study Committee:
C. Lee Burras, Major Professor
Richard M. Cruse
Thomas J. Sauer

Iowa State University
Ames, Iowa
2014

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“If we agitate the planet enough, humans may be destroyed, but the Earth, with enormous spans of geologic time on its side, will recover and record our brief existence in a thin sedimentary stratum.”

– Ronald Amundson
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF TABLES</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF ACRONYMS</td>
<td>viii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER 1. GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER 2. A DATABASE-DRIVEN CARBON ASSESSMENT OF IOWA STATE UNIVERSITY SOILS</td>
<td>3</td>
</tr>
</tbody>
</table>

## Introduction

Materials and Methods
- Site description | 3
- Database description | 7
- Digital representation of farms | 8
- A note on the term ‘carbon’ | 8
- Carbon data available in Iowa Soil Properties and Interpretations Database | 9
- Carbon data available in Web Soil Survey | 10
- Determining soil organic carbon using ISPAID in ArcMap 10.1 | 11
- Determining soil organic and inorganic carbon in Web Soil Survey | 12
- Creating an ISPAID derived Organic Matter Percentage | 13
- Determining average and percent difference values | 14

## Results and Discussion

- SOC, SIC and TC values for 0 to 18 cm depth | 15
- Comparing ISPAID and WSS derived SOC content for 0 to 18 cm depth | 18
- SOC, SIC and TC values for 0 to 100 cm depth | 22
- Comparing ISPAID and WSS derived SOC content for 0 to 100 cm depth | 27
- The vertical distribution of SIC and SOC | 28
- Creating an ISPAID derived Organic Matter Percentage | 29

## Conclusion

| Conclusion | 30 |
LIST OF TABLES

Table 2.1a. Farm SOC, SIC and TC for 0 to 18 cm depth for 35 farms.........................17
Table 2.1b. Summary statistics for all 82 farms for 0 to 18 cm depth..........................18
Table 2.2a. Farm SOC, SIC and TC for 0 to 100 cm depth for 35 farms.....................23
Table 2.2b. Summary statistics for all 82 farms for 0 to 100 cm depth.........................25
Table 2.3. Average bulk density (g cm\(^{-3}\)), percent organic matter and percent difference for both bulk density and percent organic matter for ISPAID and WSS....29
Table 3.1. Parameters, parameter gradations and accompanying factors for SOC equation..............................................................................................................................36
Table 3.2. Twenty-five farms with their management, slope, drainage, taxonomic and the resulting SOC sequestration factor........................................................................43
Table 4.1. GPS coordinates for sampled cores .................................................................50
Table 4.2. Individual core results for total C and total N, pH, bulk density and C:N ratio.........................................................................................................................56
Table 4.3. Individual averages for total C and total N, (g/ 100 g soil), pH and bulk density for all cores for 0 to 18 cm depth.................................................................59
Table 4.4. Individual averages for total C and total N, (g/ 100 g soil), pH and bulk density for all cores for 0 to 100 cm depth.................................................................59
Table 4.5. Average total C and total N, pH and bulk density for all uncropped and cropped cores for 0 to 100 cm depth.................................................................59
Table 4.6. Depth to mollic colors and clay films for individual soil cores.................59
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Map of Iowa with ISU farms highlighted in orange and ISU campus represented with a yellow star</td>
<td>5</td>
</tr>
<tr>
<td>2.2</td>
<td>Landform regions of Iowa with Story and Boone Counties highlighted</td>
<td>5</td>
</tr>
<tr>
<td>2.3</td>
<td>Glacial advances of the Des Moines Lobe with Story and Boone Counties outlined</td>
<td>6</td>
</tr>
<tr>
<td>2.4</td>
<td>Distribution of Mollisols in Iowa</td>
<td>6</td>
</tr>
<tr>
<td>2.5</td>
<td>The farms with the highest TC, SOC and SIC, as well as the lowest TC and SOC for 0 to 18 cm and 0 to 100 cm depth</td>
<td>19</td>
</tr>
<tr>
<td>2.6</td>
<td>Comparison of SOC (kg m$^{-2}$) for 0 to 18 cm depth for each of the farms according to ISPAID and WSS</td>
<td>20</td>
</tr>
<tr>
<td>2.7</td>
<td>Percent difference in farm SOC (kg m$^{-2}$) for 0 to 18 cm depth when comparing ISPAID and WSS values</td>
<td>20</td>
</tr>
<tr>
<td>2.8</td>
<td>Comparison of SOC (kg m$^{-2}$) for 0 to 100 cm depth for each of the farms according to ISPAID and WSS</td>
<td>24</td>
</tr>
<tr>
<td>2.9</td>
<td>Percent difference in farm SOC (kg m$^{-2}$) for 0 to 100 cm depth when comparing ISPAID and WSS</td>
<td>24</td>
</tr>
<tr>
<td>2.10</td>
<td>Average SOC (kg m$^{-2}$) for 0 to 18 cm and 0 to 100 cm depth for both ISPAID and WSS</td>
<td>25</td>
</tr>
<tr>
<td>2.11</td>
<td>Comparison of the average farm SOC (kg m$^{-2}$) for both ISPAID and WSS for 0 to 18 cm and 18 to 100 cm depth</td>
<td>28</td>
</tr>
<tr>
<td>2.12</td>
<td>Comparison of the average farm SOC and SIC (kg m$^{-2}$) for 0 to 100 cm depth</td>
<td>28</td>
</tr>
<tr>
<td>3.1</td>
<td>Map of Iowa with ISU farms highlighted in orange and ISU campus represented with a yellow star</td>
<td>33</td>
</tr>
<tr>
<td>3.2</td>
<td>Distribution of Mollisols in Iowa</td>
<td>33</td>
</tr>
</tbody>
</table>
Figure 3.3. SOC sequestration potential of 19 of ISU’s farms.................................44

Figure 4.1. Soil map of sampling site with cores.................................................50

Figure 4.2. Total N and total C (g/100 g of soil), pH, bulk density (g cm$^{-3}$) and C:N ratio by depth.................................................................58
LIST OF ACRONYMS

C – carbon

CAD – Committee for Agricultural Development

cm – centimeters

BD – bulk density

ICI – Iowa Carbon Index

in – inches

ISPAID – Iowa Soil Properties and Interpretations Database

ISU – Iowa State University

m – meter

mm – millimeters

N – nitrogen

NRCS-USDA – Natural Resources Conservation Service-U.S. Department of Agriculture

OM – organic matter

SIC – soil inorganic carbon

SMU – soil map unit

SOC – soil organic carbon

SOM – soil organic matter

SSURGO – Soil Survey Geographic Database

US – United States

USLE – Universal Soil Loss Equation

WSS – Web Soil Survey
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I would like to thank the talented scientists who have made up my committee. My gratitude goes to Dr. Thomas Sauer for always having an open door and thoughtful insights; to Dr. Richard Cruse for treating me like a peer, and a capable one at that; and especially to Dr. Lee Burras, for taking a chance on me.

Lee, thank you for teaching me the vigor of scientific inquiry and for bringing me into the scientific community that I always assumed was out of reach. For someone who once said, “I’m an existentialist, it’s a hostile world,” you have a lot of faith in people.

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I would like to dedicate this thesis to Jenny Richter. She will never admit it, but I could not have completed it without her. Jenny, in the past two years, I have asked you a lot of questions; thank you for your patience in answering the ones you knew, and your willingness to search for the answers you didn’t. I have been inspired by your curiosity about the world, your diligence and candor. Thank you for being such a wonderful combination of confident intelligence and humility.
CHAPTER 1: GENERAL INTRODUCTION

In 1862, Iowa State University was the first college to accept the provisions of the Morrill Act and become a land-grant university, an institution dedicated to educating and aiding the state’s landowners. Today, the university’s mission has expanded to include the global farmer and more broadly the agricultural world. With this global perspective has also come the need for self-evaluation within a broader environmental context. The Green Lands’ Team was created to evaluate the ‘green’ status of Iowa State University’s land, and in this way re-evaluate its land grant status in a modern context. One increasingly recognized method of evaluating land in an environmental context is through a soil carbon assessment.

There are both environmental and agronomic incentives for holding, or sequestering, carbon in the soil. Atmospheric carbon in the form of carbon dioxide and methane are contributing to the warming of our planet, while conversely carbon that has been removed from the atmosphere and stored in the soil improves structure and nutrient holding capacity. Soil carbon, and organic matter more broadly, stabilizes soil aggregates which has the agronomic and environmental benefit of increasing soil water retention and decreasing nutrient runoff. The soil is currently the largest terrestrial carbon pool, but it is estimated that with ‘best management practices’ 75 to 200 million additional tons of carbon can be sequestered each year by US agriculture (Batjes, 1996; Soil Science Society of America, 2001).
Just as Iowa State was the first university to become a land grant institution, through this thesis I have confidence that Iowa State will become the first US university to assess the carbon content of their land. The objectives of this thesis is to quantify the carbon content of Iowa State’s land, to estimate the potential for soil carbon to be gained, and to actively question the assumptions that are necessary to quantify a dynamic property such as soil carbon on a large scale. Another goal, in the spirit of Iowa State University’s land grant status, is to complete the research with methodologies that can be replicated by a non-academic audience.

This thesis is organized into five chapters. Chapter two is a comparison of the carbon stocks reported by two soil property databases with emphasis on the assumptions that have caused their results to diverge. Chapter three is a semi-quantitative prediction of the carbon flux of Iowa State’s land, given a change in the current management scheme, using our own set of ‘expert’ assumptions to animate a soil carbon sequestration equation. Chapter four is a case study of one of the major tenets of soil mapping, the soil map unit, and whether the variability of land use and soil properties more generally, can be captured in one soil map unit polygon. Chapter five offers some general conclusions.
CHAPTER 2. A DATABASE-DRIVEN CARBON ASSESSMENT OF IOWA STATE UNIVERSITY SOILS

Introduction

The objective of this chapter, and the goal of Iowa State University’s (ISU) Green Lands’ Team, is to quantify the carbon stocks of the university’s farmland. Carbon is a worthwhile property to measure because its quantification will allow ISU to more fully realize its environmental impact and furthermore, to target conservation measures to land parcels with the lowest carbon content. The carbon content of ISU’s land could also be useful economically were a carbon credit system every to gain regional or national support. In this chapter, the carbon content of ISU’s land is estimated using two widely-recognized databases. The methodologies used to populate these databases are also closely compared in order to provide a more complete appraisal of the results.

Materials and Methods

Site description

As a legacy of its land grant status, ISU and affiliated organizations manage 6,392 hectares of farmland in Iowa (M. Honeyman, personal communication, September 12, 2012). The majority of ISU’s land parcels or ‘farms’, as they will be termed throughout this manuscript, are owned and managed by the university, while the remainder are held by nonprofit organizations that include the Committee for Agricultural Development (CAD), the Iowa State University Foundation and local associations of
farmers, business people and citizens. One additional farm is owned by the City of Ames and leased to the university (ISU Research and Demonstration Farms, 2009).

The bulk of the farms are located on or near the university campus in Story and Boone Counties, however there are 17 outlying farms in 16 counties scattered across the state (Figure 2.1). The farms are used for a myriad of activities that include crop and livestock production, extension demonstrations and research plots. According to Mark Honeyman, Professor, Coordinator of the ISU Research Farms and Executive Director of CAD, 55% of the land is cropped while 31 and 14% are in grass and forest, respectively (personal communication, September 12, 2012). Iowa State University’s central campus is not included in this carbon assessment.

Iowa’s soils and landscapes have principally developed in Quaternary-aged sediments, especially drift and loess (Ruhe, 1969; Figure 2.2). Loess mantles the majority of Iowa in varying thicknesses, but is absent on the Des Moines Lobe, the southwestern-most point of the Laurentide ice sheet which includes modern day Story and Boone Counties (Prior, 1991; Figure 2.3). In Iowa, the mean annual precipitation from 1983 to 2013 is 835 mm, while mean annual temperature for the same period is 9°C (Iowa Environmental Mesonet, 2014).

Because of Iowa’s low relief, prairie-derived soils, temperate climate and fertile parent materials, two-thirds of the state, and the majority of ISU’s farms, are included in the Mollisols Order of Soil Taxonomy (Miller et al., 2010a; Figure 2.4).
Figure 2.1. Map of Iowa with ISU farms highlighted in orange and ISU campus represented with a yellow star.

Figure 2.2. Landform regions of Iowa with Story and Boone Counties highlighted.
Figure 2.3. Glacial advances of the Des Moines Lobe with Story and Boone Counties outlined.

Figure 2.4. Distribution of Mollisols in Iowa.
Database description

Three things made a sample-based approach unfeasible: (a) time and cost constraints, (b) lack of scientifically recognized sampling protocols for such a large and diverse area, (c) goal of easy replicability. Fortunately, two well-recognized and widely used databases with carbon data were available, the Iowa Soil Properties and Interpretations Database (ISPAID) 7.3, and USDA-NRCS Web Soil Survey. ISPAID is organized by soil map unit (SMU) and is sourced from the Iowa Cooperative Soil Survey (Miller et al., 2010b). The database contains 102 columns or ‘fields’ that detail each SMU’s extent, soil and landscape properties, and yield data. Created circa 1980 by Professors Gerald Miller and Thomas Fenton at Iowa State University, ISPAID is periodically updated. The data presented here relies on ISPAID 7.3. Because this database was developed at Iowa State, it seemed an appropriate place to start a carbon assessment of Iowa State University lands.

The second database is USDA-NRCS Web Soil Survey (Soil Survey Staff, 2014). Web Soil Survey (WSS) is an online mapping tool that allows the user to access various soil properties for a specific location. WSS is sourced from the National Cooperative Soil Survey, uses the Web Mercator coordinate system and like ISPAID, is organized on the soil map unit level. WSS contains the same soil information as the Soil Survey Geographic Database (SSURGO), however WSS’s data is at the SMU level, while SSURGO is at the horizon level. Additionally, SSURGO offers a range for many of their values, such as organic matter, while WSS only includes the ‘representative’ or midpoint value.
**Digital representation of farms**

In order to access the previous two databases with precision, 82 shapefiles – or geo-referenced spatial units – representing ISU’s farms were digitized in ArcMap 10.1 using the North American Datum 1983 coordinate system (Environmental Systems Research Institute, 2013). While there are only 77 farms, five of those farms were divided between two shapefiles, thus bringing the total to 82. The majority of the shapefiles had been previously digitized by Emily Driscoll, Bryan Ott and John Tyndall of the Natural Resource Ecology Management Department at Iowa State (J. Tyndall, personal communication, September 10, 2012). As part of their work the farms had been grouped by county into one shapefile, while the present study broke the farms apart into individual units. Additional ‘new’ farms were digitized using aerial photographs (Iowa State University Geographic Information Systems Support and Research Facility, 2013).

**A note on the term ‘carbon’**

The term ‘carbon’ is used throughout this manuscript as a vague term. It will be used analogously to the biological term ‘behavior’ in the sense that it is a widely used term that has different meanings for different groups.
Carbon data available in Iowa Soil Properties and Interpretations Database

There are two depths for which carbon data is available in ISPAID, 0 to 18 and 0 to 100 cm. For the 0 to 18 cm depth, there are three fields in ISPAID from which organic carbon values can be derived: Organic Matter Range Low, Organic Matter Range High and Organic Matter Midpoint. The first two fields are the low and high values for the percent organic matter range, respectively, while the latter is the midpoint of this range. Within ISPAID, all three fields were determined for the surface 0 to 7 in of soils in cultivation for more than 20 years. For this study, the 7 in depth (7 in = 17.8 cm) was rounded to 18 cm.

For the 0 to 100 cm depth, the Iowa Carbon Index (ICI) is used. Iowa Carbon Index is a 1 to 100 rating scale for mineral SMUs in Iowa that have been in cultivation for the past twenty years. The weight of SOC per cubic meter was found by multiplying percent SOC, bulk density (⅓ bar) and horizon thickness for a given horizon, and then summing these values to a 100 cm depth. The soil map unit with the highest SOC kg m$^{-3}$ – SMU 90, an Okoboji mucky silty clay loam – was given a value of 100 with a conversion factor of 2.2 as shown in Equation 2.1 (Miller et al. 2010b).

(Eq. 2.1) \[ ICI = SOC \ kg \ m^{-3} \times 2.2 \]

It is important to note, the ISPAID manual appears to be inconsistent with its database. Although the manual states that SMU 90, an Okoboji mucky silty clay loam was given an ICI of 100, in the database it has a value of 80. Only one soil series, Blue Earth has an ICI of 100. However, a validation of the 2.2 conversion factor can be found.
in Al-Kaisi, Fenton and others (2012); when SMU 90’s manual-reported ICI, 100, is divided by ISPAID’s conversion factor of 2.2, the resulting SOC value is consistent with the SOC value reported in Al-Kaisi, Fenton and others (2012). This gives evidence to the idea that ISPAID’s SOC values were used according to the methodology stated in the manual (multiplied by 2.2, and set by the ICI of 100), rather than being based on the adjusted index of 80. Therefore, it is likely that the ICI values were adjusted independently of the initial SOC values and that the conversion factor of 2.2 is still applicable.

Although the ICI is conflicting, this study will continue to assume that the 2.2 conversion factor is still valid because ISPAID represents extensive and careful synthesis of 50 years of Iowa soil data, and there is no indication in the manual as to how the ICI was adjusted beyond the original explanation.

No data was available for SIC in ISPAID.

*Carbon data available in Web Soil Survey*

Two fields are available for deriving carbon values from WSS, Organic Matter percentage and Calcium Carbonate percentage. The fields represent the percent on a weight/weight-basis of soil organic matter and calcium carbonate equivalent, respectively, for soil material that is less than 2-mm, (Soil Survey Staff, 2014b).
Determining soil organic carbon using ISPAID in ArcMap 10.1

In order to incorporate geo-referenced soil maps into the farm shapefiles, a polygon shapefile from SSURGO was added to ArcMap (Soil Survey Staff, 2012). Using the geoprocessing tool ‘clip’, SSURGO data was appended to each farm shapefile. ISPAID data was then added to each farm shapefile through a ‘join’ based on the ‘sms’ and ‘MUSYM’ fields, respectively. ISPAID does not contain values for land surfaces mapped as ‘water and quarries’, ‘udorthents’, ‘animal waste lagoon’ and ‘sewage lagoon’. These land surfaces were given values of ‘0’ and incorporated into the carbon estimates.

$\text{SOC kg m}^{-2}$ for 0 to 18 cm depth was calculated with Equation 2.2.

$$\text{(Eq. 2.2) } SOC \text{ kg m}^{-2} = \frac{\text{Organic Matter Midpoint}}{\text{Surface Bulk Density Midpoint}} \times \text{Depth (cm)} \times \frac{0.50 \text{ SOC}}{1.0 \text{ SOM}}$$

Surface Bulk Density Midpoint, a field in ISPAID, was given in g cm$^{-3}$, and is assumed to be for $\frac{1}{3}$ bar and to an 18 cm depth. In the ISPAID manual, all other bulk density measurements are given at $\frac{1}{3}$ bar, and the term ‘surface horizon’ is often used to characterize the surface 0 to 7 in (~18 cm). While these assumptions are logical, they remain inferred rather than cited due to lack of explanation in ISPAID. The resulting SMU SOC kg m$^{-2}$ to 18 cm values were then multiplied by the percent area of each SMU within the farm and summed to achieve a weighted average for the entire farm.

Additionally, the assumption that SOC is equal to 50% of soil organic matter (SOM) is taken from a meta-analysis by Pribyl (2010). There is ambiguity in the scientific community over the correct conversion factor for SOC to SOM. For this study, a
database comparison is still valid regardless of the specific factor used, as long as the conversion is consistent.

\[
SOC \ kg\ m^{-2} \text{ for the 0 to 100 cm depth for each SMU was found with Equation 2.3.}
\]

\[
(Eq. \ 2.3) \ SOC \ kg\ m^{-2} = \frac{ICI}{2.2}
\]

These SOC values were then converted to a weighted average for the farm following the above methods for the 0 to 18 cm depth. The total weights of SOC (kg) for 0 to 18 and 0 to 100 cm depths were found by multiplying the SOC kg m\(^{-2}\) values by SMU area, and then summing these values.

Determining soil organic and inorganic carbon in Web Soil Survey

Web Soil Survey can be used to derive both SOC and SIC values for a chosen depth of interest. In ISPAID, carbon data is only available for the 0 to 18 and 0 to 100 cm depths, thus these were the depths used in WSS. Additionally, WSS offers aggregation options for the different soils within a SMU. This study utilized the ‘dominant component’ option that returns values for the soil series with the greatest area within the SMU. This was chosen because it correlated with ISPAID’s predefined aggregation methods. Web Soil Survey does not include values for land surfaces mapped as ‘water’, ‘orthents’, ‘animal waste lagoon’ and ‘sewage lagoon’. These land surfaces were given values of ‘0’ and incorporated into the carbon estimates.

The first step in assessing WSS’s carbon values was to import, individually, the farm shapefiles as the area of interest. Once defined, SOC kg m\(^{-2}\) for 0 to 18 and 0 to 100
cm depths were determined for each SMU by multiplying Organic Matter percent, Bulk Density (⅓ bar), depth, 0.5 SOC/1.0 SOM and correcting for units. This is similar to Equation 2.2. These SOC values were then multiplied by the percent area of each SMU within the farm and summed to achieve a weighted average for the entire farm.

\[
\text{SIC kg m}^{-2} \text{ for 0 to 18 and 0 to 100 cm depths were determined for each SMU by multiplying Calcium Carbonate percent, Bulk Density (⅓ bar), depth, 0.12 C/1 CaCO}_3 \text{ and correcting for units.}
\]

\[
(\text{Eq. 2.4}) \quad \text{SIC kg m}^{-2} = \frac{\text{Calcium Carbonate } \%}{\text{Bulk Density (g cm}^{-3})} \times \text{ depth (cm)} \times \frac{0.12 \text{ C}}{1 \text{ CaCO}_3}
\]

Carbon represents 12% of the molecular weight of calcium carbonate based on an analysis by Lettens et al. (2004). The resulting SMU SIC kg m\(^{-2}\) to 18 and 100 cm values were then converted to a weighted average for the farm following the above methods for SOC.

The total weight of SOC and SIC for 0 to 18 and 0 to 100 cm depths were determined for each farm following the methodology used for calculating organic carbon from ISPAID. Total carbon was assumed to be the sum of SOC and SIC.

*Creating an ISPAID derived Organic Matter Percentage*

The carbon data available in ISPAID and WSS for a 0 to 100 cm depth are not directly comparable. However, it is possible to compare their relative methodologies.
This was done by regressing ISPAID’s ICI to its organic matter percentage so as to compare to WSS’s organic matter values.

For a given SMU, the ICI was first divided by the conversion factor of 2.2 to find SOC kg m\(^{-3}\). This value was then divided by the Subsoil Bulk Density Midpoint, multiplied by 1.0 SOM/0.5 SOC and corrected for units in order to calculate organic matter percentage. Although no bulk density values for a 0 to 100 cm depth are explicitly stated in the ISPAID manual, bulk density (⅓ bar) values for the ‘subsoil’ are included. These values correlate highly with WSS bulk density values for a 0 to 100 cm depth, although the manual does not directly state to what depth these values are tabulated.

*Determining average and percent difference values*

Once an area-weighted average SOC, SiC and TC kg m\(^{-2}\) for 0 to 18 and 0 to 100 cm depth was determined for each of the farms, an overall farm average was found by summing the individual farm averages and then dividing by the number of farms.

Percent difference between ISPAID and WSS for individual farm SOC, SiC and TC values were determined with Equation 2.6, which illustrates SOC percent different.

\[
\text{(Eq. 2.6)} \quad \% \text{SOC } \Delta = \frac{(\text{ISPAID SOC } \text{kg m}^{-2} - \text{WSS SOC } \text{kg m}^{-2}) \times 100}{\text{ISPAID SOC } \text{kg m}^{-2}}
\]

The overall average percent difference was determined by summing the individual percent differences for each of the farms, and then dividing by the number of farms.
Results and Discussion

SOC, SIC and TC values for 0 to 18 cm depth

There is tremendous variability in the carbon values for Iowa State University’s farms, however, for a 0 to 18 cm depth the averages for the two databases are similar (Figure 2.10). The average farm SOC content for both ISPAID and WSS is 5.6 kg m\(^{-2}\) for the surface 18 cm. The average SIC content for WSS is 0.8 kg m\(^{-2}\), while SIC is indeterminable for ISPAID. Average TC for WSS is 6.0 kg m\(^{-2}\) while ISPAID TC is equal to SOC content because of the absence of SIC values (Table 2.1b).

The farms with the highest SOC content according to ISPAID are Beach Bottom Farm and West Curtiss, each with 7.0 kg m\(^{-2}\) (Table 2.1a). Web Soil Survey ranks Beach Bottom Farm as having the highest SOC content with 7.1 kg m\(^{-2}\). Beach Bottom Farm is located in Story County and is currently being managed as a golf course, as well as a grassed parking lot. Beach Bottom Farm is nearly flat and has alluvial soils with a fine or fine-loamy family particle size classification. The major soils have Cumulic properties, in this case a thickened Mollic epipedon. West Curtiss is also in Story County and is used as research plots for the Iowa State Department of Agronomy. West Curtiss has low slopes and poorly to very poorly drained soils with a fine-loamy texture.

The farm with the lowest average SOC content in the surface 18 cm according to ISPAID is Western Research Farm with 2.9 kg m\(^{-2}\) (Table 2.1a). According to WSS, the lowest SOC content is found at both Western Research Farm and Haas Memorial Research Farm with 2.9 kg m\(^{-2}\). Western Research Farm is located in Monona County in
the Loess Hills and is primarily a reduced tillage cropping system of corn (*Zea mays*), soybeans (*Glycine max*) and alfalfa (*Medicago sativa*). Western Research Farm has a rolling landscape with well-drained soils of which 40% are moderately to severely eroded. Haas Memorial Farm is located in Pottawattamie County and has a cropping rotation of conventional tillage corn and no-till soybean. The majority of the farm landscape is rolling with well drained, loess-formed soils that are moderately to severely eroded.

The farm with the highest SIC content in the surface 18 cm according to WSS is Casey Farm in Boone County with 2.4 kg m$^{-2}$ (Table 2.1a). The majority of Casey Farm is forested and has soils formed in calcareous glacial till. Twenty-four farms had no SIC in the surface 18 cm. The farm with the highest TC is South Woodruff Farm in Story County with 8.7 kg m$^{-2}$ (Table 2.1a). The majority of South Woodruff Farm is in a conventionally tilled corn-soybean rotation with several research plots dedicated to switchgrass. About 40% of the farm is composed of the Canisteo soil series, a calcareous Endoaquoll. The farm with the lowest TC is Muscatine Island Research Farm in Muscatine County with 3.0 kg m$^{-2}$. Muscatine Island Research Farm is primarily used for horticulture crops, has sandy soils and low slopes that are excessively well drained.
Table 2.1a. Farm SOC, SIC and TC (kg m$^{-2}$) for 0 to 18 cm depth for 35 farms. Farm names have been shortened and are listed alphabetically.

<table>
<thead>
<tr>
<th>Farm</th>
<th>County</th>
<th>Area (ha.)</th>
<th>SOC kg m$^{-2}$</th>
<th>SIC kg m$^{-2}$</th>
<th>TC kg m$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allee</td>
<td>Buena Vista</td>
<td>65</td>
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<td>5.9</td>
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</tr>
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</table>
Comparing ISPAID and WSS derived SOC content for 0 to 18 cm depth

The average SOC content for each of the farms is highly correlated between ISPAID and WSS (Figure 2.10). When ISPAID and WSS values were plotted and fitted with a linear regression trendline, the coefficient of determination ($r^2$) is 97% (Figure 2.6). That is, 97% of the variation in ISPAID can be explained by the variation in WSS. Figure 2.7 shows the percent difference between these average SOC values, the mean of which was about 1%, with ISPAID’s values being higher on average. The percent difference ranged from –23% to 17%.

A high percent difference is largely due to variations in reported organic matter percentage for soil complexes. A soil complex is two or more soils or components that are highly mixed or indistinguishable at a SMU scale, and therefore mapped as one SMU (Schaetzl and Anderson, 2005). The highest percent difference in SOC was seen at Casey, Haas, Armstrong, Littlefield and McDonald farms. The SMU on each of these farms that had the highest variability in organic matter content is a soil complex. Organic matter values diverged because each component, or soil, in the complex has been weighted differently depending on the database.

<table>
<thead>
<tr>
<th></th>
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<th>WSS (kg m$^{-2}$)</th>
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</thead>
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<td>SOC</td>
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<td>Median</td>
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Table 2.1b. Summary statistics for all 82 farms for 0 to 18 cm depth.
Figure 2.5. The farms with the highest TC, SOC and SIC, as well as the lowest TC and SOC for 0 to 18 cm and 0 to 100 cm depth. Twenty-four farms had no SIC (lowest SIC), but are not included in this map.
Figure 2.6. Comparison of SOC (kg m$^{-2}$) for 0 to 18 cm depth for each of the farms according to ISPAID and WSS.

Figure 2.7. Percent difference in farm SOC (kg m$^{-2}$) for 0 to 18 cm depth when comparing ISPAID and WSS values. Farms with a high percent difference have been named.
In ISPAID, all components in a soil complex are given equal weight (T.E. Fenton, personal communication, June 4, 2014). In WSS only the component with the highest percent composition is represented. Web Soil Survey has options for weighing each component in a soil complex, but there is not an ISPAID-equivalent option that weighs the components equally. Because ISPAID’s aggregation methods are predetermined and WSS’s are not, this study chose to mimic ISPAID’s aggregation methods. However, ISPAID’s aggregation methods are not consistent between soil complex SMUs and consociation SMUs; each component in a soil complex is weighted equally while in consociation SMU only the component with the highest percent composition is represented. Because the majority of SMUs on ISU farms are consociation SMUs, and recalling that there is no option in WSS to weigh components equally, this study chose to mimic the latter aggregation option and represent only the component within the SMU with the highest percent composition for all SMUs.

Using an example from Casey Farm – the Spillville-Buckney complex – in both databases Spillville has an organic matter percentage of 4.5% and Buckney has a value of 2.0%. In ISPAID, since each component is given equal weight, the complex will have an organic matter percentage of 3.0% when rounded. In WSS, only the component with the highest percent composition within the SMU is represented – in this case Spillville – therefore the complex will have an organic matter percentage of 4.5%. For a consociation SMU such as 507 of the Canisteo soil series, in both databases only the component with the highest percent composition will be represented. This means that SMU 507, which is composed of 95% Canisteo with 6.5% organic matter, and 5% Okoboji
with 10.5% organic matter, will have an overall organic matter of 6.5% for both databases. Therefore, while ISPAID and WSS’s aggregation methods are comparable for consociation SMU’s, they are not directly comparable for soil complexes.

It should also be noted that SMU 11B has three different soil complexes attached to it, Ackmore-Colo-Judson, Colo-Judson, and Colo-Ely. This reflects a “simplicity rule” in soil survey that has been passed down to the two databases.

*SOC, SIC and TC values for 0 to 100 cm depth*

The average farm SOC content for a 0 to 100 cm depth for WSS is 19.5 kg m$^{-2}$, and 15.8 kg m$^{-2}$ for ISPAID (Table 2.2b, Figure 2.10). For WSS, the average SIC and TC content is 8.6 kg m$^{-2}$ and 27.8 kg m$^{-2}$, respectively. In regards to cumulative totals for a 0 to 100 cm depth, ISU’s soils contain 1,113,025,212 kg of SOC, 418,590,565 kg of SIC and 1,531,615,777 kg of TC according to WSS. Iowa State University’s cumulative total, as tabulated by ISPAID, is 957,739,419 kg of SOC. Again, in ISPAID, TC is equal to SOC since SIC values are indeterminable. In order to put these numbers in perspective, for fiscal year 2014 Iowa State University estimates their campus carbon dioxide equivalent emissions to be 505,248 tons (J.D. Witt, personal communication, August 22, 2014). When comparing WSS’s TC value and campus emissions, the carbon stocks of ISU are equivalent to over 12 years of campus emissions.
### Table 2.2a. Farm SOC, SIC and TC (kg m\(^{-2}\)) for 0 to 100 cm depth for 35 farms.

Farm names have been shortened and are listed alphabetically.

<table>
<thead>
<tr>
<th>Farm</th>
<th>County</th>
<th>Area (ha.)</th>
<th>SOC kg m(^{-2})</th>
<th>SIC kg m(^{-2})</th>
<th>TC kg m(^{-2})</th>
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Figure 2.8. Comparison of SOC \((\text{kg m}^{-2})\) for 0 to 100 cm depth for each of the farms according to ISPAID and WSS.

Figure 2.9. Percent difference in farm SOC \((\text{kg m}^{-2})\) for 0 to 100 cm depth when comparing ISPAID and WSS. Farms with a high percent difference have been named.
Table 2.2b. Summary statistics for all 82 farms for 0 to 100 cm depth.

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<tr>
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<td>20.1</td>
</tr>
</tbody>
</table>

Figure 2.10. Average SOC (kg m\(^{-2}\)) for 0 to 18 and 0 to 100 cm depth for both ISPAID and WSS.
The farm with the highest SOC content for a 0 to 100 cm according to both ISPAID and WSS is Beach Bottom Farm with 25.2 kg m\(^{-2}\) and 34.2 kg m\(^{-2}\), respectively (Table 2.2a). The lowest SOC content is found at Muscatine Island Research Farm with 4.6 kg m\(^{-2}\) according to ISPAID, and Western Research Farm with 7.9 kg m\(^{-2}\) according to WSS. Not surprisingly, these findings are consistent with earlier SOC and TC findings for the surface 18 cm (Table 2.1) and thus a discussion of the site characteristics and soil attributes of these farms can be found in earlier sections.

Web Soil Survey found that Kelley Farm in Boone County has the highest SIC content with 18.1 kg m\(^{-2}\) (Table 2.2a). The majority of Kelley Farm is in a conventional tillage corn-soybean rotation, and has calcareous Aquolls such as the Canisteo and Harps soil series. Twelve farms had no SIC for a 0 to 100 cm depth. The farm with the highest TC is Northern Research Farm in Hancock County with 40.9 kg m\(^{-2}\). The majority of Northern Research Farm is nearly flat and conventionally tilled with a corn-soybean rotation. Canisteo, again is the primary soil series found at Northern Research Farm, along with the Clarion-Nicollet-Webster soil association, the most common soils on the Des Moines lobe. The farm with the lowest TC, similarly to the 0 to 18 cm depth, is Muscatine Island Research Farm with 9.6 kg m\(^{-2}\). A listing of farms and their SOC, SIC and TC contents for a 0 to 100 cm depth can be found at Table 2.2a.
Comparing ISPAID and WSS derived SOC content for 0 to 100 cm depth

There was a substantial difference when comparing average farm SOC for a 0 to 100 cm depth for ISPAID and WSS (Figure 2.10). Figure 2.8 illustrates these SOC values plotted with a linear regression trendline of which the coefficient of determination was 67%. The percent difference ranged from –109 to 32%, with ISPAID values being, on average, about 24% lower than WSS values (Figure 2.9).

Determining the source of this variation is problematic. While ISPAID and WSS’s organic matter and bulk density values are directly comparable for the surface 18 cm, those properties are not available in ISPAID for 0 to 100 cm depth. Instead, ISPAID’s organic matter values are expressed as the Iowa Carbon Index, and no bulk density values are explicitly stated.

The two farms that represent the endpoints of the percent difference range are Muscatine Island Research Farm with ISPAID SOC values that are, on average, 109% lower than WSS values, and Western Research Farm which has values that are, on average, 32% higher than WSS values. It is of note that both Muscatine Island Research Farm and Western Research Farm both have low SOC kg m\(^{-2}\) values when compared to the overall farm averages. This can cause the percent difference between the two databases to be overstated. According to ISPAID, the overall farm average is 15.8 while at Muscatine Island Research Farm and Western Research Farm it is 4.6 and 11.6, respectively. WSS reports that the overall farm SOC average is 19.5, compared to 9.6 and 7.9 at Muscatine Island Research Farm and Western Research Farm, respectively.
The vertical distribution of SIC and SOC

According to ISPAID, on average, 35% of SOC is found in the surface 18 cm when compared to the 18 to 100 cm depth. In comparison, WSS found that 29% of SOC is found in the surface 18 cm (Figure 2.11). When SOC and SIC are compared as a proportion of TC, WSS found that 69% of TC is SOC, while 31% is SIC (Figure 2.12).

**Figure 2.11.** Comparison of the average farm SOC (kg m\(^{-2}\)) for both ISPAID and WSS for 0 to 18 cm and 18 to 100 cm depth.

**Figure 2.12.** Comparison of the average farm SOC and SIC (kg m\(^{-2}\)) for 0 to 100 cm depth.
Creating a WSS derived ICI, and an ISPAID derived Organic Matter Percentage

Although organic matter and bulk density values are not directly comparable across the databases for the 0 to 100 cm depth an indirect comparison can be made. This was done by regressing the ISPAID ICI to its organic matter percentage so as to compare to WSS values. Table 2.3 is a comparison of organic matter values and bulk density values for 10 of the largest SMUs by area on the farms. Although these SMUs are a subset of the full dataset, they do point to some overall trends; bulk densities vary minimally while organic matter values vary drastically between the two databases.

Table 2.3. Average bulk density (g cm\(^{-3}\)), percent organic matter and the percent difference for both bulk density and percent organic matter for ISPAID and WSS.

<table>
<thead>
<tr>
<th>SMU(^*)</th>
<th>Series</th>
<th>ISPAID</th>
<th>WSS</th>
<th>ISPAID</th>
<th>WSS</th>
<th>% Bulk Density Δ</th>
<th>% Organic Matter Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>138C2(^†)</td>
<td>Clarion</td>
<td>1.6</td>
<td>1.5</td>
<td>1.3</td>
<td>1.2</td>
<td>9.4</td>
<td>2.4</td>
</tr>
<tr>
<td>507</td>
<td>Canisteo</td>
<td>1.4</td>
<td>1.4</td>
<td>2.3</td>
<td>4.1</td>
<td>4.2</td>
<td>77.4</td>
</tr>
<tr>
<td>107(^†)</td>
<td>Webster</td>
<td>1.5</td>
<td>1.4</td>
<td>2.8</td>
<td>4.5</td>
<td>1.4</td>
<td>61.3</td>
</tr>
<tr>
<td>55(^†)</td>
<td>Nicollet</td>
<td>1.3</td>
<td>1.3</td>
<td>2.4</td>
<td>2.8</td>
<td>2.3</td>
<td>12.4</td>
</tr>
<tr>
<td>162E</td>
<td>Downs</td>
<td>1.3</td>
<td>1.3</td>
<td>1.4</td>
<td>0.9</td>
<td>0.8</td>
<td>32.7</td>
</tr>
<tr>
<td>95</td>
<td>Harps</td>
<td>1.5</td>
<td>1.4</td>
<td>2.6</td>
<td>3.5</td>
<td>2.1</td>
<td>33.7</td>
</tr>
<tr>
<td>163B(^‡)</td>
<td>Fayette</td>
<td>1.4</td>
<td>1.4</td>
<td>1.3</td>
<td>1.1</td>
<td>1.4</td>
<td>16.5</td>
</tr>
<tr>
<td>135(^‡)</td>
<td>Coland</td>
<td>1.5</td>
<td>1.5</td>
<td>3.3</td>
<td>5.0</td>
<td>0.0</td>
<td>50.2</td>
</tr>
<tr>
<td>222D2(^§)</td>
<td>Clarinda</td>
<td>1.5</td>
<td>1.6</td>
<td>1.2</td>
<td>1.0</td>
<td>2.0</td>
<td>16.7</td>
</tr>
<tr>
<td>10C2(^¶)</td>
<td>Monona</td>
<td>1.3</td>
<td>1.3</td>
<td>1.4</td>
<td>1.1</td>
<td>0.0</td>
<td>22.0</td>
</tr>
</tbody>
</table>

\(^*\) Some SMUs in WSS have different percent organic matter depending on the county that SMU is mapped in - for those SMUs, the county that the data is from was included.
\(^†\) Story, \(^‡\) Delaware, \(^§\) Lucas, \(^¶\) Monona
Conclusion

Soil organic carbon, SIC and TC were estimated for Iowa State University’s 6,392 hectares of farmland, using WSS, for the 0 to 18 cm and 0 to 100 cm depth. According to WSS, ISU’s farmland contains 1,113,025,212 kg of SOC, 418,590,565 kg of SIC and 1,531,615,777 kg of TC in the top 100 cm of soil. Soil organic carbon was additionally quantified using ISPAID, although SIC data was unavailable and consequently, TC was indeterminable. ISPAID found that ISU’s farmland, in the top 100 cm, contains 957,739,419 kg of SOC.

Because of the limited carbon parameters, depth increments and transparent methodologies available in ISPAID, WSS is preferred for any future carbon inventories. While databases offer a centrally-located, unified and simplified dataset, inherent in any database is a multitude of assumptions that have been used to populate it. In order to better represent database-derived results, these assumptions, or methodologies, should continue to be rigorously investigated and their limitations openly acknowledged.
CHAPTER 3: A USER-FRIENDLY EQUATION FOR SOIL ORGANIC CARBON SEQUESTRATION IN THE MIDWEST, USA

Catherine R. DeLong and C. Lee Burras

A paper to be submitted to Soil Horizons.

Introduction

Globally, the soil is the second largest pool of carbon after the world’s oceans, but the potential for carbon to be gained in the soil is also great, particularly on agricultural land where soil carbon has already been diminished (Stockmann et al., 2013). It is estimated that with ‘best management practices’ 75 to 200 million additional tons of carbon can be sequestered each year by US agriculture – making the soil a significant atmospheric carbon sink (Soil Science Society of America, 2001). Land managers are interested in increasing the carbon content of their land because of the positive role that carbon plays in soil quality and erosion control. However, in this era of precision agriculture, land managers often want to target their conservation practices to the land tracts that have the highest potential to gain carbon. In order to assist them, we created a simple, semi-quantitative equation to estimate potential soil organic carbon (SOC) gain based on four easily-accessible soil and landscape parameters. Our hope, in making the equation parameters easily accessible is that a non-academic audience, such as land managers or other land grant universities will be able to use this equation to focus their conservation efforts.
Site description

In order to evaluate the equation, it was applied to Iowa State University's 82 tracts of land or 'farms'. The majority of the farms are located on or near the campus in Story and Boone Counties, however there are 17 outlying farms in 16 counties scattered across the state (Figure 3.1). The farms cover a spectrum of land management schemes from crop production to pasture, but can generally described as 55% cropped, 31% grasslands and 14% forest (M. Honeyman, personal communication, September 12, 2012).

In Iowa, the mean annual precipitation from 1983 to 2013 is 835 mm, while mean annual temperature for the same period is 9°C (Iowa Environmental Mesonet, 2014). The majority of the state is mantled in geologically young glacial and wind-blown deposits such as drift and loess, respectively (Ruhe, 1969). Two-thirds of the state, and the majority of Iowa State's farms, are classified in the Mollisols Order of Soil Taxonomy. (Miller et al., 2010a; Figure 3.2).
Figure 3.1. Map of Iowa with ISU farms highlighted in orange and ISU campus represented with a yellow star.

Figure 3.2. Distribution of Mollisols in Iowa.
Equation limitations and parameters

Our equation is similar to the Universal Soil Loss Equation (USLE) in that it is a multiplicative equation based on specific parameters that is designed to assist landowners in conservation planning. However, unlike USLE, our equation loosely weighs the relative impact of each parameter for SOC sequestration with no intention of giving a verifiable empirical outcome. The goal was simply to create a hierarchy among land tracts addressing which are the most likely to sequester carbon under a variety of land uses.

The theoretical framework on which the equation is based asserts that a soil that has the least SOC also has the greatest potential to gain and sequester SOC. In this sense, we do not directly address the concept of pedological limitations. Instead, we assume that the precipitation, temperature and mineralogy across Iowa are sufficiently uninform and therefore need not be distinguished in our equation. However, these topics are indirectly addressed with the inclusion of drainage and soil taxonomic class. The concept of carbon saturation introduced by Hassink and Whitmore (1997) and furthered by Six et al. (2002) is also not incorporated; although a soil carbon saturation point may exist, this limit remains ill-defined.

The equation estimates the maximum possible SOC sequestration for a 0 to 100 cm depth, and is limited to the Midwest, USA. The equation is also restricted to a 30 year timespan in acknowledgement of a possible soil carbon steady state. Soil carbon fractions can have a turnover rate that ranges from 1 to 1,500 years, yet many
researchers have found that following a change in management soil carbon does reach a steady state (Mann, 1986; Parton et al., 1987; Kern and Johnson, 1993; Paustian et al., 1997). Conversion from current management to an unharvested perennial grass such as switchgrass (*Panicum virgatum* L) is also assumed. Numerous studies have shown the high carbon sequestration potential of switchgrass in the Midwest, USA, and our equation is therefore estimating the maximum SOC that each land tract can potentially gain (Burras and McLaughlin, 2002; Lee et al., 2007; Liebig et al., 2008).

The equation has four parameters: *current management, slope, drainage class* and *taxonomic Great Group* (Table 3.1). While *current management* is known by the land manager, the other three parameters can be found in the USDA-NRCS’s Web Soil Survey, a free, online mapping program that is targeted to a non-technical audience. These parameters were chosen because past research has demonstrated that each, individually, is correlated with SOC content, and a study by Tan et al. (2004) in Ohio, USA found that all four parameters are highly correlated \((p<0.001)\) with SOC content. A more detailed discussion of each parameter and its relationship with SOC is found subsequently.

Each parameter has three to five gradations. For example, the *current management* parameter has three gradations, *crop, grass and forest*, and there is a factor attached to each gradation (Table 3.1a). The factors assigned to these gradations are arbitrary and only relevant in comparison to the other gradation factors. Factors are assigned in order to give the most weight to the parameter with the greatest potential
to affect SOC. For example, the highest factor in current management is 1.4 while the highest factor in both slope and drainage class is 1.2, thus assuming that current management will have a stronger effect on SOC than either slope or drainage class. The product of the four parameter factors is the SOC sequestration factor (Equation 3.1).

Although the SOC sequestration factor should primarily be used to weigh the sequestration potential of various land tracts against each other, it can also be multiplied by the current SOC kg m\(^{-3}\) in order to estimate SOC kg m\(^{-3}\) after 30 years of perennial grass management (Equation 3.2).

(Eq. 3.1) \[ \text{Current Management} \times \text{Slope Gradient} \times \text{Drainage Class} \times \text{Taxonomic Class} = \text{SOC Sequestration Factor} \]

(Eq. 3.2) \[ \text{SOC Sequestration Factor} \times \text{Current SOC kg m}^{-3} = \text{Estimated SOC kg m}^{-3} \]

Tables 3.1. Parameters, parameter gradations and accompanying factors for SOC equation.

<table>
<thead>
<tr>
<th>a) Current Management</th>
<th>b) Slope Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>Forest</td>
</tr>
<tr>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>1.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c) Drainage Class</th>
<th>d) Taxonomic Great Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poorly</td>
<td>Somewhat Poorly</td>
</tr>
<tr>
<td>1.0</td>
<td>1.05</td>
</tr>
<tr>
<td>Endoquolls</td>
<td>Argiudolls</td>
</tr>
<tr>
<td>1.0</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Current management on the farms is divided into crops, grass and forest with crops having the highest SOC gain potential followed by forest and grass (Table 3.1a). These broad delineations were chosen for three reasons: the mosaic-layout of ISU’s research plots and farms, precedent in previous carbon sequestration studies (Liu et al., 2011; Houghton and Hackler, 2000; Tan et al., 2004; West et al., 2010) and ease and accessibility of these categories given ISU’s previous delineations (M. Honeyman, personal communication, September 12, 2012). The equation assumes a uniform cultivation history for the farms considering that the majority of Iowa’s land has been in cultivation for over 100 years (Morain and Miles, 1986). Above ground biomass such as crops, trees, and organic matter rich O horizons are not included in the assessment. Although ISU farms do include Alfisols, or forest-derived soils, these soils do not contain an O horizon.

The second factor is based on slope gradient. Slope gradient is divided into low (< 2.9%), medium (3 to 5.9%) and high (> 6%), with high having the highest potential for SOC sequestration (Table 3.1b). Many studies have shown a negative correlation with slope gradient and organic carbon; given a static set of soil properties including management, the higher the slope the more prone it is to loss of SOC by erosion (Walker and Ruhe, 1968; Vreeken, 1973; Wang et al., 2010). The equation, therefore, assumes that the higher the slope the more potential it has to regain and sequester carbon. Considering that there are several SMUs on each farm, and consequently several slope gradients, the gradient that covered the most area was chosen to
represent each farm. This areal method was also used to choose a representative drainage and soil taxonomic class for each of the farms.

The third factor is soil drainage class. Soil drainage class is an estimate of the “frequency and duration of wet periods” under natural conditions with excessively drained having the driest conditions followed by somewhat excessively, well, moderately well, somewhat poorly and poorly (Soil Survey Staff, 1993). Numerous studies have linked SOC and drainage class, and have found that at the hillslope-level, excessively well drained soils tend to have the least SOC, while poorly drained soils tend to have the most (Davidson, 1995; Trumbore and Harden, 1997; Rapalee et al., 1997; Tan et al., 2004). The equation therefore assumes that well drained soils – having less organic matter than poorly drained soils – have a greater potential to gain and sequester carbon.

Any discussion of drainage class in Iowa, however, is incomplete without the inclusion of artificial drainage, or tiling. Considering Iowa’s extensive tiling history, the equation assumes that all of ISU’s farms are artificially drained and will continue to be drained for the next 30 years (Iowa Drainage District Association, 2014). The use of artificial drainage, however, does not invalidate drainage classes according to studies completed in central Iowa (James and Fenton, 1993; Khan and Fenton, 1994). Khan and Fenton (1994) analyzed two catenas, or hillslopes, in Central Iowa – one with artificial drainage, and the other without – and found that along both, organic carbon increased systematically from well to poorly drained soils in the surface 30 cm. Consequently, it is
still a reasonable assumption that well drained soils will have a greater potential to gain SOC than poorly drained soils.

The fourth and last factor, *taxonomic Great Group*, asserts that soils have the greatest potential to sequester carbon when converted to perennial grasses in the following order:

\[ \text{Hapludalfs} > \text{Hapludolls} > \text{Argiudolls} > \text{Endoaquolls} \]

Endoaquolls, soils of the Mollisols Order of Soil Taxonomy, have the least potential to sequester SOC. Endoaquolls are characterized by having aquic conditions – continuous or periodic saturation and reduction – at some point during a normal year (Soil Survey Staff, 2006). Similarly to the rationale for poorly drained soils, Endoaquolls will have a low SOC sequestration potential because of their high initial SOC content. Considering that SOC sequestration is the results of greater carbon inputs than outputs, Endoaquolls will have a high initial SOC content due to the decreased rate of carbon oxidation and decomposition under wet conditions (Amundson, 2001). Secondly, Argiudolls will have the second lowest SOC sequestration potential. Argiudolls are characterized by an argillic horizon, or a horizon with a higher percentage of illuviated clay (Soil Survey Staff, 1999). Clay content has been positively linked to SOC content in the Midwest and beyond, and from this we assume that Argiudolls will have a higher initial carbon content than a Hapludolls and therefore less potential to gain carbon (Vreeken, 1973; Oades, 1988; Tan et al., 2004) Lastly, on ISU’s farms the Alfisols soil series such as Downs, Hayden and Lester tend to have less organic carbon in the top 100 cm than
Mollisols such as Clarion, Nicollet and Webster. Additionally, previous studies in Iowa found that many Alfisols are simply eroded Mollisols that have been reclassified (Kimble et al., 2001; Burras and McLaughlin, 2002). Therefore, it seems logical that Alfisols planted to perennial grass will have a higher potential of gaining carbon than Mollisols since they have a lower initial value.

_Evaluating carbon modeling tools_

Before deciding to create a carbon sequestration equation we assessed several pre-existing carbon models. The main goal in our search was to find a user-friendly model that a non-technical audience, such as a landowner, could also use. Our first attempt utilized COMET-Farm, a free, online tool created through the collaboration of the USDA-NRCS and Colorado State University (Natural Resource Ecology Management, Colorado State University, 2014). COMET-Farm is described as a ‘convenient yet rigorous’ tool that allows farmers and ranchers to estimate carbon sequestration on their land.

Several problems, however, led us to disregard COMET-Farm as a viable option in our study. To begin with, the results are given in tonnes per year of atmospheric greenhouse gas emissions. While atmospheric units can be converted to terrestrial units, there is not a universally agreed upon conversion, and COMET-Farm does not recommend one. Additionally, COMET-Farm does not state a depth of interest for their calculations, and without this information the user is unable to convert atmospheric units to terrestrial units. Lastly, in attempting to assess the SOC benefits of planting a
perennial grass, the tool only allows you to leave a perennial unharvested for two years. There is an option to register land with the Conservation Reserve Program, but the option is not available beyond the year 2000.

We also evaluated popular carbon tools such as the CENTURY Model 4.0 (Natural Resource Ecology Management, Colorado State University, 2000), the Rothamsted Carbon Model (Rothamsted Research 2014) and APSIM 7.6 (APSIM Initiative 2014), all of which were found to be highly technical and targeted to specialists and academics. For this reason, they were also disregarded as viable options given our goal of simplicity and ease of use.

Results and Discussion

The equation estimates that over 30 years Iowa State University’s SOC could increase, on average, by about 35% if all management were converted to perennial grasses. As quantified by DeLong (2014), ISU’s farmland currently holds 1,113,025,212 kg of SOC to a depth of 100 cm, and an increase of 35% would mean the addition of 389,558,824 kg of SOC. In order to put this number in perspective, for fiscal year 2014 Iowa State University estimates their campus carbon dioxide equivalent emissions to be 505,248 tons (J.D. Witt, personal communication, August 22, 2014). The SOC gained through conversion to perennial management would then offset campus emissions for over three years.
The farm with the lowest SOC sequestration potential is Beach Bottom Farm in Story County (Table 3.2). Beach Bottom Farm is managed entirely in grass, has low slopes and poorly drained soils. The majority of soils are Endoaquolls such as the Coland and Zook soil series. Given that Beach Bottom Farm in currently managed entirely in grass, our equation predicts that SOC levels would remain static if management remains unchanged over the next 30 years. Generally, farms with a low SOC sequestration potential tended to be managed entirely in grass and have low slopes.

The farm with the highest SOC sequestration potential is Haas Memorial Farm in Pottawattamie County (Table 3.2). The farm, according to our equation, has the potential to double its SOC. Haas Memorial Farm is entirely cropped, has moderate slope gradients and is mainly comprised of well drained Hapludolls such as the Monona soil series. The majority of farms with a high SOC sequestration factor were managed in forest or crops and had moderate to high slopes.
Table 3.2. Twenty-five farms with their management, slope, drainage, taxonomic and the resulting SOC sequestration factor. Current SOC kg m\(^{-3}\), predicted SOC kg m\(^{-3}\) and percent change after 30 years of perennial grass are also included.

<table>
<thead>
<tr>
<th>Farm</th>
<th>County</th>
<th>Area (ha.)</th>
<th>Management Factor</th>
<th>Slope Factor</th>
<th>Drainage Factor</th>
<th>Tax. Factor</th>
<th>C Seq. Factor</th>
<th>Current SOC kg m(^{-3})</th>
<th>Predicted SOC kg m(^{-3})</th>
<th>% Change Cur. vs. Pred. SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allee</td>
<td>Buena Vista</td>
<td>65</td>
<td>1.4</td>
<td>1</td>
<td>1.05</td>
<td>1.10</td>
<td>1.6</td>
<td>24.1</td>
<td>38.6</td>
<td>37.5</td>
</tr>
<tr>
<td>Armstrong</td>
<td>Pottawattamie</td>
<td>162</td>
<td>1.3</td>
<td>1.1</td>
<td>1.15</td>
<td>1.10</td>
<td>1.8</td>
<td>10.9</td>
<td>19.6</td>
<td>44.4</td>
</tr>
<tr>
<td>Baird</td>
<td>Jasper</td>
<td>92</td>
<td>1.4</td>
<td>1</td>
<td>1.15</td>
<td>1.05</td>
<td>1.7</td>
<td>14.9</td>
<td>25.3</td>
<td>41.2</td>
</tr>
<tr>
<td>Beach</td>
<td>Story</td>
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<td>1</td>
<td>1.00</td>
<td>1.0</td>
<td>1.0</td>
<td>34.2</td>
<td>34.2</td>
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<td>1.2</td>
<td>1.15</td>
<td>1.15</td>
<td>1.9</td>
<td>10.4</td>
<td>19.8</td>
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<td>Casey</td>
<td>Boone</td>
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<td>1.2</td>
<td>1.1</td>
<td>1.05</td>
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<td>42.8</td>
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<td>Dairy</td>
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<td>36.5</td>
<td>33.3</td>
</tr>
<tr>
<td>Finch</td>
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<td>1</td>
<td>1.0</td>
<td>1.10</td>
<td>1.5</td>
<td>24.7</td>
<td>37.1</td>
<td>33.3</td>
</tr>
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<td>Haas</td>
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<td>11.0</td>
<td>22.0</td>
<td>50.0</td>
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<tr>
<td>Johannes</td>
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<td>1.4</td>
<td>21.7</td>
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<td>44.4</td>
</tr>
<tr>
<td>Johnson</td>
<td>Story</td>
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<td>1.3</td>
<td>1</td>
<td>1.05</td>
<td>1.10</td>
<td>1.5</td>
<td>20.7</td>
<td>31.1</td>
<td>33.3</td>
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<tr>
<td>Kelley</td>
<td>Boone</td>
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<td>1</td>
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<td>1.5</td>
<td>19.7</td>
<td>29.6</td>
<td>33.3</td>
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<tr>
<td>McNay</td>
<td>Lucas</td>
<td>796</td>
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<td>1.2</td>
<td>1.05</td>
<td>1.05</td>
<td>1.5</td>
<td>11.5</td>
<td>17.3</td>
<td>33.3</td>
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<td>Muscatine</td>
<td>Muscatine</td>
<td>43</td>
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<td>1.2</td>
<td>1.10</td>
<td>1.8</td>
<td>9.6</td>
<td>17.3</td>
<td>44.4</td>
</tr>
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<td>Neely-Kinyon</td>
<td>Adair</td>
<td>65</td>
<td>1.2</td>
<td>1.1</td>
<td>1.05</td>
<td>1.05</td>
<td>1.4</td>
<td>15.2</td>
<td>21.3</td>
<td>28.6</td>
</tr>
<tr>
<td>Northeast</td>
<td>Floyd</td>
<td>105</td>
<td>1.3</td>
<td>1.1</td>
<td>1.05</td>
<td>1.10</td>
<td>1.7</td>
<td>20.8</td>
<td>35.4</td>
<td>41.2</td>
</tr>
<tr>
<td>Northern</td>
<td>Hancock</td>
<td>70</td>
<td>1.3</td>
<td>1</td>
<td>1.05</td>
<td>1.10</td>
<td>1.5</td>
<td>26.8</td>
<td>40.2</td>
<td>33.3</td>
</tr>
<tr>
<td>Packer</td>
<td>Story</td>
<td>16</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.05</td>
<td>1.5</td>
<td>18.9</td>
<td>28.4</td>
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<td>Monona</td>
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<td>1.2</td>
<td>1.15</td>
<td>1.05</td>
<td>1.7</td>
<td>7.9</td>
<td>13.4</td>
<td>41.2</td>
</tr>
</tbody>
</table>
Figure 3.3. SOC sequestration potential of 19 of ISU’s farms. The key on the left is the SOC Sequestration Factor. The higher the Sequestration Factor, the more potential the farm has to gain SOC if converted to perennial grass.
Is it possible for Haas Memorial Farm to double its SOC content? While numerous sources have stated that since agricultural cultivation soils have lost 50% of their SOC, is it possible to regain that amount in 30 years (Haas et al., 1957; Huggins et al., 1998; Lal, 1999; Guo and Gifford, 2002)? This is a difficult question to answer given that the majority of cultivated-to-grassland sequestration studies (and carbon sequestration studies generally) in the Midwest do not evaluate beyond the 30 cm depth (Burke et al., 1989; Knops and Tilman, 2000; Al-Kaisi et al., 2005; McLaughlan et al., 2006) However, a study by Burras and McLaughlin (2002) in Southern Iowa found that switchgrass fields that had been planted for 3 to 14 years had a mean carbon sequestration rate of 0.34 kg m$^{-2}$ yr$^{-1}$ to a 100 cm depth. According to our equation, and assuming a linear SOC sequestration rate, Haas Memorial Farm – the farm with the highest potential sequestration rate – would have a mean SOC sequestration rate of 0.37 kg m$^{-3}$ yr$^{-1}$.

While the Burras and McLaughlin (2002) rate correlates with the carbon sequestration rate predicted by our equation, other studies have found more divergent results. At the lower end, Gebhart et al. (1994) estimated that perennial grasses at three Conservation Reserve Program sites in Texas, Kansas and Nebraska had a mean SOC sequestration rate of 0.11 kg m$^{-2}$ yr$^{-1}$ to a 300 cm depth. Liebig et al. (2008) found a mean sequestration rate of 0.29 kg m$^{-2}$ yr$^{-1}$ to a 120 cm depth after a cropped field had been converted to switchgrass for 5 years at sites in North Dakota, South Dakota and Nebraska. And at the higher end, Lee et al. (2007) examined two switchgrass fields in South Dakota that had been fertilized with different forms of nitrogen, and measured
SOC sequestration rates of 0.24 and 0.40 kg m\(^{-2}\) yr\(^{-1}\) to a 90 cm depth. While carbon sequestration rates are variable across the High Plains region of the US, the highest rate that our equation predicts falls within the observed results of other studies, and therefore seems a reasonable approximation.

Carbon sequestration rates do not remain static over time and many researchers have found that, given a change in management, soil carbon can eventually reach a steady state (Mann, 1986, Kern and Johnson, 1993; Paustian, 1997). It is therefore possible that carbon sequestration rates found by the above studies – over 3 to 14 years – are higher (or possibly lower) than what would have been found after several decades. The majority of studies, however, that advocate for a steady state have only analyzed the surface layers of the soil profile. Other studies that examined soil carbon dynamic to a meter depth on decadal time scales have found that soil development remains in flux and that SOC continues to be gained (David et al., 2009; Veenstra, 2010; Chendev et al., 2012). Given that so few studies analyze to a meter depth, and our knowledge of carbon dynamics at that depth interval remains incomplete, our results are speculative, but reasonable.
Conclusion

The objective of this paper was to create a user-friendly equation that weighs the SOC potential of various land tracts. In this way, landowners and managers that are outside the realm of academia will be able to use the equation to focus their conservation measures on the tracts of land that are most likely to respond to their efforts. The equation, when applied to the farmland of Iowa State University, estimates that after 30 years of perennial grass management SOC could increase by 35% on average. No independent verification is available for this statement given the complexity of soils and land uses that we are considering. However, the range of sequestration rates that our equation predicts have been corroborated in previous field studies in the Midwest. Of course, it is unlikely that Iowa State University’s land will be uniformly converted to perennial grass, but an upper limit has now been set. The equation also estimates that the potential SOC gain of the farms ranged from 0 to 100%. With this range of potential impact, we are confident that landowners will be able to use this equation to assess the SOC sequestration potential of their various land tracts, and then target the tracts that are most likely to respond to management changes.
CHAPTER 4:
PROFILE VARIABILITY WITHIN ONE SMU POLYGON, 362 OF THE HAIG SOIL SERIES, McNAY MEMORIAL RESEARCH FARM, IOWA

Catherine R. DeLong, C. Lee Burras and Jennifer L. Richter

A paper to be submitted to Journal TBD.

Introduction

The soil-landscape paradigm, the concept that directs modern soil survey, assumes that one can draw conclusions about the soil by observing the landscape (Zhu et al., 2001). The paradigm also rests on the idea that a soil in which all five soil-forming factors – parent material, biota, topography, climate and time – are the same will be more alike than one with different soil forming factors (Hudson, 1992). With these ideas in mind, soil survey has broken apart the soil continuum into soil map units (SMU) with the assumption that pedons within a SMU are similar (Soil Survey 1999). In this chapter, these assertions will be tested through a case study of a single SMU polygon. Here, we intend to test the following hypotheses:

\( H_0 \) Profiles within a single SMU polygon are comparable.

\( H_{A1} \) Profiles within a single SMU polygon vary proportionally with land use type.

\( H_{A2} \) Profiles within a single SMU polygon vary, but in an unpredictable manner.
Materials and Methods

Soil sampling

Five soil cores were taken at the northeast intersection of 170th Avenue and 450th St. at the McNay Memorial Research Farm in Chariton, Iowa (Table 4.1). All soil cores were taken at SMU 362 of the Haig soil series. Haig, a fine, smectitic, mesic Vertic Argiaquoll, is the major component of the SMU occupying 90%. The minor component is the Edina soil series, a fine, smectitic, mesic Vertic Argialbolls comprising 10% (Soil Survey Staff, 2014b). Soil cores were taken to a minimum 120 cm depth with a truck-mounted hydraulic soil probe using a 150 cm long, 5 cm diameter soil sampling tube (Gidding’s Machine Company, Windsor, CO). Two of the cores were taken from a historically uncropped area – the yard surrounding a one room schoolhouse. Three cores were taken in a corn field adjacent to the school yard. (Figure 4.1). According to historical photos from the 1930s onwards, the school yard is unplowed, while the field has been continuously cropped (Iowa State University Geographic Information Systems Support and Research Facility, 2013).

Soil core description

Cores were described using the methodology in the Field Book for Describing and Sampling Soils (Schoeneberger et al., 2002). Description of each core included horizon type, depth, boundary, structure and consistence. Horizons were also analyzed for clay films, redoximorphic features, and root quantity and size. Texture – the percent sand, silt and clay – was determined by the ‘feel method’ outlined in the Journal of Agronomic...
Figure 4.1. Soil map of sampling site with cores (Soil Survey Staff, 2014).

Table 4.1. GPS coordinates for sampled cores.

<table>
<thead>
<tr>
<th>Soil Core</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td># 2 Uncropped</td>
<td>40° 58’ 12.10” N</td>
<td>93° 25’ 19.44” W</td>
</tr>
<tr>
<td># 3 Uncropped</td>
<td>40° 58’ 12.70” N</td>
<td>93° 25’ 19.41” W</td>
</tr>
<tr>
<td># 7 Cropped</td>
<td>40° 58’ 14.25” N</td>
<td>93° 25’ 20.79” W</td>
</tr>
<tr>
<td># 8 Cropped</td>
<td>40° 58’ 12.74” N</td>
<td>93° 25’ 18.47” W</td>
</tr>
<tr>
<td># 9 Cropped</td>
<td>40° 58’ 12.19” N</td>
<td>93° 25’ 18.48” W</td>
</tr>
</tbody>
</table>
Horizon color was characterized by corresponding hue, value, and chroma in the Munsell Soil Color Charts (Munsell Soil Color Charts, 1990). The presence of carbonates was tested for by applying 10% hydrochloric acid to each horizon and noting the severity of reaction.

**Laboratory analysis**

After soil description, each horizon was placed in a 105°C oven for 24 hours, and weighed to determine oven dry mass. The volume of each horizon was found by multiplying its height and the cross-sectional area of the core. Bulk density was determined by dividing the oven dry mass by this volume. Importantly, core #3 and #8 were described before being weighed and some of the soil used for texturing was discarded, and thus the bulk density may be inaccurate. Additionally, each horizon was ground so it could pass through a 2-mm sieve and then tested for pH using a 1:1 soil-water ratio.

**Total carbon and total nitrogen**

Sub-samples of each horizon were sent to the Soil and Plant Analysis Lab at Iowa State University where they were analyzed for total carbon (TC) and total nitrogen (TN) using the dry combustion method on a LECO Tru-Spec CN Analyzer (Leco Corp., St. Joseph, MI). Results were returned to the 100th decimal place, however, we did not feel the instrumentation was that sensitive, so values were rounded to the tenth. Soil
inorganic carbon (SIC) was tested for three horizons that had a pH greater than 6.8. For all other horizons soil organic carbon (SOC) was assumed to be equal to TC. Soil inorganic carbon was determined gravimetrically by loss with acid treatment. This was done by combining a known weight of each ground sample and a known weight of 6M hydrochloric acid on a front-loading balance and measuring carbon dioxide emissions, as mass loss, at two time intervals; after 30 seconds, the mass loss was attributed to calcite, and after 30 minutes mass loss was attributed to dolomite. For two of our three samples, there was a mass loss of 0.01 g after 30 minutes, and for the third sample, no change after 30 minutes. A trial run of this method, without a soil sub-sample, was also executed in order to evaluate possible scale fluctuations; after 30 minutes there was a mass loss of 0.01 g. This led us to conclude that the 0.01 g mass loss in two of our soil sub-samples was negligible, and that SOC is equal to TC for all of our samples.

Soil core data was normalized to 18 and 100 cm depths in order to accurately compare soil properties as well as to agree with standards in previous chapters. Data was normalized by dividing the horizon thickness (up to the depth of interest) by the depth of interest, which was then multiplied by the soil property value. These weighted averages were then summed to find the overall average.
Results and Discussion

Morphological properties

The Haig soil series is officially described as a poorly drained, silt loam that transitions from an Ap horizon to an A, and finally Btg horizon. Dark brown accumulations begin close to the 48 cm depth, along with yellowish brown redoximorphic concentrations (Soil Survey Staff, 2014a).

In this case study, several morphological features varied proportionally with land use. The cropped profiles have an Ap horizon, a horizon that has been mechanically disturbed, while the uncropped profiles do not. All cores have an E horizon – a ‘bleached’ horizon characterized by the eluvial loss of silicate clays, iron and/or aluminum (Soil Survey Staff, 2006) – although it is more pronounced in the uncropped cores. The E horizons in the uncropped cores have an average thickness of 27 cm, or 38 cm if the transition AE horizons are included, while the cropped cores have an average thickness of 19 cm. Additionally, at 137 cm depth the soil has very slight effervescent in both the uncropped cores. Only one cropped core was sampled beyond 121 cm, but there was no observable effervescence in this core, despite it extending to a 153 cm.

Some morphological properties varied with no observable trends. At certain depths, properties might be uniform, only to diverge at other depths. For instance, in the top 45 cm of all the profiles the texture was described as silt loam, while in the lower half of the profile texture varied from silty clay loam to silty clay. Consistence, or the force required to break a soil unit, was described as friable – extremely weakly
cemented – in the surface horizon of all profiles while the lower horizons (consistently past 83 cm) were described as very firm. In the horizons that fell between these zones the consistence ranged from very friable to very firm. Rooting density and size were uniformly described across the cores, although rooting depth varied slightly between the cores ranging from 50 to 60 cm. Orange concentrations also appeared at similar depths along with dark brown concretions – most likely manganese – which appeared uniformly, but at disparate depths. Other properties that varied inconsistently included depth to clay films, mollic colors and soil color more generally.

While discernible trends were evident at certain depths and ambiguous at others, there were some overall features of the soils that were consistent throughout the SMU polygon. Eluvial horizons were found that transitioned into Bt or Btg horizons. Clay films were also found in all cores along with specific redoximorphic features (Table 4.6).

Chemical properties

The Haig soil series is officially described as having 4.0% organic matter in the surface 18 cm, and an average of 1.6% organic matter from a 0 to 100 cm depth. According to Web Soil Survey, the average bulk density is consistently 1.38 g cm\(^{-3}\) for both a 0 to 18 and 0 to 100 cm depths (Soil Survey Staff, 2014b). Haig is also described as being slightly acid throughout the soil profile (Soil Survey Staff, 2014a).
In this case study, TC varied according to land use (Figure 4.2). In the surface 18 cm TC was 36% higher in the uncropped cores than in the cropped cores, while it was 21% higher when averaged over a 0 to 100 cm depth (Table 4.3 – 4.5). Total nitrogen (TN) also varied according to land use in the surface 18 cm with all the cropped cores having an average of 0.2% while the uncropped cores had an average of 0.3% (Table 4.3). When averaged over a 0 to 100 cm depth, however, all cores were comparable having 0.1% TN (Table 4.4). Bulk density, like TN, varied according to land use in the surface 18 cm, but over a 100 cm depth there was no observable pattern (Table 4.3 and 4.4). The uncropped cores had a consistently lower bulk density than cropped, however the difference was slight. From a 0 to 100 cm depth, as Figure 4.2 demonstrates, bulk density ranged inconsistently although both land uses resulted in a 1.3 g cm$^{-3}$ average.

The C:N ratio also seemed to vary according to its land use (Figure 4.2). In the cropped soils the ratio increased from the first to the second horizon before systematically decreasing in the lower depths. Alternatively the uncropped soils decreased from the first to the second horizons, and then increased to first horizon levels before steadily decreasing. One property that varied unpredictably for both depths was pH (Figure 4.2). For the 0 to 100 cm depth pH ranged from 5.5 to 6.4 for the cropped cores, and 5.4 to 6.0 for the uncropped cores (Table 4.4). The overall average for the 100 cm depth was slightly higher for cropped cores (0.2), but a consistent trend was not observed (Table 4.5).
**Table 4.2.** Individual core results for total C and total N (g/100 g soil), pH, bulk density (g cm\(^{-3}\)) and C:N Ratio. *Blanks indicate N content was below a detectable limit.*

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>TC (g C/100 g soil)</th>
<th>TN (g N/100 g soil)</th>
<th>pH</th>
<th>Bulk Density (g cm(^{-3}))</th>
<th>C:N Ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2 Uncropped</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>13</td>
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<td>0.3</td>
<td>7.4</td>
<td>1.1</td>
<td>15:1</td>
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<tr>
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<td>0.2</td>
<td>6.6</td>
<td>1.3</td>
<td>12:1</td>
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<td>14:1</td>
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<td>0.1</td>
<td>5.8</td>
<td>1.3</td>
<td>11:1</td>
</tr>
<tr>
<td>Btg1</td>
<td>67</td>
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<td>0.1</td>
<td>5.6</td>
<td>1.4</td>
<td>10:1</td>
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<td>0.0</td>
<td>5.6</td>
<td>1.4</td>
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<tr>
<td>Btg3</td>
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<td>1.6</td>
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<td></td>
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<tr>
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<td>0.2</td>
<td>5.8</td>
<td>1.0</td>
<td>12:1</td>
</tr>
<tr>
<td>E1</td>
<td>39</td>
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<td>0.1</td>
<td>5.4</td>
<td>1.2</td>
<td>15:1</td>
</tr>
<tr>
<td>E2</td>
<td>50</td>
<td>1.0</td>
<td>0.1</td>
<td>5.2</td>
<td>1.2</td>
<td>10:1</td>
</tr>
<tr>
<td>Btg1</td>
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<td>0.8</td>
<td>0.1</td>
<td>4.9</td>
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<td>8:1</td>
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<td>1.3</td>
<td>13:1</td>
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<tr>
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<td>6.2</td>
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Table 4.2. Continued. Individual core results for total C and total N (g/ 100 g soil), pH, bulk density (g cm\(^{-3}\)) and C:N Ratio. * Blanks indicate N content was below a detectable limit.

<table>
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<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>TC (g C/ 100 g soil)</th>
<th>TN (g N/ 100 g soil)</th>
<th>pH</th>
<th>Bulk Density (g cm(^{-3}))</th>
<th>C:N Ratio*</th>
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<td>0.1</td>
<td>5.1</td>
<td>1.2</td>
<td>15:1</td>
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<tr>
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<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>TC (g C/ 100 g soil)</th>
<th>TN (g N/ 100 g soil)</th>
<th>pH</th>
<th>Bulk Density (g cm(^{-3}))</th>
<th>C:N Ratio*</th>
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<td>0.2</td>
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<td>1.5</td>
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Figure 4.2. Total N and total C (g/100 g of soil), pH, bulk density (g cm$^{-3}$) and C:N ratio by depth.
Table 4.3. Individual averages for total C and total N (g/100 g soil), pH and bulk density (g cm\(^{-3}\)) for all cores for 0 to 18 cm depth.

<table>
<thead>
<tr>
<th>Core Averages for 0 to 18 cm</th>
<th>TC (g C/100 g soil)</th>
<th>TN (g N/100 g soil)</th>
<th>pH</th>
<th>Bulk Density (g cm(^{-3}))</th>
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</thead>
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<tr>
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<td>1.4</td>
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Table 4.4. Individual averages for total C and total N (g/100 g soil), pH and bulk density (g cm\(^{-3}\)) for all cores for 0 to 100 cm depth.

<table>
<thead>
<tr>
<th>Core Averages for 0 to 100 cm depth</th>
<th>TC (g C/100 g soil)</th>
<th>TN (g N/100 g soil)</th>
<th>pH</th>
<th>Bulk Density (g cm(^{-3}))</th>
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</table>

Table 4.5. Average total C and total N (g/100 g soil), pH and bulk density (g cm\(^{-3}\)) for all uncropped (2) and cropped cores (3) for 0 to 100 cm depth.

<table>
<thead>
<tr>
<th>Cores Averages for 0 to 100 cm depth</th>
<th>TC (g C/100 g soil)</th>
<th>TN (g N/100 g soil)</th>
<th>pH</th>
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<td>0.1</td>
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Table 4.6. Depth (cm) to mollic colors and clay films for individual soil cores.

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<th>Maximum Depth to Mollic Colors (cm)</th>
<th>Minimum Depth to Clay Films (cm)</th>
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<td>23</td>
<td>50</td>
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<tr>
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<td>49</td>
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<tr>
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<td>35</td>
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</table>
While many chemical properties varied according to land use in the surface 18 cm, patterns of any kind were difficult to observe when the whole soil core was considered. Often, when analyzing properties for the complete core, differences were slight throughout the SMU, or else followed an indiscernible pattern.

**Conclusion**

For the majority of soil properties, when results are averaged to a 100 cm depth, or several pedons are averaged, differences are slight. For this reason, the null hypothesis that profiles within a single SMU polygon are comparable seems a reasonable assertion. However, when differences are observed, they either vary according to land management for specific depth intervals, or they vary with no discernable pattern. While TC did diverge according to management, other properties such as pH appeared to vary haphazardly. Thus, the first alternative hypothesis that profiles vary proportionally with land use type must be rejected because it does not hold true when all soil properties are considered. We fail to reject the second alternative hypothesis that profiles vary in an unpredictable manner. While TC may vary according to management, the entirety of the profile does not follow this trend.
CHAPTER 5: GENERAL CONCLUSION

Iowa State University currently holds approximately 1.5 billion kg of TC to a 100 cm depth according to WSS. Total carbon is indeterminable using ISPAID because SIC was not tabulated in that database. Soil organic carbon was quantified using both databases and is strongly correlated in the surface 18 cm, but divergent when the whole profile to a 100 cm depth is included. This difference appears to be due to conflicting organic matter percentages and SMU aggregation, although because of opaque methodologies on ISPAID’s part, we cannot be certain.

Iowa State University has significant carbon stocks, but the SOC sequestration equation introduced in Chapter 3 predicts that it can have much more. Maximum future carbon stocks were estimated after 30 years of perennial grass management, and ISU’s land could conceivably increase their stocks by 35% or the equivalent of 536,065,522 kg.

At the SMU level, we find that profiles within one SMU polygon differ, and not in a predictable manner. Total carbon and total nitrogen, however, did vary according to land management particularly in the surface soil layers. Here, again, we find the theme of predictability in the surface horizon of soils, but uncertainty when the entire soil profile is considered.

Through this thesis, I have attempted to answer the question, what is the carbon content of ISU’s land? And I have no shortage of answers. According to WSS it is 1,531,615,777 kg. According to ISPAID it is 957,739,419 kg. Both of these numbers could be printed in an academic journal or advertised on a university website because both
numbers are accurate. Is SIC a worthwhile carbon pool to include? If it is not, then ISPAID’s number is correct. But if SIC is valued, then the number reported by WSS is correct.

Even after deciding which carbon pools to include, there are still questions. How should the components in a soil complex be weighted? And perhaps the biggest question, does one SMU polygon represent the complexity of the soil properties beneath it? The appeal of databases, perhaps, is that all these questions have already been answered, and the answers take on the validity that simplicity brings with it.

I am left with only one conclusion. And it is a risky one with which to end a thesis dedicated to quantification. In Soil Science, as in any science that attempts to quantify the natural world, there are few, if any, objective results. Results rely on assumptions. Just as I have assumed, in taking so much effort to complete this thesis, that people will actually read it. But these assumptions are necessary, and beyond that they are required for us to communicate. So we must keep assuming, but we must also convey our assumptions as eagerly as we convey our results, and with equal weight given to both.
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Additional Information can be found at www.ag.iastate.edu/farms.


### APPENDIX A. CARBON TOTALS FOR 0 TO 18 CM DEPTH FOR ALL FARMS

<table>
<thead>
<tr>
<th>Farm</th>
<th>Area (ac.)</th>
<th>WSS Weighted SOC kg m²</th>
<th>ISPAID Weighted SOC kg m²</th>
<th>WSS vs. ISPAID % Difference SOC kg m²</th>
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### APPENDIX B. CARBON TOTALS FOR 0 TO 100 CM DEPTH FOR ALL FARMS

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### APPENDIX C. SOC SEQUESTRATION FACTORS FOR ALL FARMS

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APPENDIX D. LABORATORY DATA FOR McNAY MEMORIAL
RESEARCH FARM

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<th>pH</th>
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## APPENDIX E. SOIL DESCRIPTIONS FOR McNAY MEMORIAL RESEARCH FARM

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### Field Sheet for Recording Soil Characteristics

- **Volume:** 2.950 m³
- **PH:** 7.49
- **CEC:** 1.4%
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**Field Sheet for recording soil characteristics**

Volume: 2373.8 cu. ft.

COP 1.8

No. 9 6 121 131 122 123 124 125 126 127 128 129 130 131 132