Management effects on near-surface soil properties in a temperate corn-soybean cropping system

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Management effects on near-surface soil properties in a temperate
corn-soybean cropping system

by

Eric Britt Moore

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Co-majors: Soil Science; Sustainable Agriculture

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The student author, whose presentation of the scholarship herein was approved by the program
of study committee, is solely responsible for the content of this dissertation. The Graduate
College will ensure this dissertation is globally accessible and will not permit alterations after a
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Iowa State University
Ames, Iowa
2021

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>CHAPTER 1. GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>The Case for Cover Crops</td>
<td>3</td>
</tr>
<tr>
<td>Challenges and Opportunities for Cover Crops and Soil Water Research</td>
<td>5</td>
</tr>
<tr>
<td>The Role of Soil Texture in Water Retention</td>
<td>8</td>
</tr>
<tr>
<td>The Role of Soil Organic Matter in Water Retention</td>
<td>9</td>
</tr>
<tr>
<td>Exploring Interactions between Texture, Organic Matter, Structure, and Water Retention</td>
<td>13</td>
</tr>
<tr>
<td>Advancing our Understanding of Near-Surface Soil Water Retention</td>
<td>16</td>
</tr>
<tr>
<td>References</td>
<td>18</td>
</tr>
<tr>
<td>CHAPTER 2. LONG-TERM EFFECTS OF A RYE WINTER COVER CROP ON NEAR-SURFACE SOIL WATER RETENTION IN A CORN SILAGE-SOYBEAN CROPPING SYSTEM</td>
<td>25</td>
</tr>
<tr>
<td>Abstract</td>
<td>25</td>
</tr>
<tr>
<td>Introduction</td>
<td>26</td>
</tr>
<tr>
<td>Methods</td>
<td>30</td>
</tr>
<tr>
<td>Results &amp; Discussion</td>
<td>34</td>
</tr>
<tr>
<td>Conclusion</td>
<td>37</td>
</tr>
<tr>
<td>Tables &amp; Figures</td>
<td>37</td>
</tr>
<tr>
<td>References</td>
<td>48</td>
</tr>
<tr>
<td>CHAPTER 3. FARM-SCALE EVALUATION OF EPIPEDON MAPS ON DES MOINES LOBE SOILS: A CASE STUDY OF THE BOYD RESEARCH FARM</td>
<td>53</td>
</tr>
<tr>
<td>Abstract</td>
<td>53</td>
</tr>
<tr>
<td>Introduction</td>
<td>54</td>
</tr>
<tr>
<td>Methodology</td>
<td>57</td>
</tr>
<tr>
<td>Results &amp; Discussion</td>
<td>59</td>
</tr>
<tr>
<td>Conclusion</td>
<td>61</td>
</tr>
<tr>
<td>Maps, Tables, and Figures</td>
<td>62</td>
</tr>
<tr>
<td>References</td>
<td>71</td>
</tr>
</tbody>
</table>
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Soils are at the nexus of the atmospheric, geological, and hydrological cycles; providing invaluable ecosystem services, such as water storage. This compendium explores connections between near-surface soil properties and management practices, with a particular focus on soil-water. This research has explored, in detail, the hypothesis that long-term cover crop management significantly influences near-surface soil properties, and found that rye winter cover crops enhance soil water retention, macroporosity, and water holding capacity, while also augmenting soil organic carbon. This research has also evaluated publicly available Web Soil Survey maps to assess their utility at farm-scale and found that aeolian deposition may have a more significant soil management impact than previously thought. Lastly, this research assessed the efficacy of a novel soil science pedagogy to enhance undergraduate soil science learning and increase student enthusiasm about soil.
CHAPTER 1. GENERAL INTRODUCTION

Agriculture is in the midst of a defining era. While precise estimates vary, there is near universal consensus that global food production will need to increase substantially in the coming decades to meet the demands of a growing population. These production gains must occur against the backdrop of climate change, which is likely to cause significant disruptions to global agricultural production (Seneviratne et al. 2012). Incidences of extreme temperatures and heatwaves are expected to increase significantly (Seneviratne et al. 2012, Melillo et al. 2014, Wuebbles et al. 2017), likely straining rain-fed cropping systems. Availability of freshwater, the lifeblood of agriculture, is also expected to change markedly in the coming years. Warmer air temperatures are expected to cause changes to global precipitation patterns which will increase the severity of floods in some areas and exacerbate drought in others (Seneviratne et al. 2012). Additionally, trends in groundwater depletion, if continued, will further aggravate water stresses in regions across the globe.

The economic impacts of climate change are expected to have profound consequences for U.S. and global agricultural markets. Environmental stresses associated with climate change are expected to diminish U.S. agricultural exports, and by extension the export of virtual water. (Brown et al. 2015). Significant reductions in the export of virtual water, which is the combined total of water needed in each step of the agricultural production process, is likely to exacerbate global food insecurity (Brown et al. 2015), particularly in arid and semi-arid regions (Falkenmark 1995, Brown et al. 2015).

The challenges that climate change present are compounded by the continuance of severe and pervasive degradation of agricultural soils, which presents an extraordinary challenge to
sustaining and improving upon current levels of agricultural production. Across the globe, approximately 25% of all agricultural lands are classified as highly degraded (DeLong et al. 2015), and soils are being degraded at a faster rate than they can be sustained (Hatfield et al. 2017). Soils are sensitive to the impacts of agricultural production and can take decades, or longer, to recover pre-cultivation soil quality characteristics (Acín-Carrera et al. 2013). Given the fact that soil-water supports approximately 90% of global agricultural production (Amundson et al. 2015), soil degradation is inescapably tied to water management. The impacts of climate change, including excessive spring precipitation are expected to intensify in the Upper Mississippi River Basin; reducing overall crop yields and exacerbating soil erosion (Rogovska & Cruse, 2011). Moreover, crop yield reductions from these environmental stressors will not be fully compensated for by crop physiological benefits attributable to increased atmospheric carbon (Rogovska & Cruse 2011). The cumulative effects of climate change and natural resource depletion, along with a burgeoning global middle class and a growing world population, will require agriculture to intensify while simultaneously using fewer resources. Failure to implement viable solutions to address these momentous challenges will increase the likelihood of conflict and political instability across the globe (Cassman et al. 2011).

Adapting rain-fed cropping systems to meet the challenges of the 21st century will require considerable advancements in our understanding of the biophysical processes governing soil water dynamics. Soil and water are inextricably linked, and agricultural management practices must take this complexity into account if crop productivity is to be maintained and improved. Sustainable intensification of agriculture is possible, and while big-data and improved cultivars will undoubtedly play a significant role in this transition, agriculture will fall short of
the monumental challenges that lie ahead unless better soil and water resource management strategies are developed. This challenge is demanding; however, viable solutions are attainable.

**The Case for Cover Crops**

One conservation management strategy that has been gaining popularity in the U.S. Corn Belt is cover crops. Although the total percentage of farmland managed with cover crops remains minute, growth rates in cover crop adoption may be signaling the beginnings of a shift in the role that cover crops play in modern row-crop agriculture. Cover cropped acres in the region have increased an average of 99% between 2012 and 2017 (USDA Staff 2012, 2017). Iowa, which leads the region in cover crop gains, had approximately 3% of its farmland managed with cover crops in 2017; however, the increase in cover crop acreage was 156% from 2012-2017; and, if current trends continue, cover crop acreage will further increase 44% between 2020 and 2025 (USDA Staff 2012, 2017). Increases in cover crop adoption are due in large part to demonstrated benefits to soil and nutrient conservation. For example, cover crops have been shown to reduce soil erosion (Wilhelm et al. 2010), mitigate nutrient leaching (Kaspar et al. 2007) and enhance soil organic matter content (Moore et al. 2014). As living roots play a substantive role in shaping the soil biophysical environment (Pierret et al. 2011), it stands to reason that cover crop-mediated ecosystem services are attributable, at least in part, to enhanced root zone biological activity.

The importance of soil microbes in facilitating and maintaining soil biogeochemical processes cannot be overstated. In addition to mediating nutrient cycles, microbes are also an integral part of soil food webs, creating microhabitats that in turn foster enhanced biodiversity in the root zone (Chenu & Cosentino, 2011). Soil microbes require carbon compounds to meet their
energy needs, which make them highly dependent on plant root exudates. Research results suggest that a temporal expansion of the rhizosphere (e.g. incorporation of winter cover crops), can improve soil quality through enhancing soil biological activity (Pierret et al. 2011, McDaniel et al. 2014), which in turn promotes soil aggregation (Jastrow 1996, Daynes et al. 2013, Ontl et al. 2015) and soil organic matter accrual (Benjamin et al. 2008). McDaniel et al. (2014) found that cover crops increased soil carbon by more than double compared to treatments that added one or more crops to a rotation, but which lacked a cover crop, adding further evidence that the benefits of cover crops are due, in part, to a temporal expansion of the rhizosphere during the growing season.

Although cover crops have been shown to improve soil quality (Moore et al. 2014), little is known about cover crop influences on soil water retention. Daigh et al. (2014) assert that cover crops may aid flood mitigation in tiled drained landscapes, which are common in the Upper Mississippi River Basin. Research by Zhuang et al. (2008) has shown that undisturbed native prairie soils have higher water contents than cultivated soils, with restored prairie having soil water contents intermediate between the two. These studies support the hypothesis that minimal soil disturbance, increased biodiversity, perennial surface cover, and perennial living roots alter soil water dynamics; however, an empirical basis for extrapolating these results to enhancements in soil water use has yet to be established.

One of the most viable means by which freshwater resources can be conserved is through increased soil water use efficiency (Hatfield et al. 2017). Meta-analytic data from Hatfield et al. (2001) found that increased plant populations can enhance soil water use efficiency in temperate climes. To date, few studies have investigated winter cover crops effects on soil water use efficiency in temperate rain-fed row crop agriculture.
Challenges and Opportunities for Cover Crops and Soil Water Research

Plant available water (PAW) is defined as the amount of soil water that is held between field capacity (FC) and permanent wilting point (PWP). The standard used for FC varies across the globe, with values generally ranging from -5 to -33 kPa; however, a fixed value of -1,500 kPa for PWP is more universally agreed upon (Minasny & McBratney, 2018). Although water in soils is physically present at matric tensions less than -1,500 kPa (i.e., PWP), the water is held so tightly that plants are typically unable to extract it at a rate sufficient to meet the transpiration demand.

Estimations of PAW are dependent on accurate measurements of FC. Field capacity is the water content at which free drainage (i.e., drainage due to gravity) of a previously saturated soil has become negligible. The period between wetting and negligible drainage is usually 48-72 hours (SSSA, 2008). Although -33 kPa is the generally accepted value for FC in the U.S. Corn Belt, FC can vary substantially across soils and landscapes.

One of the challenges that complicates the study of soil-water properties is an accurate approximation of the relative importance of soil organic matter across varying matric potentials. Research by Hudson (1994) and Emerson (1995) reported increases in water retention resulting from organic carbon additions are more pronounced on FC than at PWP. Therefore, soil water retention characteristics could potentially be influenced by soil organic inputs derived from management practices that augment plant root biomass.

Another factor that merits serious consideration is soil structure changes caused by enhanced root zone activity. Evidence suggests that cover crop roots alter soil structure through increasing the number of soil macropores (Chen et al. 2014), which in turn increases water
infiltration (Dabney, 1998). Water flow and retention can also be influenced by hydrophobic compounds produced by the fungal hyphae (Chenu & Cosentino, 2011). There is also evidence to suggest that soil microbe-derived labile organic matter fractions have hydrophilic properties which enable them to retain disproportionately large volumes of water (Hudson, 1994; Rosenzwieg et al. 2012).

One of the factors that both complicates and speaks to the importance of soil-water research is anthropogenic impacts on soil. Soil erosion rates, while improving in many areas across the U.S. Corn Belt, remain alarmingly high (Gelder et al. 2018), and are occurring at a pace that is unsustainable for long-term productivity (Cox et al. 2011, Cruse et al. 2013). Soil erosion has altered landscapes across the U.S. Corn Belt, resulting in loss of topsoil and the concomitant loss of soil organic matter. Tillage, which is a major contributor to soil erosion in the Upper Mississippi River Basin, can alter soil structure-dependent properties as a function of both depth and time (Zhang et al. 2018). Increased soil erosion is also likely to strain crop productivity as topsoil is disproportionately high in organic matter. Increased soil erosion, and the concomitant loss of SOM, could decrease plant available water (Hudson, 1994), further exacerbating crop stresses associated with climate change. It therefore stands to reason that soil hydrology has been disproportionately affected by the loss of topsoil across agricultural landscapes.

Iowa, which has a well-documented history of anthropogenic soil formation and transformation processes over the past 50+ years (Veenstra & Burras, 2015) has documented soil erosion rates that exceed soil formation by at least an order of magnitude (Cruse et al. 2013; Gelder et al. 2018). The continued rate of unsustainable soil losses will undoubtedly alter soil hydrology, highlighting the urgency for implementation of management practices that effectively
combat soil erosion. Studies by Kaspar et al. (2001) and Wilhelm et al. (2010) have demonstrated that winter cover crops offer a viable means to ameliorate negative influences of soil erosion.

Another major anthropogenic factor that may influence soil erosion rates, and concomitantly soil hydrology, is climate change. Climate models predict that the Upper Mississippi River Basin will experience changes in annual precipitation patterns which will likely result in a greater number of high-intensity rainfall events (Takle, 2011; Melillo et al. 2014; Brown et al. 2015), increasing the risk of summer flooding. Improved flood and drought management strategies will be required to mitigate crop yield losses amidst a changing climate. The poorly drained soils that comprise significant areas of agricultural land in the Upper Mississippi River Basin make flooding concerns acutely relevant.

Agricultural management practices that improve soil water retention may offer a means to blunt the severity of flooding. Emerson (1995) reported that increases in soil carbon are positively correlated to increases in soil water retention, with these increases more pronounced at field capacity than at permanent wilting point. These results suggest that agricultural practices which increase soil carbon may be viable components of integrated water management plans, particularly for extreme precipitation events. Additionally, Daigh et al. (2014) surmised that cover crops may aid flood mitigation in tile-drained landscapes. While flooding results from a multitude of converging factors, including antecedent soil moisture, topography, drainage, and infrastructure design; a better understanding of soil water retention in the upper root zone would undoubtedly serve to strengthen integrated flood management strategies for the Upper Mississippi River Basin. Although there is urgent need to expand agricultural management tools to address the challenges of sustainable intensification, there remains a dearth of basic scientific
knowledge regarding the biophysical processes governing interactions between soil structure, organic matter, and soil hydrology.

The Role of Soil Texture in Water Retention

One of the basic soil properties that can help elucidate the impacts of cover crops on soil water retention is texture. Soil texture is a dominant factor in determining the kinetics of soil water transport and retention processes (De Jong et al. 1983; Saxton & Rawls, 2006). It is well established that coarser-textured soils have larger pore spaces and increased hydraulic conductivity relative to finer-textured soils; however, the relationship between soil texture and soil water retention is complicated by climate and soil organic matter. Jenny (1941) considered climate the sine qua non of soil formation, especially given its interdependence with other key factors such as biologic and weathering processes. Manns & Berg (2013) reported that while soil textural differences account for most of the soil water variability under wet conditions, soil organic carbon (SOC) is responsible for most of the water variability under dry conditions. The same study found that soil mineral fraction of sand and fraction of SOC are the best predictors of soil water content across a wide range of soils. The impacts of SOC seem to be most pronounced in coarse-textured soils. For example, studies by Magdoff (1996) and Basso et al. (2013) found that SOM significantly alters matric potential in sandy soils. Other studies have found that plant available water in coarse-textured soils respond more positively to SOC inputs than other texture classes (Hudson, 1994; Rawls et al. 2003; Libohova et al. 2018; Minasny & McBratney 2018), even when SOC is added to coarse-textured soils with relatively high antecedent SOC (Rawls et al. 2003). Rawls et al. (2003) also found that when SOC was added to coarse-textured soils with low antecedent SOC, soil water retention responded more dramatically to SOC additions. The same study found that organic carbon additions to low SOC clay soils decreased soil water
retention, whereas organic carbon additions at high SOC levels increased soil water retention in clay and all other soil textures.

A meta-analysis by Libohova et al. (2018) reported that silt content is the single best textural predictor of plant available water. Clay and silt content are also significant factors in determining how SOC inputs respond to management changes, with clay-silt soils storing increased amounts of particulate organic matter (POM) after they have become carbon saturated (Carter et al. 2003). Burke et al. (1989), using regional database regression analyses, found that higher clay content generally resulted in reduced SOC losses caused by cultivation than occurred with coarser textures. Burke et al. (1989) also found that SOC increases with precipitation in uncultivated soils, although the response in cultivated soils is opposite. Data from the previous study support the theory that clay protects SOM against microbial degradation, which may indicate that clay content has a disproportionate impact on SOC levels.

The Role of Soil Organic Matter in Water Retention

As aforementioned studies have demonstrated, soil physical properties can be significantly influenced by organic matter. Soil organic matter is a broadly defined term; it technically encompasses everything from living organisms to decomposing plant tissues and humic substances. Soil organic matter pools can vary significantly depending upon multiple factors, including age and chemical composition of the original organic substrate, soil hydrology, and climate (Metherell et al. 1993). Soil organic matter is often categorized according to relative chemical reactivity. These categories include labile, slow, and recalcitrant organic matter pools.

The labile SOM pool has a decomposition rate ranging from several months to several years and consists largely of microbes and microbial-derived substances (Metherell et al. 1993).
One category of microbial-derived substances germane to soil-water research is extracellular polymeric substances (EPS). These carbon-rich compounds are secreted by soil microbiota and are a widespread character in soil microbes across multiple phylogenic lines (Chenu & Cosentino, 2011). Although EPS constitute only a small percentage of SOM, they have been shown to promote soil aggregation and ameliorate the impacts of rapid changes in soil water potential (Chenu, 1993; Chenu & Cosentino, 2011; Holden, 2011). Extracellular polymeric substances have chemical properties which endow them with significant water storage capacity. A study by Rosenzwieg et al. (2012) has demonstrated the ability of xanthan, an EPS analogue, to increase soil water content by as much as 270%. Although the previous study analyzed water retention resulting from the addition of isolated xanthan, it stands to reason that in-situ EPS may elicit a similar response. Chenu & Cosentino (2011) and Holden (2011) demonstrate the hydrophobicity of certain fungal extracellular polymeric substances, which is not surprising given the fact that most soil fungi are obligate aerobes, and therefore require protection against extended periods of saturation. These studies seem to agree that a primary function of soil EPS is to buffer against rapid changes in soil water potential that can cause hypoxia, cellular lysis, or pneumatic rupturing of soil aggregates. The aforementioned studies also seem to agree that EPS can function in both hydrophilic and hydrophobic capacities depending on factors such as the relative abundance of carbon-rich plant exudates and soil matric potential.

Measurements of EPS could potentially serve as a proxy for comparisons of water retention across various soils of similar textural class as small changes to EPS have been shown to result in significant changes in soil water retention. Labile carbon mineralization (LCM) shows a strong relationship to soil microbial biomass carbon (Franzluebbers et al. 2000), and could serve as a proxy for changes in soil extracellular polymeric substances. Permanganate-
oxidizable carbon (POXC) may also serve a similar function; however, evidence of its utility remains inconclusive. While some publications argue that POXC is highly correlated to biomass carbon (Soil Health Staff, 2014), other studies found that POXC is not a reliable measure of labile carbon and is not correlated to microbial biomass (Tirol-Padre & Ladha, 2004). Sequeira & Alley (2011) found that POXC was not an effective indicator of management changes, while Stiles et al. (2011) assert that POXC, while not appropriate for determining an isolated SOM fraction, is appropriate for comparing management practices.

The slow SOM pool has a decomposition rate ranging from 20-50 years and consists of plant structural compounds, such as lignin, that are relatively resistant to decomposition. Particulate organic matter has properties that are consistent with the slow SOM pool (Cambardella & Elliot 1992, Metherell et al. 1993) and can serve as a sensitive indicator of soil quality changes resulting from crop management (Moore et al. 2014). Particulate organic matter shows evidence of acting as a transitional space for soil organic matter that can either be utilized by microbes upon mineralization or transition into longer-term (i.e., recalcitrant) organic matter storage. Carter et al. (2003) found that fine-textured soils store increased amounts of POM after they have become carbon saturated, which suggests that POM can transition cyclically into active organic matter pools as ambient carbon availability changes. Moore et al. (2014) found that approximately 38% of all soil organic matter gains resulting from long-term cover crop management are attributable to increases in particulate organic matter. Ontl et al. (2015) found that while total carbon storage did not change as a result of alternative crop management, POM was increased. Both studies attributed the increase in POM to enhanced root biomass activity.

The recalcitrant SOM pool has a decomposition rate of 400-2000 years (Metherell et al. 1993) and consists of refractory compounds including humic acids and biochar. Skjemstad et al.
(2002) argue that organic carbon is too often over-estimated in soils due to the relatively large proportion and recalcitrance of biochar. Recalcitrant SOM is generally deemed important for cation exchange capacity, especially in coarse and medium-textured soils (Magdoff 1996). However, while Magdoff (1996) asserts that the humic fraction of soil significantly increases cation exchange capacity, Basso et al. (2013) found that biochar additions have no impact on cation exchange capacity. Metherell et al. 1993 found that cropped soils are lower in humic acids than nearby woodland soils, and Ghabbour et al. (2013) reported that humic acids retain more water on a gravimetric basis than does total organic matter. These studies suggest that land use changes could influence a soil’s relative refractory SOM content, and concomitantly soil water retention. A biochar study by Basso et al. (2013) found that recalcitrant SOM altered soil matric potential for given gravimetric water contents, particularly in sandy soils. While recalcitrant SOM plays an important role in soil biogeochemical processes, edaphological studies that do not incorporate biochar amendments or employ controlled burning have little reason to suspect that baseline recalcitrant organic matter levels will change as a result of crop management.

Despite studies demonstrating the positive effects of SOM on soil water retention, there remains a lack of consensus on the extent to which SOM alters retention characteristics across the plant available water range. While soil texture is the dominant factor in determining the kinetics of soil water transport and retention processes, SOM does affect the shape and position of the soil water retention curve (SWRC), resulting in higher water content across the PAW range (De Jong et al. 1983). Hudson (1994) found a strong, positive correlation between volumetric water content and SOM at field capacity in coarse and medium-textured soils. A study by Daynes et al. (2013) reports that plants colonized by arbuscular mycorrhizal fungi significantly increase soil water contents across all PAW matric potentials in soils where
compost was also present. However, research by Minasny & McBratney (2018) found that increases in soil water content from SOM additions are negligible. The study found, on average, a 1% increase in SOC corresponds to a 1-3% increase in soil volumetric water content. Results from Libohova et al. (2018) found a similar relationship between SOM and plant available water.

The studies by Minasny & McBratney (2018) and Libohova et al. (2018), while insightful, do not resolve the uncertainty surrounding the relationship between SOM and plant available water. The meta-analytic methods in both studies fail to distinguish organic matter additions due to exogenous inputs (e.g., sludge or manure) from organic matter added by living plants and plant residues. Furthermore, neither study spoke to the relative impacts of short-term versus long-term organic matter additions. Daynes et al. (2013) found that soil water content increases most when exogenous organic matter inputs, living plants, and soil fungi were simultaneously present; suggesting that analyses which only investigate exogenous organic matter inputs may fail to fully account for PAW contributions from other types of organic matter.

**Exploring Interactions between Texture, Organic Matter, Structure, and Water Retention**

The physical and chemical diversity that exists among SOM pools renders general statements about the relationships between SOM, texture, structure and water retention overly broad with respect to advancing our understanding of soil carbon dynamics. While some studies have shown that total SOM and POM increase with cover crop use (Moore et al. 2014); other studies, including Ontl et al. (2015), have shown that management effects on organic carbon storage are inconsistent, and that soil texture is the dominant factor in SOC storage. These inconsistencies highlight the need for additional research into interactions between SOM, soil texture, and soil structure as they relate to soil water retention.
While texture is the dominant factor influencing soil-water properties, the interactions between texture, SOM, soil structure, and land management practices can significantly affect soil hydrology. The importance of these interactions is apparent in processes governing soil aggregation. Dexter et al. (2007) conclude that a bi-modal distribution of pore spaces in soil is common, regardless of texture; with the sole exception being pure sands. Similarly, Peters & Durner (2006) determined that soil water retention characteristics are best described using bi-modal functions. An increase in the relative percentage of soil macroaggregates can therefore act to increase the relative abundance of macropore spaces with concomitant increases in capillary water storage. Pierret et al. (2011) assert that living plant roots act to promote soil aggregation and create macropore spaces. Cover crops essentially serve to extend the presence of living roots in the root zone and have potential to increase or decrease soil water retention at field capacity through alteration of the soil physical environment.

Soil management also plays a significant role shaping the soil physical environment. Kahlon et al. (2013) found that tillage reduces the amount of macroaggregates and increases the number of microaggregates. The study also reported that macroaggregates contain, on average, 30% more carbon and nitrogen than microaggregates. Furthermore, these investigators found that the proportion of macroaggregates increases with the adoption of long term no-tillage and residue mulch. Additionally, Carter et al. (2003) found that carbon within water-stable soil aggregates account for the majority of SOC storage.

No-tillage systems generally have increased aggregation and SOM in the upper root zone relative to conventionally tilled systems. Six et al. (2000) cite tillage as a major cause in reduced stability and number of soil aggregates when native ecosystems are converted to agriculture. Soil aggregates act to physically protect SOM from decomposition as evidenced by a spike in SOM
mineralization after aggregate disruption (Balesdent et al. 2000). Six et al. (2000) present a theoretical model to explain the process of soil aggregation whereby: (i) Fresh plant residues become intra-aggregate POM, which promotes microbial activity by serving as a carbon energy source. This in turn promotes the production of microbe-derived binding agents (e.g., EPS) which hold soil particles together. (ii) Intra-aggregate POM transitions from coarse to finer particles as it decomposes. (iii) Microaggregates begin to form within macroaggregates. Eventually the binding agents that hold macroaggregates together weaken; releasing the microaggregates that are held inside (iv) The released microaggregates serve as the foundation on which subsequent macroaggregates are built.

Al-Kaisi et al. (2014) reported that SOC is positively correlated ($r = 0.65$) to soil aggregate stability. The same study also reports a moderate, positive correlation between SOC and soil water content in the upper surface soil layer. Results from Balesdent et al. (2000) and Al-Kaisi et al. (2014) suggest that soil aggregation may play a role in increasing SOC, and by extension soil water content. However, the extent to which aggregated structures have an impact on soil water retention through either direct alteration of pore size distribution or an indirect impact on soil water content through increased SOM was not the primary focus of either study. Saxton & Rawls (2006) found that aggregation and SOM had negligible impacts on soil water content at low matric potentials; however, SOM did increase water retention at high matric potentials. The authors attribute the increased water retention at higher matric potentials to enhanced soil aggregation. Although Kemper and Rosenau (1986) claim that most investigators prefer measuring aggregate stability over aggregate size distribution, more recent studies such as Kahlon et al. (2013) focus on aggregate size distribution, particularly the relative proportion of macroaggregates to microaggregates. Carter et al. (2003) found that water stable aggregates and
POM account for the majority of SOC storage, 60% and 20% respectively; suggesting that a comparison of intra-aggregate particulate organic matter and unprotected particulate organic matter may provide a useful metric to assess soil organic carbon as well as the relative extent to which POM and water-stable aggregates influence soil water retention.

Advancing our Understanding of Near-Surface Soil Water Retention

The research detailed in the ensuing chapters of this compendium are predicated on the hypothesis that long-term cover crop management significantly influences near-surface soil properties; and that rye winter cover crops in particular enhance soil water retention through improved macroporosity and augmented soil organic carbon. As such, salient questions explored include:

i) Does long-term winter cover crop management alter soil properties at saturation and field capacity?

ii) Does long-term winter cover crop management enhance soil organic carbon? If so, what is the relative impact of labile organic carbon?

iii) What, if any, significant interactions exist between water retention, texture, pore size distribution, and organic carbon in soils with long-term winter cover crop management?

iv) Do publicly available soil maps accurately detail near-surface soil properties at farm-scale? If so, what are the potential implications for soil-water management?
v) Is interactive student participation in ongoing soils research an effective means to
enhance soil science learning, communication skills, and technical laboratory skills?

Each of the ensuing chapters addresses one or more of these questions in detail.

Chapter 2 “Long-Term Effects of a Rye Winter Cover Crop on Near-surface Soil Water Retention
in a Corn Silage-Soybean Cropping System” explores the extent to which winter cover crops
influence near-surface soil water retention, as well as the role that organic carbon plays in soil
water retention.

Chapter 3 “Farm-Scale Evaluation of Epipedon Maps on Des Moines Lobe Soils: A Case Study
of the Boyd Research Farm” evaluates existing soil maps to determine the extent to which
additional pedogenic data improve map utility at farm-scale, particularly as it relates to soil-
water management.

Chapter 4 “Development of an Interactive Teaching-as-Research Pedagogy for Undergraduate
Soil Science Learning” considers the extent to which interactive participation in an ongoing soils
research project furthers undergraduate student learning in soils, environmental science,
scientific communication, and technical laboratory skills.
References


DeLong, C., R. Cruse, J. Wiener. 2015. The soil degradation paradox: Compromising our resources when we need them most. Sustainability 7:866-979.


CHAPTER 2. LONG-TERM EFFECTS OF A RYE WINTER COVER CROP ON NEAR-SURFACE SOIL WATER RETENTION IN A CORN SILAGE-SOYBEAN CROPPING SYSTEM

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Abstract

There is increasing interest in winter cover crops as conservation management tools. However, despite a substantial increase in research efforts devoted to cover crops, their effects on soil hydrology are not well understood. This study examines the long-term effects of a rye (Secale cereale) winter cover crop on selected near-surface soil properties. The experiment took place from 2015-2018 in central Iowa on no-till plots managed with a rye cover crop each year since 2001. Two primary treatment effects, (1) rye cover crop following corn silage and soybean; and (2) no cover crop (control), were analyzed for soil water retention, pore size distribution, total organic carbon, permanganate oxidizable carbon, and labile carbon mineralization. Soil particle size analyses were also conducted to elucidate a potential influence of texture variability. On average, rye cover crops increased soil water retention at saturation (0.025 g cm⁻³); however, there were no observed treatment effect on field capacity. Rye cover crops, on average, increased water holding capacity (0.034 g cm⁻³), relative macroporosity (10.1%), total soil organic carbon (2.19 g kg⁻¹), and permanganate oxidizable carbon (181.6 mg kg⁻¹) compared to control treatments. Neither bulk density nor soil texture varied significantly across treatments, and there was weak correlation between water content and each of the organic carbon analyses, suggesting that increases in macropore volume fraction may be responsible, in part, for the observed enhancements in soil water retention. These data offer timely insight into the potential of rye
cover crops to enhance soil water content at saturation and drainable macroporosity. Additionally, these data could help support integrated landscape management strategies to increase the resilience of temperate cropping systems to extreme precipitation events.

**Abbreviations:** EPS-extracellular polymer substances, FC-field capacity, LCM-labile carbon mineralization, PAW-plant available water, POM-particulate organic matter, POXC-permanganate oxidizable carbon, PWP-permanent wilting point, SOC-soil organic carbon, SOM-soil organic matter, SWRC-soil water retention curve, UMRB-Upper Mississippi River Basin, WHC-water holding capacity, Θv-volumetric water content

**Introduction**

Winter cover crops have gained increasing popularity in the Upper Mississippi River Basin (UMRB) as an effective conservation management tool. Increases in cover crop adoption are due, in large part, to demonstrated benefits to soil and nutrient conservation. For example, cover crops have been shown to reduce soil erosion (Wilhelm et al. 2010), mitigate nutrient leaching (Kaspar et al. 2007) and enhance soil organic matter (SOM) content (Moore et al. 2014).

As roots play a substantive role in shaping the soil biophysical environment (Pierret et al. 2011), it stands to reason that cover crop-mediated ecosystem services are attributable, at least in part, to enhanced root zone activity. Previous research suggests that a temporal expansion of the rhizosphere can improve soil quality through enhanced soil biological activity (Pierret et al. 2011, McDaniel et al. 2014) and soil organic matter accrual (Benjamin et al. 2008). McDaniel et al. (2014) found that cover crops increased soil carbon by more than double compared to treatments that added one or more crops to a rotation, but which lacked a cover crop. While these
studies demonstrate the soil health benefits of cover crops, little is known about cover crop influence on soil hydrology.

One of the challenges that complicates the study of soil water retention is an accurate approximation of the relative importance of soil organic carbon (SOC) across varying matric potentials. Despite studies demonstrating the positive effects of SOC on soil water retention, there remains a lack of consensus on the extent to which SOC alters water retention.

Organic carbon has a wide-range of chemical structures and reactivity and plays an integral role in soil biogeochemical processes. Organization of SOC by relative chemical reactivity yields two broad categories: labile organic carbon, which is the fraction of SOC that is most readily oxidized, and recalcitrant organic carbon, which is the refractory component of soil organic carbon (Metherell et al. 1993). Labile organic carbon is associated with soil flora and fauna, as well as plant tissues and biologically-derived exudates (Metherell et al. 1993; Chenu & Cosentino, 2011). These exudates, while constituting a small percentage of soil organic carbon, have been shown to promote soil aggregation and ameliorate the impacts of rapid changes in soil water potential (Chenu, 1993; Chenu & Cosentino, 2011; Holden, 2011).

Two commonly used methods for measuring labile SOC are the 3-day CO$_2$ flush analysis of labile carbon mineralization (LCM) and the permanganate-oxidizable carbon (POXC) analysis. The LCM method shows a strong relationship to soil microbial biomass carbon (Franzluebbers et al. 2000), and could serve as a proxy measure of biologically-derived exudates. Permanganate-oxidizable carbon may also serve a similar function; however, evidence of its utility remains inconclusive. While some studies have argued that POXC is highly correlated to biomass carbon (Soil Health Staff, 2014), other studies found that POXC is not a reliable
measure of labile SOC and is not correlated to microbial biomass (Tirol-Padre & Ladha, 2004). Sequeira & Alley (2011) found that POXC was not an effective indicator of management changes, while Stiles et al. (2011) assert that POXC, while not appropriate for determining an isolated SOM fraction, is appropriate for comparing management practices.

While soil texture is the dominant factor in determining the kinetics of soil water transport and retention processes, SOM affects the shape and position of the soil water retention curve (SWRC), resulting in higher water content across the plant available water (PAW) range (De Jong et al. 1983). Hudson (1994) also found a strong, positive correlation between volumetric water content and SOM at field capacity in coarse and medium-textured soils. Hudson (1994) and Emerson (1995) both reported that increases in water retention resulting from organic carbon additions are more pronounced at field capacity than at permanent wilting point. Manns & Berg (2013) reported that while soil textural differences account for most of the soil water variability under wet conditions, soil organic carbon (SOC) is responsible for most of the water variability under dry conditions. The same study found that soil mineral fraction of sand and fraction of SOC are the best predictors of soil water content across a wide range of soils. Contrarily, research by Minasny & McBratney (2018) found that increases in soil water content from SOC additions are negligible. The study found, on average, a 1% increase in SOC corresponded to a 1-3% increase in soil volumetric water content. Libohova et al. (2018) found a similar relationship between SOM and plant available water.

However, the studies by Minasny & McBratney (2018) and Libohova et al. (2018), while insightful, do not resolve the uncertainty surrounding the relationship between SOM and soil water retention. The meta-analytic methods in both studies fail to distinguish organic matter additions due to exogenous inputs (e.g., sludge or manure) from organic matter added by living
plants and plant residues. Furthermore, neither study spoke to the relative impacts of short-term versus long-term organic matter additions. Daynes et al. (2013) found that soil water content increases most when exogenous organic matter inputs, living plants, and soil fungi are simultaneously present, suggesting that analyses which only investigate exogenous organic matter inputs may fail to accurately describe the full impact that organic carbon has on soil water retention.

One of the soil-water parameters useful for elucidating soil-water characteristics is water holding capacity (WHC). Water holding capacity is the total measure of a soil’s water retention at field capacity (FC). The filter-paper method (Fawcett & Collis-George, 1967; Robertson et al. 1999; Grace et al. 2006) is commonly used in both agronomic and ecological assessments as an inexpensive, rapid means to approximate water holding capacity (Whalley et al. 2013). Field capacity is a characteristic that describes the matric potential and water content at which gravity-driven drainage of a previously saturated soil has become negligible. The period between saturation and negligible drainage under in-situ conditions is usually 48-72 hours (SSSA, 2008). Matric potential at FC generally ranges from -50 to -330 cmH$_2$O (Minasny & McBratney, 2018). Although -330 cmH$_2$O is commonly used to identify field capacity, FC can vary substantially across landscapes, as it is dependent on pore structure and water table depth. Soils have secondary pore structure due to aggregation and can be described using bimodal retention functions (Peters & Durner, 2006; Dexter et al. 2007). As water table depth determines the energy status associated with capillary water, deeper water tables are associated with a more negative average matric potential given that increasingly smaller capillaries are required to conduct capillary flow across greater distances. Matric potential is, therefore, dependent on the size and continuity of voids, soil gases, and soil water content (Kemper & Rosenau, 1986).
To date, few studies have investigated the long-term effects of winter cover crops on soil water retention in temperate cropping systems. Although winter cover crop effects on water retention are not fully understood, a synthesis of the current scientific literature supports the hypothesis that minimal soil disturbance, increased biodiversity, perennial surface cover, and perennial living roots significantly alter soil water retention.

This study investigated the long-term effects of rye winter cover crop management on selected soil properties in a temperate corn silage-soybean cropping system. The main objectives of this study were threefold:

i) Investigate the extent to which long-term (>14 years) rye winter cover crop management alters selected soil properties.

ii) Assess the relative impacts of total and labile organic carbon on soil water retention.

iii) Determine what, if any, significant interactions exist between texture, organic carbon, and water retention in these soils.

Methods

Site and Experimental Plot Description

Field experiments were conducted in Boone County, IA (Lat. 42.007895, Long. -93.791384). Average elevation is approximately 302-m above sea level. This location was chosen, in part, because soil quality enhancements attributable to rye winter cover crop management were previously documented at this site (Moore et al. 2014). The field site was managed with no-tillage and a corn-soybean main crop rotation. Soil samples were taken in early summer each year from 2015-2018. The field site had an area of approximately 1.5 hectares with
a 2% slope (IDNR Staff, 2019). Two soil series, Clarion loam and Nicollet loam, dominate the surrounding landscape (Andrews & Diderikson, 1981; Soil Survey Staff, 2018). Rye winter cover crop treatments and no-tillage were established at the site in 2001.

The experimental layout was a randomized complete block design with treatments randomly assigned to plots in ten blocks. The two treatments analyzed in this experiment were: i) rye cover crop following both corn silage and soybean; and ii) no cover crop. Each experiment plot was 54.9-m long and 3.8-m wide and consisted of five primary crop rows spaced 0.76-m apart. Climate data (Table 1) were recorded approximately 2-km from the field site (Iowa Environmental Mesonet, 2020).

**Crop Management**

Winter-hardy cereal rye (*Secale cereale* – variety not stated) was used for the rye cover crop treatments. Rye was seeded using a no-till grain drill following main crop harvest. Rye seed was drilled into the main crop inter-row in three rows spaced 0.19-m apart. Rye cover crops were terminated with glyphosate 10-14 days prior to main crop planting. Weed management included pre-emergence herbicides in corn and post-emergence applications of glyphosate in both corn and soybean.

**Soil Sampling**

Soil samples were taken early to mid-June during the period when the rye cover crop roots had begun decomposition but before the main crop roots spread into the crop inter-rows. Care was taken to minimize the presence of living roots in the soil samples. Samples were collected from untrafficked crop inter-rows. Intact, undisturbed soil cores were taken in each plot to 5-cm depth using 4-cm diameter, 250-mL stainless steel coring tubes. Bulk soil samples were
taken in each plot to 5-cm depth using a 2.54-cm diameter soil probe and were collected in close proximity to undisturbed soil core sampling locations to minimize spatial variability.

Soil samples were transported to the laboratory in insulated coolers and refrigerated until processing. Bulk soil samples were sieved through 8-mm and 4-mm diameter sieves and then air-dried for 48 hours. After air-dry sample weights were recorded, bulk soil samples were refrigerated until further processing.

**Soil Analysis: Water Retention Curves, Water Holding Capacity, & Pore Size Distribution**

Soil water retention curves were derived through application of pneumatic pressures to a sealed, freely-drained intact soil core at equilibrium, where the amount of water drained was equal to the change in water content of the sample at the negative value of pressure applied (Papendick & Campbell, 1981).

Intact, undisturbed soil cores were weighed and soaked in a solution of 0.01 M calcium chloride (CaCl₂) for 12 hours in a vacuum chamber. Samples were subsequently weighed and placed into sealed pressure cells. A subsequent series of pressures were applied as follows:

- 2.5 cmH₂O (3 hrs)
- 10 cmH₂O (12 hrs)
- 25 cmH₂O (24 hrs)
- 50 cmH₂O (24 hrs)
- 100 cmH₂O (24 hrs)
- 200 cmH₂O (48 hrs)
- 500 cmH₂O (48 hrs)
Drainage was collected and weighed after each pressure application to determine the volumetric water content ($\Theta_v$) at each matric potential. The resulting water retention curves were used to identify soil water content at saturation ($\Psi_m = 0 \text{ cmH}_2\text{O}$) and field capacity ($\Psi_m = -100 \text{ cmH}_2\text{O}$).

Water holding capacity was measured using a filter-paper method adapted from a procedure detailed in Robertson et al. (1999) and Grace et al. (2006) whereby 10-g ($\pm$ 0.05 g) of air-dry soil was completely saturated, covered to minimize evaporative loss, and allowed to drain freely for 6 hours. Mean pore diameter was approximated using the capillary rise equation ($d \approx 0.3/h$, where $h$ is the pressure head expressed in $\text{cmH}_2\text{O}$). As there has been no universal consensus for soil pore size classifications (Luxmore, 1981), distinctions must be made explicit for each study. This study defines macropores as pore spaces with a mean diameter $\geq 30 \mu\text{m}$, whereas micropores are defined as having a mean diameter $< 30 \mu\text{m}$. These classifications were adapted, with modification, from Kirkham (2014).

**Soil Analysis: Particle Size Distribution**

Soil particle size analyses (PSA) were performed using a laser diffraction method (Fig.1) on a Malvern Mastersizer 3000®. Sample preparation was adapted from a method described by Soil Survey Staff (2014). Approximately 10-mL of 30% hydrogen peroxide ($\text{H}_2\text{O}_2$) was added to 10-g of oven-dried soil. Samples were soaked in $\text{H}_2\text{O}_2$ for approximately 2 hours and decanted to remove dissolved organic matter. Samples were then dried at 40°C for 48 hours. Sodium hexametaphosphate ($\text{NaPO}_3\text{)}_6$ was added to the soil solution at a concentration of 0.06 M for particle deflocculation prior to laser diffraction.
Soil Analysis: Organic Carbon

A dry combustion precision analytical method utilizing elemental analysis was used to determine total soil organic carbon (Matejovic, 1993). Permanganate-oxidizable carbon was measured using the procedure outlined by Weil et al. (2003), Culman et al. (2012), and USDA-NRCS (2014). Labile carbon mineralization was measured using a 3-day CO2 flush method adapted from Franzluebbers et al. (2000).

Results & Discussion

Neither bulk density (1.32 ± 0.13 g. cm$^3$), nor texture (Fig. 1) varied significantly across treatments over the duration of this experiment, and there was weak correlation between $\Theta_v$ and all organic carbon analyses, suggesting that increases in relative macroporosity may be responsible, in part, for the observed enhancements in soil water retention.

Total organic carbon was significantly higher in plots managed with a rye cover crop (Fig. 2). Notably the treatment effect for year 2018 was borderline for statistical significance ($P$-value = 0.05). Further study is needed to clarify whether these data are anomalous or the beginnings of a plateau in SOC levels at this site. Labile organic carbon was also significantly higher in rye cover crop plots from years 2015-2017; however, 2018 data were not significantly different (Table 2). Although the cause of variances in 2018 data are unknown, climate influences may be, in part, responsible for the observed variability. Precipitation during June, when samples were taken, was 156-mm above the 50-year average, while air temperatures during the preceding month were 4°C above the 50-year average (Table 1).
Permanganate-oxidizable carbon showed an increase resulting from the cover crop treatments when averaged over the duration of the experiment (Fig. 2). Each labile carbon analysis showed an increase within both cover crop and control treatments, suggesting that long-term no-till management (i.e. 14+ years) alone may increase soil organic carbon.

Soil water retention curves showed that rye cover crop treatment effects were more pronounced at saturation ($P$-value = 0.04) than at field capacity (Fig. 5). Water content at saturation differed while bulk density remained similar, suggesting that there may be particle density differences between treatments. On average, rye cover crops increased soil water retention at saturation by 0.025 g. cm$^{-3}$; however, there were no observed treatment effects on field capacity (Table 2). Field capacity is a characteristic that describes the matric potential and water content at which gravity-driven drainage of a previously saturated soil has become negligible. Although a FC matric potential of -330 cmH$_2$O is commonly used as default, this value does not accurately reflect FC on soils drained by shallow water tables. This study defined FC as the soil water content associated with a -100 cmH$_2$O matric potential. The empirical rate of moisture release change ($\Delta \Theta_v/\Delta \Psi_m$) suggests that a field capacity of -100 cmH$_2$O was most appropriate when interpreting the soil water retention curves detailed herein (Fig. 4). Research by Bonfante et al. (2020) also supports our use of this FC matric potential value.

There were higher volumetric water contents in the cover crop plots during years 2015 and 2016; however, there were no significant differences in either during years 2017-2018 (Fig. 5). Cover crop soils showed greater variance in SWRC from saturation to field capacity (Fig. 4), suggesting more heterogeneity of pore structure distribution in these treatments compared to the control.
While water content varies in the soil profile, there is not always a clear relationship between water content variability and depth; although, there tends to be greater variability in water content closer to the soil surface (Longchamps et al. 2015). Despite this variability, treatment effects were observed for each soil property measured in this experiment, with the exception of bulk density, texture, and field capacity-Θv.

The relatively high degree of soil macrofauna activity (e.g., earthworm middens) in both the cover crop and control treatments may have also contributed to the significant year-to-year variability observed in these data (Fig. 5). High variability in water retention curves are not uncommon. Other studies, including Zhang et al. (2018), also found that management practices cause water retention curves to fluctuate significantly over time. Given the experiment site is located in a temperate clime, annual differences in freeze-thaw cycles may also explain some of year-to-year variability.

Pore volume fraction was approximated using the capillary rise equation (d ≈ 0.3/h, where h = pressure head). Data indicate that relative macroporosity increased 10.1% in cover crop soils over the duration of this study. These results, however, should be interpreted with caveat. While pore volume is approximated using the capillary rise equation, pore drainage is largely a function of mean pore neck diameter. Therefore, calculated values based on pore volume drainage at a specific pressure head may not fully represent pore neck diameter distributions.

Rye cover crops, on average, increased water holding capacity by 0.034g. cm$^3$ compared to the control treatments (Fig. 6). It is important to note that extrapolation of laboratory matric potential measurements to in-situ scenarios may not always be applicable (Papendick &
Campbell, 1981), especially given the complex variables associated with in-situ soils. However, despite these limitations, the laboratory-derived data herein provide for comparative analyses of management practices and offer a reasonable estimate of in-situ soil water retention.

**Conclusion**

Long-term rye winter cover crop management has significant impact on near-surface soil properties in a temperate corn silage-soybean cropping systems. Our data show that rye winter cover crops enhance relative soil macroporosity and water holding capacity while also augmenting organic carbon. Although rye cover crops enhanced organic carbon, there was weak correlation between enhanced organic carbon and increased water retention. These data offer timely insight into the potential of rye cover crops to enhance soil water holding capacity and drainable macroporosity.

**Tables and Figures**

Table 1. Average monthly air temperature and total precipitation.

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Average Air Temperature (°C)
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<td>90</td>
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† Average values for January through December.

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**Particle Size Distributions**

![Particle Size Distributions](image)

**Soil Texture Class:** Sandy Loam

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Figure 1. Particle size distributions
Table 2. Summary statistics of selected soil properties (2015-2018).

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<td></td>
<td>x̅ SD</td>
<td>max</td>
<td>min</td>
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<td>Total Organic Carbon (%)</td>
<td>2.02 ± 0.34</td>
<td>2.53</td>
<td>1.51</td>
<td>Total Organic Carbon (%)</td>
<td>1.57 ± 0.26</td>
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<td>POXC (mg/kg⁻¹ soil)</td>
<td>562 ± 118</td>
<td>736</td>
<td>482</td>
<td>POXC (mg/kg⁻¹ soil)</td>
<td>366 ± 63</td>
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<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>46 ± 15</td>
<td>30</td>
<td>67</td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
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<td>WHC (Θg)</td>
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<td>0.60 ± 0.03</td>
<td>0.65</td>
<td>0.56</td>
<td>Θv-Saturation</td>
<td>0.52 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>Θv-Field Capacity</td>
<td>0.34 ± 0.02</td>
<td>0.37</td>
<td>0.33</td>
<td>Θv-Field Capacity</td>
<td>0.39 ± 0.02</td>
</tr>
<tr>
<td>2016</td>
<td>Total Organic Carbon (%)</td>
<td>2.26 ± 0.20</td>
<td>2.59</td>
<td>1.86</td>
<td>Total Organic Carbon (%)</td>
<td>1.89 ± 0.25</td>
</tr>
<tr>
<td></td>
<td>POXC (mg/kg⁻¹ soil)</td>
<td>610 ± 78</td>
<td>714</td>
<td>496</td>
<td>POXC (mg/kg⁻¹ soil)</td>
<td>423 ± 76</td>
</tr>
<tr>
<td></td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>37 ± 19</td>
<td>23</td>
<td>60</td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>24 ± 12</td>
</tr>
<tr>
<td></td>
<td>WHC (Θg)</td>
<td>0.34 ± 0.01</td>
<td>0.37</td>
<td>0.33</td>
<td>WHC (Θg)</td>
<td>0.31 ± 0.01</td>
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<td></td>
<td>Θv-Saturation</td>
<td>0.55 ± 0.06</td>
<td>0.62</td>
<td>0.47</td>
<td>Θv-Saturation</td>
<td>0.53 ± 0.05</td>
</tr>
<tr>
<td></td>
<td>Θv-Field Capacity</td>
<td>0.29 ± 0.06</td>
<td>0.36</td>
<td>0.20</td>
<td>Θv-Field Capacity</td>
<td>0.26 ± 0.03</td>
</tr>
<tr>
<td>2017</td>
<td>Total Organic Carbon (%)</td>
<td>2.23 ± 0.27</td>
<td>2.57</td>
<td>1.6</td>
<td>Total Organic Carbon (%)</td>
<td>1.80 ± 0.32</td>
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<tr>
<td></td>
<td>POXC (mg/kg⁻¹ soil)</td>
<td>610 ± 83</td>
<td>743</td>
<td>481</td>
<td>POXC (mg/kg⁻¹ soil)</td>
<td>433 ± 108</td>
</tr>
<tr>
<td></td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>35 ± 13</td>
<td>67</td>
<td>20</td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>22 ± 8</td>
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<td>WHC (Θg)</td>
<td>0.34 ± 0.02</td>
<td>0.36</td>
<td>0.31</td>
<td>WHC (Θg)</td>
<td>0.33 ± 0.02</td>
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<tr>
<td></td>
<td>Θv-Saturation</td>
<td>0.61 ± 0.02</td>
<td>0.64</td>
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<td>Θv-Saturation</td>
<td>0.60 ± 0.03</td>
</tr>
<tr>
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<td>Θv-Field Capacity</td>
<td>0.37 ± 0.04</td>
<td>0.46</td>
<td>0.32</td>
<td>Θv-Field Capacity</td>
<td>0.40 ± 0.03</td>
</tr>
<tr>
<td>2018</td>
<td>Total Organic Carbon (%)</td>
<td>2.06 ± 0.35</td>
<td>2.72</td>
<td>1.56</td>
<td>Total Organic Carbon (%)</td>
<td>1.77 ± 0.29</td>
</tr>
<tr>
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<td>POXC (mg/kg⁻¹ soil)</td>
<td>641 ± 101</td>
<td>804</td>
<td>458</td>
<td>POXC (mg/kg⁻¹ soil)</td>
<td>525 ± 153</td>
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<tr>
<td></td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>32 ± 17</td>
<td>64</td>
<td>14</td>
<td>LCM 72-hr. (µCO₂/g⁻¹ soil)</td>
<td>29 ± 10</td>
</tr>
<tr>
<td></td>
<td>WHC (Θg)</td>
<td>0.33 ± 0.03</td>
<td>0.35</td>
<td>0.28</td>
<td>WHC (Θg)</td>
<td>0.30 ± 0.02</td>
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<td>0.59 ± 0.02</td>
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<td>Θv-Saturation</td>
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<td>0.36 ± 0.01</td>
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<td>Θv-Field Capacity</td>
<td>0.36 ± 0.02</td>
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Figure 2. Total and labile organic carbon analyses with standard errors (2015-2018): Total organic carbon (top), Permanganate-oxidizable carbon (bottom).
Figure 3. Relative pore size distributions (2015-2018)
Soil Water Retention Curves (2015)

Figure 4a. Soil water retention curves (2015). Heavy lines are treatment means.
Figure. 4b. Soil water retention curves (2016). Heavy lines are treatment means.
Figure 4c. Soil water retention curves (2017). Heavy lines are treatment means.
Figure 4d. Soil water retention curves (2018). Heavy lines are treatment means.
Figure 5. Water content at saturation and field capacity (2015-2018).
Figure 5 Continued
Figure 6. Average water holding capacity using the simplified filter paper method (2015-2018).

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Iowa Department of Natural Resources. IDNR Staff. 2019. Iowa LiDAR elevation profiles. Iowa Department of Natural Resources. https://programs.iowadnr.gov/maps/elevation/ (accessed 31 May, 2019).


CHAPTER 3. FARM-SCALE EVALUATION OF EPIPEDON MAPS ON DES MOINES LOBE SOILS: A CASE STUDY OF THE BOYD RESEARCH FARM

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Modified from a manuscript to be submitted to the Journal of Soil & Water Conservation

Abstract

The Des Moines Lobe has some of the most detailed and thoroughly documented field soil maps of any region in the world. Publicly available soil maps, particularly those under the auspices of USDA-NRCS, are regularly used by land managers and academicians alike to elucidate soil properties and landscape functions. However, Web Soil Survey (WSS), a commonly used USDA-NRCS soil map interface may, despite its many merits, have limited utility with regards to farm-scale interpretations, especially as they pertain to real-time soil management. This case study evaluates WSS maps to determine what, if any, additional pedometric data significantly improves WSS map utility at farm-scale on mollic epipeds typical of the Des Moines Lobe landform. Five epipelon biophysical properties (particle size distribution, bulk density, pH, organic carbon, and total nitrogen) were intensively sampled (n ≈18 ha⁻¹) and independently analyzed for comparison to WSS maps of the area. Results show that most measurements were accurately detailed by current WSS maps; however, there were notable exceptions for fine sand and pH distributions. Particle size analyses indicated an unexpected distribution of fine sand as a function of elevation, with hill summits having the highest volume fraction of fine sand. Aeolian saltation, a mechanism seldom considered in hillslope sediment transport processes in the region can, in part, explain the observed distributions. Soil pH measurements across the landscape also differed significantly from WSS values. Soil pH was significantly increased on soils within 65-m of the roadway. Aeolian
depositions from the adjacent limestone gravel roadway may have significantly contributed to the observed pH distributions. These data suggest that modern aeolian deposition plays a more significant role in describing epipedon properties on the Des Moines Lobe landform than previously thought, and therefore warrants consideration when designing and assessing soil maps in the region.

**Abbreviations:** LiDAR-light detection and ranging, UMRB-Upper Mississippi River Basin, PSA-particle size analysis, PTF-pedotransfer function, SMU-soil map unit, SOC-soil organic carbon, SOM-soil organic matter, SWR-soil water retention, TN-total nitrogen, USDA-NRCS-United States Department of Agriculture Natural Resource Conservation Service, WSS-Web Soil Survey

**Introduction**

The Des Moines Lobe is renowned for its highly productive maize-soybean row crop agriculture, which dominates land use in the region. However, the region’s productivity has come at significant costs to soil and water resources. Severe and persistent soil degradation has continued to cause significant environmental impacts to water quality across the Upper Mississippi River Basin (UMRB). The magnitude of soil degradation has altered soil formation and transformation processes in ways that may hinder the continued viability of rainfed cropping systems in the region.

Of the six factors that drive soil formation; biota, climate, parent material, topography, time, and human impact (Jenny, 1980), human impact has often been a dominant force in re-shaping Des Moines Lobe landscapes in the modern era (Veenstra & Burras, 2015). Amundson et al. 2015 argue that the impact of management on agricultural soils parallels the impacts of
glaciation in terms of the speed and magnitude in which soil changes are occurring. Jenny (1941) considered climate particularly important to soil formation, especially given its interdependence with the other soil forming factors. A changing climate will likely exacerbate anthropogenic soil degradation in the UMRB as precipitation events are expected to occur with increasing severity and frequency (Melillo et al. 2014).

Shifting climate patterns, along with concomitant increases in extreme precipitation events, will undoubtedly influence near-surface soil hydrological processes in the Upper Mississippi River Basin. Accelerated rates of sediment transport and deposition can alter soil surface hydrology in several key ways, including diminished soil water holding capacity and reduced effective porosity. Although residual porosity may increase as a result of increased bulk density in the near-surface layer, these increases would not fully offset losses in relative macroporosity. Furthermore, the positive feedback mechanisms driving soil erosion processes will intensify over time if current levels of degradation are left unmitigated. Although the impacts of soil degradation have been masked by increases in crop productivity resulting from technological advancements, unabated soil degradation will undoubtedly impede efforts to foster sustainable intensification in the region.

Soil degradation, coupled with the ever-increasing demands on soil resources, necessitates reliable data inventories to inform soil and water management practices. Current, accurate farm-scale soil data inventories are a vital precursor for transitioning towards sustainable water management in the Upper Mississippi River Basin. Reliable soil maps can play an essential role in the design and evaluation of improved soil-water management practices; however, existing soil maps may have limited utility at farm-scale. Although the need for reliable
soil inventories is urgent across the UMRB, the need is especially acute for intensively cultivated sub-regions such as the Des Moines Lobe.

The Des Moines Lobe is a geographic area characterized by relatively young mollic soils and poorly drained level-relief landscapes; many of which are dominated by a Clarion-Nicollet-Webster soil association (Soil Survey Staff, 2017). Landscapes in the region were shaped during the retreat of the Wisconsinian Glacier approximately 12,000 B.P., leaving the Des Moines Lobe in its wake (Prior, 1991). The glacial retreat that formed the Des Moines Lobe was marked with significant periods of ice stagnation and melting; resulting in the glacial-till depositions that constitute soil parent material throughout the region (Prior, 1991).

The Des Moines Lobe has some of most detailed and thoroughly documented field soil maps of any region in the world, with soil surveys dating back 100+ years (USDA Staff [2], 2017). Publicly available soil maps, particularly those under the auspices of USDA-NRCS, are regularly used by land managers and academicians alike to elucidate soil properties and landscape functions. Web Soil Survey (WSS) is a commonly used USDA-NRCS soil map interface. However, Web Soil Survey may, despite its many merits, have limited utility at farm-scale, especially as it pertains to real-time soil management.

Many of the soil properties most sensitive to management changes are being altered at rates faster than soil maps are being updated. Richter & Burras (2017) posit that management impacts, which are largely absent from classic catena models, can alter catena functioning at a rate that far outpaces soil map creation. Therefore, pedometrics assessed to create soil maps decades ago may fail to adequately describe current soil properties that have been altered by more recent management practices.
Consensus among catena association studies of Des Moines Lobe soils suggest a predictable distribution of soil biophysical properties based on hillslope position (Walker & Ruhe, 1968; Burras & Scholtes, 1987; Steinwand & Fenton, 1995; Richter & Burras, 2017). Walker & Ruhe (1968) observed a pattern of increasing percent volume of finer sediments from summit to toeslope position, which the authors attributed to preferential erosion of finer sediments. Data from Burras & Scholtes (1987) and Gelder et al. (2018) show that Anthropocene soil erosion exceeds non-anthropogenic Holocene soil erosion rates by at least an order of magnitude. However, despite the impact of soil erosion on the region’s landscapes, human impact is not regularly considered in classic catena models. As such, Richter & Burras (2017) argue for improved soil maps that incorporate more sophisticated catena models.

Reliable, accessible field-scale soil maps can play a prominent role in the design and assessment of soil-water management practices, which is especially salient given the scale and intensity of the region’s current and projected land uses. However, web-based soil maps in the public domain, particularly those under the ambit of USDA-NRCS may have limited utility with regard to real-time farm-scale management interpretations. Therefore, this study conducted a site-specific case analysis to evaluate USDA-NRCS Web Soil Survey maps. The objective was to compare ground-truth and WSS data to identify what, if any, pedometric data could improve soil map utility at farm-scale on mollic epipedons typical of the Des Moines Lobe landform.

**Methodology**

This case study assessed the Iowa State University Boyd Research Farm in November 2017. The site is located in Boone County, Iowa (Lat. 42.007 Long. -93.791) on the Des Moines Lobe landform. Elevation data (Map 5) were collected using publicly available LiDAR and
Ortho-GIS data (IGMS 2019, IDNR Staff 2019). Field slope is approximately 2% and mean site elevation is 332-m above sea level. Fixed infrastructure and geographic features were used to establish global positioning system benchmarks and sampling location coordinates. A grid-sampling technique was used to ground-truth epipedon pedometrics. Soil samples were collected every 30-m south, and every 20-m east starting from the northwest farm boundary (Map 2). The sampling area comprised approximately 50,225 m², or 5 hectares. A total of 93 locations were sampled to a depth of 15-cm using a 2-cm diameter probe. Approximately 60-g of soil was collected at each sampling location. All soil sampling occurred subsequent to crop harvest.

**Pedometric Analyses**

Epipedon properties, including bulk density, particle size distribution, pH, organic carbon, and total nitrogen were analyzed for comparison to WSS data from the field site. Soil water content and bulk density were analyzed using a gravimetric method. Field moist soil weight was recorded and then sub-samples were oven-dried at 105º C for 24 hours to determine gravimetric water content. Soil particle size analysis (PSA) via laser diffraction was conducted on a randomized sub-set (n=38) of soil samples. Sample preparation, including organic matter oxidation and particle deflocculation employed methods described by Soil Survey Staff [1] (2014). Soil pH was analyzed via pH reference electrode using a 1:1 water-pH method as described by Soil Survey Staff [1] (2014). Soil organic carbon analysis was conducted using a modified loss-on-ignition technique as described by Schulte & Hopkins (1996) while total nitrogen was analyzed using a dry combustion method as described by Amacher et al. 2003.
Web Soil Survey Data Analyses

USDA-NRCS Web Soil Survey data (Soil Survey Staff, 2017) were assessed against ground-truth data to determine congruity at farm-scale. The WSS data criteria used in these analyses were:

Aggregation method: Weighted average
Tie break rule: Higher
Interpret null as zero: No
Depth range: 0-15cm

Soil series determination using both tabular and spatial data (Map 1), along with texture classification and particle size distribution were used for comparative analyses. Soil bulk density at 33 kPa, as well as 1:1 pH and soil organic matter were also used to assess WSS data congruity. Soil organic matter (g g⁻¹ soil) was approximated using a soil organic carbon conversion factor detailed in the WSS analyses descriptions (Soil Survey Staff, 2017).

Results and Discussion

Publicly available WSS and Ortho-GIS data were used to evaluate elevation (Map 5), and landscape gradients (Map 4). While Web Soil Survey cautions “soil map may not be valid at this (farm) scale” there is general congruity between ground-truth and WSS for most of the selected soil biophysical properties. There were, however, notable exceptions.

Web Soil Survey soil pH (Map 3) showed poor congruity with ground-truth data. Soil pH did however, show significant variation in relation to road proximity (Fig. 3). A limestone gravel road is located 5-m from the northernmost sampling locations (Map 2), and given that a major
constituent of gravel roads in this region are limestone (CaCO$_3$), aeolian roadway dust
depositions could be, in part, responsible for the observed soil pH distributions. Ground-truth
data show that soil pH is significantly higher at distances ≤ 65-m from the road (Fig. 3). There
was no evidence to support that the soil pH distributions were as a function of elevation.
Previous research by Richter & Burras (2017) also found no general correlation between pH and
landscape position across multiple sites on the Des Moines Landform. Therefore, proximity to
gravel roads should be taken into consideration when modeling and mapping soil pH in the Des
Moines Lobe region.

Particle size analyses indicate that loam is the dominant soil texture class (Fig. 5). Particle
size descriptive statistics indicate a substantive degree of variance in the sand fraction (Fig. 4).
Although large variances in sand percentage are not entirely unexpected given the wide range of
particle sizes that are classified as sand (i.e. 50 to 2000-μm diameter), the distribution of sand,
and fine sand (50 to 250-μm) in particular, was unexpected. Ground-truth data show unexpected
concentrations of fine sand as a function of elevation, with hill summits having the highest
percentage of fine sand. Conflation of gravel-dust and fine sand-sized particles was deemed a
non-factor given that hill summits at the site are located furthest away from gravel roads. The
observed fine sand distribution may be attributable to preferential saltation of fine sand initiated
by water-erosion particle dispersion. Further research is needed, however, to conclusively
determine whether the observed fine sand distributions are attributable to Holocene or
Anthropocene factors.

Although field site slope is relatively low (≈ 2%), the landscape gradient is significant
enough to observe sediment transport processes. Notably, distribution of clay (Fig. 2) and SOC
(Fig. 1) did follow expected patterns of distribution as a function of elevation. Web Soil Survey
does not directly report SOC data, and therefore SOC data were approximated using a conversion of soil organic matter values. A SOM-SOC conversion factor of 0.55 g·SOC/g·SOM (Soil Survey Staff, 2017) was used to compare ground-truth and WSS data. Soil organic carbon (SOC) showed variation as a function of elevation across the site, with locations at lower elevations having higher SOC values (Fig. 1). This distribution is well-explained by classic hillslope models (Walker & Ruhe, 1968; Burras & Scholtes, 1987; Steinwand & Fenton, 1995; Richter & Burras, 2017).

These data indicate that while current Web Soil Survey maps show congruity with most of the measured soil properties selected for this study, WSS maps may not fully account for significant aeolian deposition effects on the Des Moines Lobe soils. In short, these data suggest that aeolian deposition may play a more significant role in predicting epipedon properties on the Des Moines Lobe than previously thought. As such, aeolian deposition should be considered in the design and interpretation of soil maps in the region.

**Conclusion**

The Des Moines Lobe is one of the world’s most highly productive rainfed agriculture regions. Demands on the region’s soil and water resources will likely increase, necessitating current and accurate farm-scale soil map inventories. This case study evaluated existing publicly available USDA-NRCS soil maps to assess their utility at farm-scale. Ground-truth data show that while these maps are reliable for most of the selected soil biophysical properties, they do not accurately describe soil pH and fine sand distribution at farm-scale. Our analyses suggest that modern aeolian deposition plays a more significant role in describing epipedon properties on the Des Moines Lobe landform than previously thought. Therefore, aeolian deposition should be
considered in the design and assessment of soil and water management tools in the Des Moines Lobe region.

Maps, Tables, and Figures

Map 1. Boyd Farm WSS Soil Consociation Units & Legend

135: Coland Clay
485: Spillville Loam
585B: Coland-Spillville Complex
L55: Nicollet Loam
L138B: Clarion Loam
Map 2. Boyd Farm sample area.
Map 3. Boyd Farm WSS soil pH
Map 4. LiDAR 1-m hillshade (top) & USDA Spring 2017 orthophotos (bottom). IGMS (2019)
Table 1. Data from Boyd Farm soil sample analyses.

<table>
<thead>
<tr>
<th>Boyd Farm Epipedon Pedometrics</th>
<th>n</th>
<th>$\bar{x}$ SD</th>
<th>max</th>
<th>min</th>
<th>mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density (g/cm$^3$)</td>
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<td>1.50 ± 0.22</td>
<td>1.87</td>
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<td>Soil Organic Carbon (%)</td>
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<td>1.98 ± 0.70</td>
<td>4</td>
<td>1.15</td>
<td>1.88</td>
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<td>Soil pH</td>
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<td>6.15 ± 0.68</td>
<td>7.5</td>
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</tr>
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<td>Clay -laser diffraction (%)</td>
<td>38</td>
<td>23.43 ± 2.33</td>
<td>27.53</td>
<td>18.94</td>
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</tr>
<tr>
<td>Silt -laser diffraction (%)</td>
<td>38</td>
<td>36.54 ± 2.69</td>
<td>41.55</td>
<td>32.79</td>
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</tr>
<tr>
<td>Sand -laser diffraction (%)</td>
<td>38</td>
<td>40.00 ± 4.83</td>
<td>47.74</td>
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<td>N/A</td>
</tr>
<tr>
<td>Soil Texture</td>
<td>38</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Loam</td>
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</tbody>
</table>
Figure 1. Ground-truth values for SOC as a function of elevation.

Soil Organic Carbon and Elevation

$R^2 = 0.5701$
Figure 2. Clay and fine sand distributions as a function of elevation.
Figure 3. Average soil pH as a function of distance from limestone gravel road.
Figure 4. Boyd Farm particle size distributions.
Figure 5. Boyd Farm soil texture classification randomized subset (n=38). USDA Staff (2019) Soil Texture Calculator.

References


CHAPTER 4. DEVELOPMENT OF AN INTERACTIVE TEACHING-AS-RESEARCH PEDAGOGY FOR UNDERGRADUATE SOIL SCIENCE LEARNING

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Authors’ affiliation: Iowa State University

Modified from a manuscript to be submitted to the North American Colleges and Teachers of Agriculture Journal

Abstract

The importance of soils and their role in economic and environmental health is becoming increasingly recognized in programs of study outside of the traditional academic domain of agronomy. However, exceedingly few undergraduate academic programs offer interactive engagement in soils learning and research as a matter of course. This study describes the design, implementation, and evaluation of an interactive teaching-as-research pedagogy for undergraduate soil science learning. Students with varied academic concentrations and a-priori soils knowledge were invited to participate in on-going soil hydrology research. Interactive soil science training was given to three groups of students, each having one of the following foci: A) pedological field assessments and soil map evaluation, B) laboratory analyses of soil health indicators, and C) laboratory analyses of soil hydrologic properties. Pedagogy efficacy was assessed through student self-evaluations utilizing both ranked and free-written responses. Upon course conclusion, students were asked to rank their individual learning on a 1-10 scale: (1=learned nothing, 10=gained significant knowledge). Summative student self-assessments reported a weighted average of 9.1 for soils knowledge gains, 7.2 for scientific communication gains, and 7.9 for laboratory skill gains. Free-written responses indicated that students highly valued the interactive focus of the learning experiences beyond any course credit incentives; with 89% of students reporting that they would have participated in the learning experience even in
the absence of course credit. Interactive participation and learner-centered instruction were the most cited favorable program aspect amongst all groups, whereas inclement field conditions were the least favorable program aspect amongst Group (A); and time limitations for extended course engagement was the least favorable program aspect amongst Group (B) and Group (C). These data suggest that a learner-centered interactive teaching-as-research pedagogy can be an especially effective means of enhancing undergraduate students’ soils knowledge, scientific communication, and technical laboratory skills.

Abbreviations: FC-field capacity, GPA-grade point average, PAW-plant available water, POM-particulate organic matter, SOC-soil organic carbon, SOM-soil organic matter, USDA-ARS-United States Department of Agriculture Agricultural Research Service

Introduction

The interwoven challenges of a growing global population, climate change, and natural resource depletion pose serious challenges to the environmental and economic wellbeing of global civilization. These challenges require technical solutions that are both circumspect and sustainable: solutions that cannot be facilitated in absence of intensive human capital investments, particularly in the applied natural sciences. Tertiary education institutions are well-positioned to respond to this urgent demand; however, few academic programs offer students the opportunity to engage in interactive soil science learning and research as a matter of course. A dearth of interactive learning experiences may hinder development of students’ critical analysis and technical skills; thus impeding students’ ability to be globally competitive in graduate education and/or scientific careers. Given these challenges, a teaching-as-research pedagogical
model offers a promising framework to improve student mastery of scientific and technical concepts in the applied natural sciences.

Conventional teacher-centered approaches focus heavily on content knowledge transmission by a subject area expert, while learner-centered approaches, on the other hand, involve a facilitation of learning environments through focus on students’ individual backgrounds, interests, and needs within the context of a subject area (McCombs & Whisler, 1997, Brown, 2003). Although both of these pedagogical approaches have contextual merits and limitations, learner-centered approaches are specifically designed to nurture the intellectual curiosity, creativity, and critical thinking skills. One of the learner-centered approaches to instruction that is becoming increasingly recognized is teaching-as-research, a pedagogical practice that employs “deliberate, systematic, and reflective use of research methods to develop and implement teaching practices that advance the learning experiences and outcomes of students” (CIRTL Staff, 2019).

The need for more instruction practices that place primacy on the needs of the learner is made evident through examination of typical undergraduate research experiences. A common refrain among undergraduates is that internships and employment experiences in the applied natural sciences too often focus on the throughput of student labor with little thought given to the development of higher-order understanding. This managerialist approach leaves many students without a clear understanding of the practical science or theory underlying the tasks they are being asked to perform, and thus adds little to students’ intellectual development. As such, the novel teaching-as-research pedagogy detailed herein is predicated on the hypothesis that learner-
centered, interactive experiences linked to on-going soil science research projects significantly improves undergraduate student learning and interest in soil science. This pedagogical framework addresses the relative lack of interactive undergraduate participation in on-going research projects through offering a learner-centered scientific research experience. Therefore, objectives for development, implementation, and evaluation of our pedagogy were fourfold:

i) Create well-defined student learning objectives.
ii) Define the standards by which student learning outcomes will be assessed.
iii) Develop and implement learner-centered teaching practices to achieve student learning objectives.
iv) Evaluate the resultant teaching model for efficacy as an undergraduate soil science pedagogical tool

**Methodology**

Students with varied academic concentrations and a-priori soils knowledge were given an opportunity to participate in data collection, processing, and analysis as part of a soil hydrology research venture under the joint auspices of Iowa State University and United States Department of Agriculture – Agricultural Research Service (USDA-ARS) during the 2017-2019 academic years. Student participation was recognized with earned course credit under agronomy and environmental science at Iowa State University. A total of 24 students participated in the program (Table 1). Students were allocated into one of the following groups:
Group A - Pedological field assessments and soil map evaluation (n=11)

Group B - Laboratory analyses of soil health indicators (n=5)

Group C - Laboratory analyses of soil hydrologic properties (n=8)

A teaching-as-research framework was used in the design, implementation, and evaluation of our pedagogy as outlined by the Center for the Integration of Learning and Teaching (CIRTL Staff, 2019), which lists the conceptual steps of the teaching-as-research process as:

1. Learn foundational knowledge.
2. Create objectives for student learning.
3. Develop a hypothesis for practices to achieve the learning objectives.
5. Develop and implement teaching practices within an experimental design.
6. Collect and analyze data.
7. Reflect, evaluate, and iterate.

Student interest in the interactive soil hydrology research project exceeded availability; necessitating the use of selection criteria. Diversity of student participants was the primary selection criterion. Every effort was made to facilitate a diversity of race, gender, and a-priori knowledge. Grade point average (GPA) was the secondary selection criterion. As our goal was the development of a pedagogical tool effective across a broad range of students, not only those with exceptional academic performance records, students with a cumulative GPA of 2.2 - 3.2
(0 - 4.0 scale) were prioritized. The learning objectives were presented to each group at program commencement:

**Group (A)**- Develop technical skills to conduct in-field soil analyses and better understand the process of soil map creation.

**Group (B)**- Develop technical, communication, and critical thinking skills useful to understanding soil health and soil biogeochemical laboratory analyses.

**Group (C)**- Develop technical, communication, and critical thinking skills useful to understanding soil water flow and retention.

Learning objectives were achieved through instruction and activities that employed a learner-centered pedagogical approach within the context of teaching-as-research. Efficacy of our teaching-as-research pedagogy was quantified via student self-evaluation metrics (Fig. 1). These evaluations utilized both ranked and free-written responses. Pedagogy success was defined as learning outcomes that either ranked above average ( > 5.0 ) on ranked responses, or demonstrated increased student enthusiasm and/or interest on soil science. An initial one-on-one interview was conducted with all participants. The students’ individual backgrounds, interests, and learning needs were used to tailor each participants learning experience within the ambit of their group’s learning objective. In addition to mandatory supervised technical and safety training, students were required to develop and communicate a final research report.
Results & Discussion

Group A: Pedological field assessments and soil map evaluation

Students in Group (A) analyzed in-field pedological data, including A horizon depth, soil matrix color, soil structure, inorganic carbon concretions, and texture at the Iowa State University Boyd Research Farm (Lat. 42.007 Long. -93.791) (Map 1). Soil texture was approximated using a modified hand-feel method described by Thien (1979). Students in this cohort had learning objectives that focused on both soils and geography knowledge acquisition. Student free-written self-evaluation comments offered revelatory insight into our pedagogy’s foundational hypothesis. When invited to comment on their individual learning experiences, student responses ranged from the general, “(learned) how soil sampling works and how to go about it”, to the more specific “(learned about) concretions and oxidation/reduction”. Furthermore, student responses to the question “What was your favorite part of this activity?” generally centered around the interactive and learner-centered aspects of our pedagogy:

“Learning how to determine soil structure”.

“hands on learning”.

“when I found (soil inorganic carbon) effervescence”.

“real world experience”.

“learning and participating in something I haven’t done before”.
In response to the question “What was your least favorite part of this activity?” students cited inclement weather and physical fatigue; with 66% of respondents specifically mentioning cold and/or windy conditions as the least favorable aspect of their learning experience. This cohort reported significant gains in soil knowledge (8.6) and modest (6.3) gains in geography knowledge (Table 2). Students all reported that they would have participated in these soil field measurements even in the absence of earned course credit; suggesting that these students placed a high-degree of intrinsic value on the learning experience.

**Group B: Laboratory analyses of soil health indicators**

Students in Group (B) performed laboratory analyses of soil health indicators, including gravimetric water content, bulk density, particle size analyses, pH, and soil organic matter content. Students in this cohort had learning objectives that focused on the acquisition of soils knowledge, technical skills, and critical analysis. Student self-evaluations reported exceptional gains in soil knowledge (9.8) and communication skills (9.2), with lesser, although significant (7.6) gains in technical laboratory skills (Table 2). Student responses to the question “What was your favorite part of this Research Project?” shared common themes related to the learner-centered foci of our pedagogy:

“The involvement in lab techniques and practices. I didn’t study soil before, this is an eye-opening experience to learn the basics of soil”.

“The ability to have authority on my personal (lab) report, as well as have a mentor to guide the writing quality and direction of the report. I also appreciated the environment
where I could embark on a challenge and engage with the material hands-on”.

“being able to gain knowledge on a topic I was entirely unfamiliar with by jumping in and doing hands-on analysis”.

“having to practice on the spot problem solving and the educational talks with (the instructor)”.

“choosing the topics I wanted to work on”

Student responses to the question “What was your least favorite part of this Research Project?” also shared common themes; the most common being that either they felt the question was not applicable to their experience (40%), or the limited time for on-going participation (40%). The repetitiveness laboratory analyses was also cited, although at a much lower rate (20%) than the other aforementioned responses. The majority (80%) of this cohort reported that they would have participated in the laboratory analyses even in the absence of earned course credit.

**Group C: Laboratory analyses of soil hydrologic properties**

Students in Group (C) performed laboratory analyses of soil hydraulic properties, including volumetric water content, particle size analyses, saturated hydraulic conductivity, and soil water retention curves. Students in this cohort had learning objectives that focused on the acquisition of soils knowledge, technical skills, and critical analysis. Student self-evaluations reported exceptional gains in soil knowledge (9.0) and significant gains in technical laboratory
skills (8.1). However, students reported very modest (5.9) gains in communication skills (Table 2). Similarly, to Group (A) and Group (B), student responses to the question “What was your favorite part of this Research Project?” shared themes consistent with the learner-centered foci of our pedagogy:

“Being able to have discussions on the topics before doing lab work”.

“Lab work, very monotonous, but interesting”.

“The hands-on experience and the ability to ask questions”.

“Being able to learn while doing hands on work”.

“opportunity to communicate one on one and to work in lab”.

“1 on 1 and small group interaction”.

“Learning about my particular project details and what it is”.

“Learning all of the material, working closely with peers and (instructor)”.
Student responses to the question “What was your least favorite part of this Research Project?” also shared common themes, the most common being the lack of time (25%); i.e. preference for extended course duration and extending meeting opportunities. Another least favorable aspect of the experience was the final student presentations (13%), which involved a public speaking event to present preliminary research data. A majority (87%) of this cohort reported that they would have participated in the laboratory research even in the absence of earned course credit.

**Analysis of Pedagogy Efficacy**

Students reported exceptional soil science learning, with a weighted average of 9.1 for soils knowledge gains across all groups. Technical laboratory skill gains were also significant, with a weighted average of 7.9 across all groups. Student willingness to participate in the project solely for the intrinsic learning value was also high, with 89% of all participants saying that they would participate in the program even in the absence of earned course credit. While encouraging, these data should be interpreted within context given that student participation was selective. Student sampling bias was undoubtedly a factor given that all student participation was entirely voluntary; thus students that participated were already highly motivated to learn more about the subject matter. The type of interactive learning environment also played a role in how well students learned. While students engaged with in-field assessments reported an average of 8.6 for soil knowledge gains, students engaged in laboratory assessments reported an average of 9.3 for soil knowledge gains.

Development of enhanced scientific communication skills was integral to the learning objectives in two of the three student groups. Data show that, on average, learning gains were
significant for scientific communication skills, with a weighted average of 7.2 for scientific communication skill gains across all groups (Table 2). Student responses to communication activities, including public speaking and written reports, were in some cases cited as the least favorable aspect of the learning experience. Future iterations of our pedagogy that incorporate a scaffolded approach to communication building activities may ease anxiety associated with public speaking and technical writing.

Data analyses of our pedagogy demonstrates the general efficacy of our approach with regards to soil science learning and technical laboratory skills acquisition across all sample groups (Table 2); however, there are several important caveats that should be considered when contextualizing these data. For example, the efficacy of our pedagogy was measured against student self-assessments of learning and not to an objective assessment. While the evaluation metric used in our study is wholly consistent with a learner-focused pedagogical ethos, the addition of some standardized assessments may have helped better elucidate student learning.

Additionally, a comparative analysis of students participating in our pedagogy with students spending comparable time in a traditional learning environment was not conducted. While the prior point is highlighted to provide context for interpreting our data, it is not particularly problematic given that goal of our study was not a direct comparison across various pedagogical approaches. Rather, the goal of our study was to measure the effectiveness of an interactive learner-centered approach through real-world research projects, with an emphasis on students’ self-perceptions of learning gains and skills acquisition. While a direct comparison
across various pedagogical practices was outside the ambit of our study, these data indicate significant, positive learning experiences associated with our pedagogical framework.

The relatively small sample size of students also warrants mention. Student enrollment was kept deliberately low to facilitate the time demands of a learner-centered interactive pedagogy. As such, this study was not designed to assert broad, general claims on the effectiveness of our approach across the majority of tertiary education environments. However, despite the limitations of a smaller data set, our data clearly demonstrates contextual efficacy of our pedagogical framework.

Instructor time investments are also noteworthy. The amount of individualized time that each student required was inherently variable across students given the nature of learner-centered education; however, it is worth noting that the supplemental time investments required to execute this pedagogy were non-trivial. This is not to say that the overall student learning per unit time invested was inefficacious; rather that the pedagogy detailed herein is best suited for situations in which depth of student learning takes primacy over breadth of content dissemination.

**Conclusion**

A learner-centered teaching-as-research pedagogy meets the urgent need for substantive and interactive undergraduate soil science learning. Our data suggest that a learner-centered interactive teaching-as-research pedagogy can be an especially effective means of enhancing undergraduate students’ soils knowledge, scientific communication, and technical laboratory skills, while also increasing student enthusiasm about soil science research. Replicating the
entirety of our pedagogy may not be practical in all circumstances; however, the core tenets of this framework can be adapted to a wide range of undergraduate soil science learning scenarios so long as the facilitator has an active, on-going soils research project and is willing to invest sufficient time resources into creating a learner-centered environment. While the former is a given in many tertiary soil science and environmental science programs, the latter can pose significant challenges.

Maps, Tables, and Figures

Table 1. Student demographics.

<table>
<thead>
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<th>Total</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
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</thead>
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<tr>
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<tr>
<td>n</td>
<td>10</td>
<td>14</td>
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<td>11</td>
<td>5</td>
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<td>Declared Major: Other</td>
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<td>NA</td>
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Table 2. Learning evaluation group averages. (scaled responses: 1=learned nothing, 10=gained significant knowledge)

<table>
<thead>
<tr>
<th></th>
<th>Soil</th>
<th>Communication</th>
<th>Laboratory Skills</th>
<th>Geography</th>
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<td>Group A</td>
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<td>NA</td>
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<tr>
<td>Group C</td>
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<td>9.1</td>
<td>7.2</td>
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</table>
Map 1. Group A field assessment area; total area of approximately 8 hectares.
Agronomy / Environmental Science 490

In-Field Measurements & Soil Mapping: Student Post-Project Survey

Sex:

Major:

Number of Undergraduate course credit hours completed:

Would you have participated in this project if no incentive was offered?

What was your favorite part of this activity?

What was your least favorite part of this activity?

How much did you learn about the following on a scale of 1-10:

1 = learned nothing  
10 = gained significant knowledge

Soil:

Geography:

Other (please specify):

Figure 1. Student (Group A) post-course self-evaluation.
Agronomy / Environmental Science 490

Soils Research: Student Post-Project Survey

Sex:

Major:

Number of Undergraduate course credit hours completed:

Would you have participated in this project if no course credit incentives were offered?

What was your favorite part of this Research Project?

What was your least favorite part of this Research Project?

How much did you learn about the following on a scale of 1-10:

1 = learned nothing  10 = gained significant knowledge

Soil:

Laboratory Techniques:

Scientific Communication:

Other (please specify):

Figure 2. Student (Groups B, C) post-course self-evaluation.
References


CHAPTER 5. GENERAL CONCLUSION

Soils are at the nexus of the atmospheric, geological, and hydrological cycles; providing invaluable environmental services such as climate regulation and water storage. Despite their importance, soils are often an afterthought in policy decisions (Hatfield et al. 2017), and environmental assessments too often minimize the importance of soils to physiological and economic health. Sustained environmental health, as well as sustained human health and prosperity, will hinge on our collective ability to develop, employ, and assess soil-water management strategies. Bossio et al. (2010) offer an apt and succinct summation of this challenge: “every land use decision is a water use decision”.

Winter cover crops are an effective and practical natural resource conservation tool in temperate row-cropping systems; however, gaps in our understanding of the long-term effects of cover crops on near-surface soil properties must be addressed in order to effectuate improved in-field water management strategies. This research has explored, in detail, the hypothesis that long-term cover crop management significantly influences near-surface soil properties (Chapter 2), and found that rye winter cover crops enhance soil macroporosity and water holding capacity, while also augmenting soil organic carbon.

The Upper Mississippi River Basin (UMRB) is one of the world’s most highly productive rainfed agriculture regions, and the demands placed on the region’s soil and water resources will likely increase, necessitating current and accurate farm-scale soil map inventories to inform management decisions. Chapter 3 evaluated existing publicly available soil maps to assess their utility at farm-scale. Data show that while these maps reliably detail most soil biophysical
properties, they do not accurately describe soil pH and fine sand distribution at farm-scale. Our analyses suggests that aeolian deposition in the UMRB may have a more significant soil management impact than previously thought.

Janzen et al. (2010) remarked “It is the land…that ultimately sustains us. People in the past, now gone, did not learn that in time. We, no less than they, are nourished in body and spirit by the ecosystems in which we are enmeshed, sometimes obliviously”. The obviousness to which these authors refer cannot be fully addressed by soil biophysical research alone. The inclusion of an improved soil science pedagogy into this compendium (Chapter 4) was deemed crucial, as ultimately it is not solely technical advancements, but also advancements in the ways we engage the next generation of soil scientists that will best position us to avert the consequences that Janzen’s admonition portends. Data from our novel pedagogy analysis has demonstrated that the learner-centered, teaching-as-research pedagogy detailed in this compendium not only meets the urgent need for substantive undergraduate soil science learning, it also increases student engagement and enthusiasm about soil.

In short, this compendium has explored connections between near-surface soil properties and management practices. The research detailed herein provides data to help meet the urgent need for sustainable soil and water management practices.